Market based frameworks for CCUS in the power sector

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1 Executive summary

1.1 Overview and report structure

Cornwall Insight and WSP were commissioned by the Department for Business, Energy and Industrial Strategy (BEIS) to conduct a review of market-based frameworks for power Carbon Capture Usage and Storage (CCUS), as part of BEIS' wider Review of CCUS Delivery and Investment Frameworks. In addition to this specific workstream on CCUS in power, there are two other workstreams taking place that focus on the frameworks for the CO_2 transport and storage (T&S) infrastructure and CCUS in industry.

This report is structured in the following way:

- **Section 2 - Project scope and key assumptions** – covers the objectives and principles of the study, including an overview of the policy, technology and assumptions used for the study
- **Section 3 - Identification of adaptations for a CCUS CfD –** Identifies the key areas where adaptations may be needed for the existing CfD to be applied to CCUS power to ensure suitability for CCUS projects, which will help to shape the archetype model options
- **Section 4 - CCUS CfD Models -** Three archetype models have been devised to address these adaptations for CCUS projects and create frameworks which align to the broader policy aims set out by BEIS
- **Section 5 - Alternative market-based options for CCUS in power -** summary of the key alternative market-based mechanisms
- **Section 6 – Conclusions and next steps for CCUS in power –** recommendations on the market-based mechanism for CCUS in power
- Annex's are also provided which cover acronyms and defined terms (Annex 1) and an overview of the key metrics of the CfD and regulatory background (Annex 2)

1.2 Project assumptions

Taking into consideration the objectives of this study, the stated policy intentions at the time of writing for CCUS as set out in the Government's 2018 CCUS Action Plan, as well as the technical considerations and potential market interactions for any project, Cornwall Insight set out some key assumptions to guide assessment of areas for adaptation and model design. These assumptions are:

- **CCUS CfDs will be bilaterally negotiated in the first instance:** It's assumed that initial contracts will take the form of a bilateral negotiation between projects. developers and BEIS. This is in line with current legislation as any CCUS CfD can only be awarded on the direction of the BEIS Secretary of State and cannot, currently, enter allocation rounds.
- **Market indexation will be to wholesale power:** Payment incentives will be based around the production of clean electricity from the CCUS power plant. This is to seek to ensure incentives can be aligned to positioning in the merit order to try and minimise distortion for other low carbon generation. Additionally, power markets provide more investor certainty than other payment forms, such as carbon savings, through the maturity of the market and investment precedents.
- **Carbon incentives would be penalties based:** The incentive to ensure carbon sequestration is based on non-payment against power output which is not associated with CCUS. CfD payments would only be made against the low carbon electricity generated and CO_2 stored (or transferred to the CO_2 transport and storage operator). This means there is a need to have a contract design feature around the metering and measurement of CO_2 capture and storage. Any residual emissions would be subject to carbon pricing.

- **Technical feasibility of CCUS capture is assumed to be in line with current best available technology:** to accurately assess capabilities the technical parameters of capture plant are assumed to be similar to today and analysis does not consider technological advancements of today's current technology nor new technologically becoming commercially available. Where model designs could incorporate features that incentivise improved capabilities over time is discussed in section 4.
- **New build and retrofit CCGT, coal and biomass are the technologies considered:** This is to reflect the current technical potential and fuel inputs likely for a CCUS plant. Coal has been included, as the Government has committed to remove unabated coal generation from the electricity system by 2025, and new build or retrofit of coal plants with CCUS may be a possibility. Open Cycle Gas Turbines (OCGT) have not been considered in assessing the models as their running profile means capture opportunities would be limited with current capture plant technology. But it is accepted this could be viable in future.
- **T&S usage costs would be pass-through fees:** CCUS power plants are assumed to pay T&S fees for use of the T&S infrastructure. This fee could be charged per unit of CO_2, or on a capacity basis (this decision is outside of the scope of this work). It has been assumed that this mechanism would sit outside of the CfD arrangement, possibly being a direct agreement between the power station and T&S owners. However, the cost of this fee to the power plant would be incorporated into a strike price. It is assumed the CCUS power plant has firm access 24/7 to the T&S infrastructure, regardless of the output profile of the CCUS power plant. The CCUS CfD would still need to incorporate features to mitigate interface risk, these are covered in section 3.6.
- **All plant will be subject to decommissioning requirements:** CCUS plant will have decommissioning requirements either at the end of the CfD contract or asset life, and there may need to be regulatory or other provision to avoid unabated running of the power plant in the period post-CfD term.

1.3 Identification of adaptations

With this assumption framework Cornwall Insight has undertaken detailed research into the structure of current CfD contracts and their key parameters as they relate to CCUS projects. This covered the key areas where adaptations may be needed to the CfD to ensure suitability for CCUS projects, which will help to shape the Model options. The end to end analysis of a project and CfD interactions has been categorised into the following sections:

- Planning
- Construction
- Operations
- Technical requirements
- Commercials
- Decommissioning and termination
- Broader linkages to other infrastructure for CCUS – Transport and Storage (T&S)

Each area of adaptation identified within the current CfD contract has been given a RAG status indicator based on two key factors, the commercial importance of the adaptation to CCUS for power projects for their deployment, and the applicability of the current CfD and degree to which adaptation might be needed, if possible, to suit CCUS project requirements.

The RAG status for each is outlined below for the **commercial importance to CCUS for power**

- Green – little or no risk that would impact the deployment of a CCUS for power CfD

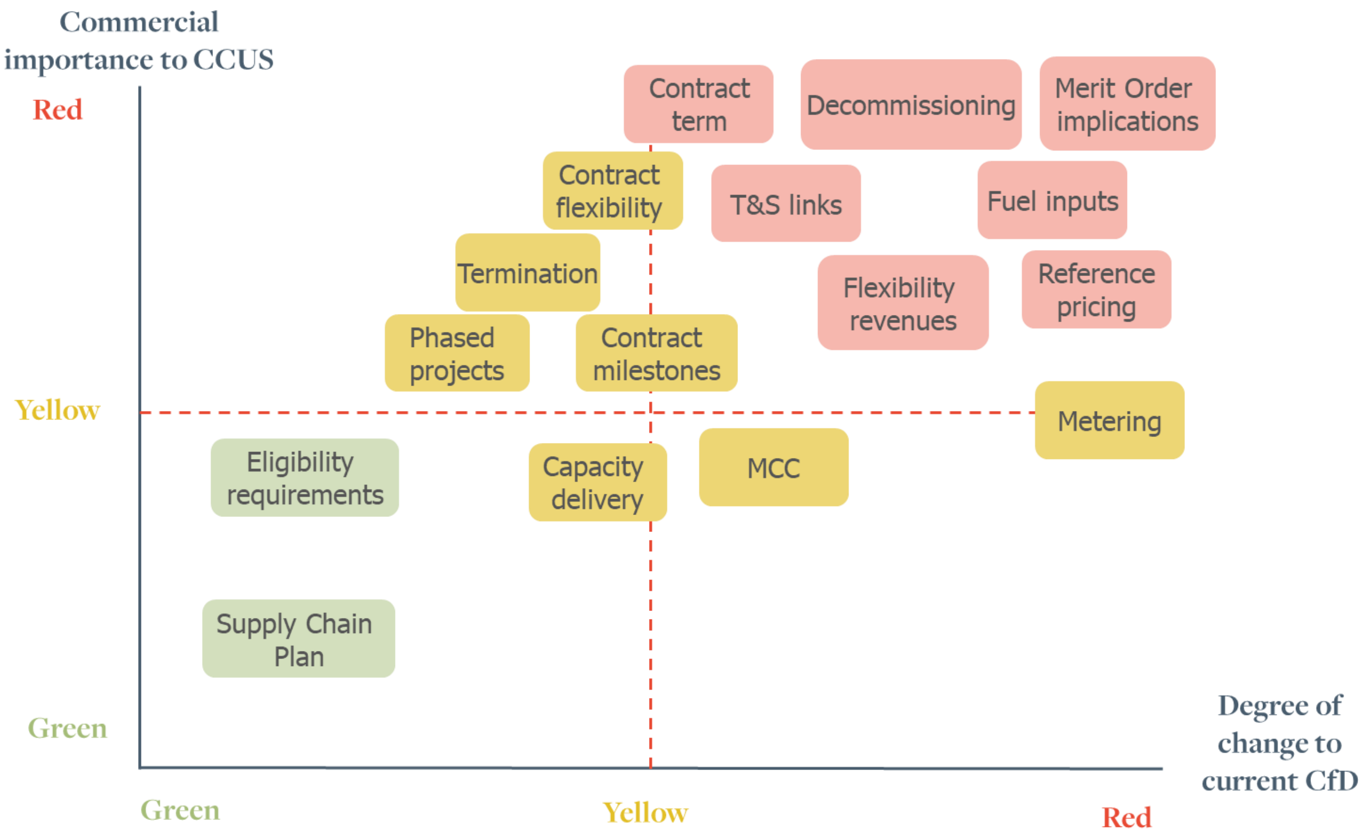
- Yellow – some or moderate risk to the deployment of a CCUS for power CfD
- Red – high or significant risk to the deployment of a CCUS for power CfD

The RAG status for each is outlined below for the **applicability of the current CfD**

- Green – requires little or no intervention for CCUS for power CfD to be adopted
- Yellow – requires some intervention to manage for CCUS for power CfD to be adopted
- Red – requires significant alteration to the existing scheme or may not make it viable for CCUS for power CfD to be adopted

Figure 1: RAG status of CfD contract adaptations for CCUS below provides a summary of these adaptations.

Figure 1: RAG status of CfD contract adaptations for CCUS



1.4 CCUS CfD Models

Following identification of areas for adaptation, Cornwall Insight has created archetype models to address these for CCUS projects and create frameworks which align to the broader policy aims set out by BEIS.

Three models have been devised:

- A baseload incentivised CCUS asset with limited flexibility
- A hybrid CCUS plant with lower baseload output and more flexibility
- A flexible CCUS plant with a running profile determined by the merit order

The models have been reviewed against the following criteria to ensure consistency when evaluating the different model options.

- **Investability -** CCUS must be an investable proposition to a variety of lender and investor types. In particular, this must remain the case even in the event of cross-chain risks arising (i.e. with T&S infrastructure)
- **Merit-order position -** At the plant level, CCUS facilities should operate efficiently without distorting market signals or the merit order and should not deter renewables dispatch
- **Cost reduction -** Any framework for power CCUS must support a cost-reduction trajectory for both levelised costs of electricity of the plant and in ensuring value for the electricity system and consumers. This is key to achieving the ambition set out in the CCUS Deployment Pathway.

In addition to Cornwall Insight's review, interviews with independent investment advisors have been conducted on the proposed models and alternative options available. Figure 2 below provides a comparison of the different models proposed based on the assessment criteria.

Figure 2: Model Comparison

Objectives	Option 1: Baseload CfD	Option 2: Hybrid CfD	Option 3: Flexible CfD with capacity payment
Investability	• Most akin to current CfD, although fuel price hedging adjustments and protections would be key to investability	• Investment case could be made against the minimum output level and revenue returns from this strike price. However, significant divergence from current CfD and lack of precedents.	• So long as a floor price is set at the correct level this contract would be investable. Upside may attract certain equity investors
Merit order position	• Largest merit order impact with the plant running ahead of new and some existing renewables.	• Signficiant proportion of output has no flexibility incentive which would impact merit order	• Short Run Marginal Cost (SRMC) calculation would ensure running after renewables and negate need for long-term fuel price hedging
Cost-reduction	• Potential adjustments over time to strike price levels. Likely to provide the cheapest £/MWh strike price, but also the highest overall costs through increased run times. Arguably, higher run times could allow technology cost reductions to be achieved more quickly	• Potential adjustments for top-up levels over time to incentivise improvements. Inefficient nature likely more expensive than equivalent baseload option and debt leverage would be lower	• Floor prices and SRMC triggers could be adjusted over time to incentivise improvements. Likely higher strike prices and payments than baseload option and short run times may limit technology improvements and cost reductions relative to the baseload option, however, this could incentivise the development of more flexible CCUS technologies which may provide greater value to the electricity system

Source: Cornwall Insight

Option 3, the flexible CfD model, had the most appeal with investors and met objective criteria most closely in Cornwall Insight assessment. The design aims to align the plant operation most closely to the flexible operations of current non-capture equivalents of the technology and seeks to ensure a position in the merit order that does not distort either existing or future renewables assets based on a dynamic Short Run Marginal Cost (SRMC) assessment. Due to the unknown running pattern of plant under the design a floor price or availability payment would be required as an addition to the CfD to provide investors with a known minimum level of return that could be financed against.

However, there could be concerns with this model around wider criteria of T&S interface risk and technical carbon capture potential. Due to the flexible nature of this model running patterns could be uncertain and based against extrinsic market factors, T&S usage patterns would therefore mirror this variability. Any impact this may have on the technical or commercial operation of the T&S network would depend on the T&S business model and on individual T&S network considerations. From a technical perspective, very short (e.g. 2 hour) start up periods could also mean differing levels of capture arising from the difference of technical parameters between power station and CCUS start up.

During the investor review of the model options, a number of issues and concerns were identified that related to all the potential options outlined. These included:

- A desire to keep the structure of the arrangement as simple as possible to minimise the risk of not getting internal buy in from investment and credit committees in lender organisations
- Investors will calculate the risks of CCUS against a known investment such as offshore wind, onshore wind or solar PV. CCUS is therefore likely to have a higher risk premium compared to these relatively mature technologies
- CCUS CfDs would have additional risk compared with other CfD projects due to the fuel input volatility and potential merit order position
- First of a kind technology risk will result in a higher risk premium, versus other CfD technologies, regardless of other risks that could be mitigated through the contract design
- Infrastructure risks for the technology, including interface with the T&S, the type and maturity of technologies used for the power plant and storage facilities and interface with the conventional power plant, are likely to be high
- There is the potential need for buy-out arrangements under the CfD to protect the investor from first of kind, infrastructure risk and government changes that may result in disruption
- Investors are now comfortable with the risk associated with pay when paid principle of the Low Carbon Contracts Company

1.5 Conclusions

This study has demonstrated how the broad structure of the CfD contract could be adapted to become a market-based incentive for CCUS power projects. In comparison to alternative investment models which were assessed at a high level, the CfD has more suitability when adapting for potentially flexible running patterns than models such as RAB and Cap and Floor and is more understood and trusted in the investment community than options such as tax credits or certificate schemes.

However, there are a number of areas in which the design of the CfD would need amending for the CCUS asset type. These adaptations broadly cover:

- **CCUS technology aspects –** including defined contract milestones, T&S interface risk, metering arrangements and accounting for carbon measurement and incentives

- **CfD payment aspects –** including how and what is being paid for (wholesale power or carbon offset), managing the volatility in fuel price inputs, linking the CfD mechanism to potentially flexible running patterns and how strike price adjustments may be treated

Whilst Cornwall Insight believes that the majority of adaptations could be integrated into the contract through redesign and amendments, payment aspects may be more difficult as they would need to be more carefully designed around investor requirements, risk profiles and wider wholesale market interactions.

Overall Cornwall Insight views option 3, the flexible CfD, as the model which most aligns with assessment criteria and investor requirements. This is due to its minimal merit order impacts and greater potential for investability despite changes from the current CfD design. Whilst the baseload design is an investable format, its disruption to the merit order (i.e. running regardless of market signals) may increase the degree of price cannibalisation impacts on future unsubsidised renewables

The flexible CfD would limit merit order impacts due to dispatch SRMC levels responding to market conditions and fuel price changes. As a result, the flexible CfD approach could see plants playing different roles over their project lifetimes based on the wider market and the relative roll-out of further renewables capacity. For example, under a system with a moderate level of intermittent renewable generation (such as in the 2020s), a power CCUS plant could play more of a "baseload" role under this model, providing consistent clean electricity when renewables and nuclear do not meet demand. As further intermittent renewable generation is added throughout the 2020s and 2030s, this role may change, with power CCUS plants seeing lower load factors and moving to mid-merit operation, only providing generation in periods of relatively low supply or high demand. This makes option 3 more adaptable than the baseload CfD, which would effectively lock-in CCUS generation to the market regardless of the wider system changes and potentially significantly impact the merit order.

There are potential technical limitations to the flexible CfD approach in terms of levels of capture, especially for post-combustion technologies, that could arise if the plant has frequent cold starts and very short running periods (i.e. less than 2 hours) particularly if today's standard configuration of technology is used (see section 2.4). Further analysis will need to be conducted to understand the future running patterns of different types of CCUS power plants as greater capacities of intermittent renewables are added to the system and what effect, if any, this has on CO_2 capture rates.

Whether or not this is the case, there are a number of approaches which could improve capture plant flexibility, and the final model could include provisions designed to incentivise improvement of capture start up and ramping times against current technology. This could incentivise developers and technology providers to find technological and/or operational solutions to this, so long as the contract being awarded was seen to reward these efforts commensurately.

Which model is most suitable will also ultimately depend on the aims for BEIS around deployment of CCUS and potential strategy for any "fleet" of assets.

- **To prove CCUS commerciality –** a baseload CfD option may be more suitable for the first CCUS plant(s) in order to prove technical capabilities of the technology and to allow CCUS power projects to provide economies of scale to a wider industrial T&S system
- **To ensure minimum power sector disruption and provide flexible back-up for low carbon power –** then a flexible CfD option is more appropriate to ensure that CCUS plants do not run ahead of other low carbon assets, especially future subsidy free renewables, and provides low or zero carbon flexible back-up

While providing a baseload option to earlier contracts may help catalyse the development of a wider CCUS industry, this would materially limit flexibility from these plants. To secure investment they would also need to be "grandfathered" for the contract duration, likely 10 years or more. This would potentially lock in assets which have no incentive to provide flexibility. Further assessment may be necessary to discern the impact this may have on dispatch of future generation capacity, such as subsidy free renewables or CCUS power plants with a lower CfD strike price or flexible CfD model.

Additionally, providing two contracts to the market, baseload contracts to earlier projects and flexibility contracts to later ones, may create uncertainty around investment and push certain investors towards their preferred option. Setting clear timelines or deadlines on the type of contract that developers could access could help, but would also lock government policy into a structure which may need to be adapted after implementation.

Therefore, a more rational approach may be to opt for one type of CfD and adapt the contract for new assets over time as the technology matures. If option 3, the flexible CfD was chosen, this could include:

- The floor payment being set to higher levels in early contracts to provide more investor certainty on returns for First Of A Kind (FOAK) assets. As CCUS technology matures this could be lowered to shift revenues more towards capture in operations
- The trigger point for operations against a defined SRMC could be set at lower levels for earlier contracts to ensure a greater period of operation. This could allow for earlier projects to prove technical feasibility but does carry the risk of creating merit order distortion if trigger levels are set artificially low
- Strike price levels for CCUS top-up could also be amended for contracts as levelised costs of the technology fall or are incentivised to fall to meet future strike prices
- A commissioning window could be provided to FOAK projects that allows for a period of baseload operations to account for testing, feasibility and snagging. This could be akin to some of the time-based windows given in the current CfD with a set time provided to run at baseload and prove operation capability. However, this would need to be carefully managed to ensure minimal merit order disruption when running baseload. Clear criteria on when this period would end and the correct incentives to not over reward on payments in these periods would need to be established

Overall, providing a single CfD structure to the market and amending this overtime to suit technical requirements and incentivise cost reductions should prove an investable format. It also allows the sector to get comfortable with the terms provided, as has happened with the existing CfD, instead of adapting to different structures, i.e. baseload to flexible contracts, as the technology matures.

2 Project Scope and key assumptions

2.1 Objectives for projects

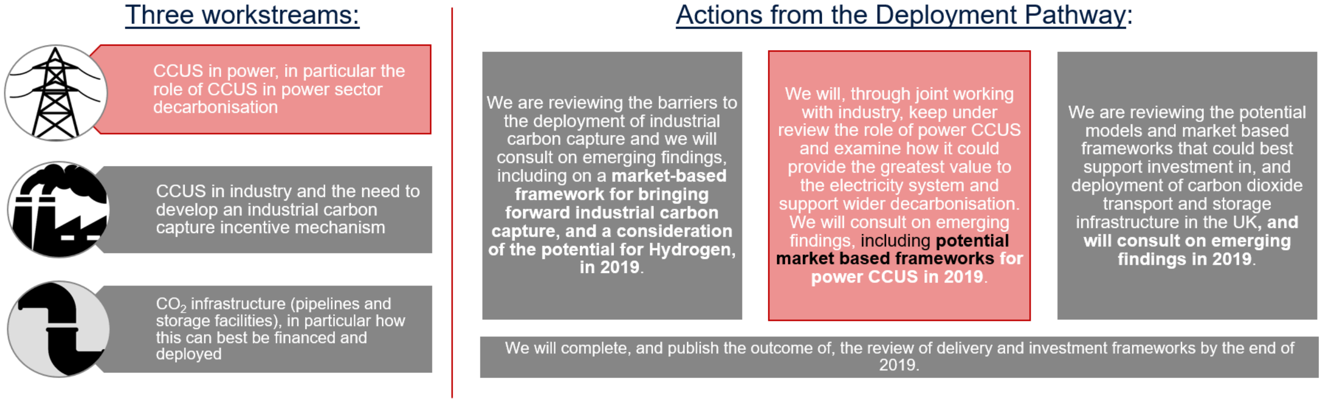
Cornwall Insight and WSP were commissioned by the Department for Business, Energy and Industrial Strategy (BEIS) to conduct a review of market-based frameworks for power CCUS, as part of BEIS' wider Review of CCUS Delivery and Investment Frameworks. In addition to this specific workstream on CCUS in power, there are two other workstreams taking place that focus on the frameworks for the CO_2 transport and storage (T&S) infrastructure and CCUS in industry. The objectives of this work are as follows:

- To provide specific advice on how the structure of the generic CfD can be adapted to support power CCUS. A consideration throughout will be what is the framework that best enables power CCUS to be an investable proposition and which supports a cost reduction trajectory. Specifically, it is expected that this work will explore:
    - The appropriateness of adapted CfD for CCUS in power and consider any other alternatives at a high level
    - Consideration of the long-term applicability of the CfD for power CCUS and whether alternatives may be required in future
    - The structural adaptations to the CfD to enable it to incentivise flexible and/or baseload generation in power CCUS, assuring revenue without over-remuneration or locking in generation capacity in a fashion that distorts the merit order
    - Identification of the investor or lender types that the mechanism is best suited towards
    - The basis/ indexation of the CfD – e.g. whether it should be written against a power price, fuel price, power plant spread, carbon price, or other metric
    - Identification of risks and their allocation between the government, consumer, and private sector, including the CCUS power operator and Transport and Storage (T&S) operator, and any further counterparties. Of particular importance will be identification of the risk posed by fluctuating gas prices
    - The duration of the CfD term and the impact of moving beyond a 15-year term, and analysis on the economics of a plant following the end of the CfD term
    - Consideration of on-going industry-led work, where appropriate, on barriers to the investability of power CCUS and identification of any further barriers/ key points for making power CCUS investable

The study does not include detailed analysis of cross chain risks in interactions between power CCUS and Transport and Storage (T&S). However, the analysis does include identification of the options for continuing the revenue stream to the generator if CO_2 T&S unavailable, and a high-level examination of the impact of these options on investability.

In addition to this specific workstream on CCUS in power, there are two other workstreams taking place, as show below in Figure 3.

Figure 3: Addressing policy barriers workstreams



Source: BEIS (2019)

2.2 Objectives and guiding principles

The overarching objectives have been agreed with BEIS, which seeks to ensure the following:

- **Investability -** CCUS must be an investable proposition to a variety of lender and investor types. In particular, this must remain the case in the event of cross-chain risks arising
- **Length of applicability -** The duration of the CfD term may need to be amended from the standard 15 years in the case of CCUS facilities
- **Indexation -** The generic CfD is indexed to the wholesale electricity price. Alternatives, either alone or in some combination, may be more appropriate for CCUS
- **Appropriate risk sharing -** Options set out should consider the risk allocation between Government and Industry and the impacts that this will have on investability
- **Ensure Power CCUS is 'correctly' situated in the dispatch merit order -** At the plant level, CCUS facilities will need to operate efficiently without distorting market signals or the merit order and not deter renewables dispatch
- **Cost-reduction -** Any framework for power CCUS must support a cost-reduction trajectory. This is key to achieving the ambition set out in the CCUS Deployment Pathway

These objectives are set against the four principles for the for the power sector outlined in the Secretary of State's speech on the 15th November 2018[1], see Figure 4.

[1] After the trilemma - 4 principles for the power sector: https://www.gov.uk/government/speeches/after-the-trilemma-4-principles-for-the-power-sector

Figure 4: Four Principles guiding the future strategy for the power sector

Four principles guiding future strategy for the power sector
Market principle:
• The government must, wherever possible, use market mechanisms that take full advantage of innovation and competition
Insurance principle:
• Government must be prepared to intervene to provide insurance and preserve optionality
Agility principle:
• Energy regulation must be agile and responsive to opportunities
No 'free-riding' principle:
• Consumers of all types should pay a fair share of system costs

Source: BEIS (2019)

2.3 Overview of CCUS policy

2.3.1 Clean Growth Strategy

On the 12th October 2017 The Department for Business, Energy and Industrial Strategy (BEIS) released its Clean Growth Strategy[2] (amended April 2018). This Strategy sets out a comprehensive set of policies and proposals that aim to accelerate the pace of "clean growth", i.e. deliver increased economic growth and decreased emissions.

In the context of the UK's legal requirements under the Climate Change Act, the UK's approach to reducing emissions has two guiding objectives:

1. To meet our domestic commitments at the lowest possible net cost to UK taxpayers, consumers and businesses
2. To maximise the social and economic benefits for the UK from this transition

The strategy included the Government's approach to Carbon Capture Usage and Storage (CCUS), setting an ambition to have the option of deploying CCUS at scale in the UK, subject to the costs coming down sufficiently. It outlined two key policy decisions:

- Demonstrate international leadership in CCUS, by collaborating with our global partners and investing up to £100 million in leading edge CCUS and industrial innovation to drive down costs
- Work in partnership with industry, through a new CCUS Council, to put us on a path to meet our ambition of having the option of deploying CCUS at scale in the UK during the 2030s, subject to costs coming down sufficiently, and to maximise its industrial opportunity

2.3.2 The UK Carbon Capture Usage and Storage deployment pathway: An Action Plan

On the 28th November 2018 BEIS published "The UK Carbon Capture Usage and Storage deployment pathway: An Action Plan"[3]. Through the CCUS Action Plan, Government re-affirmed the commitment to the

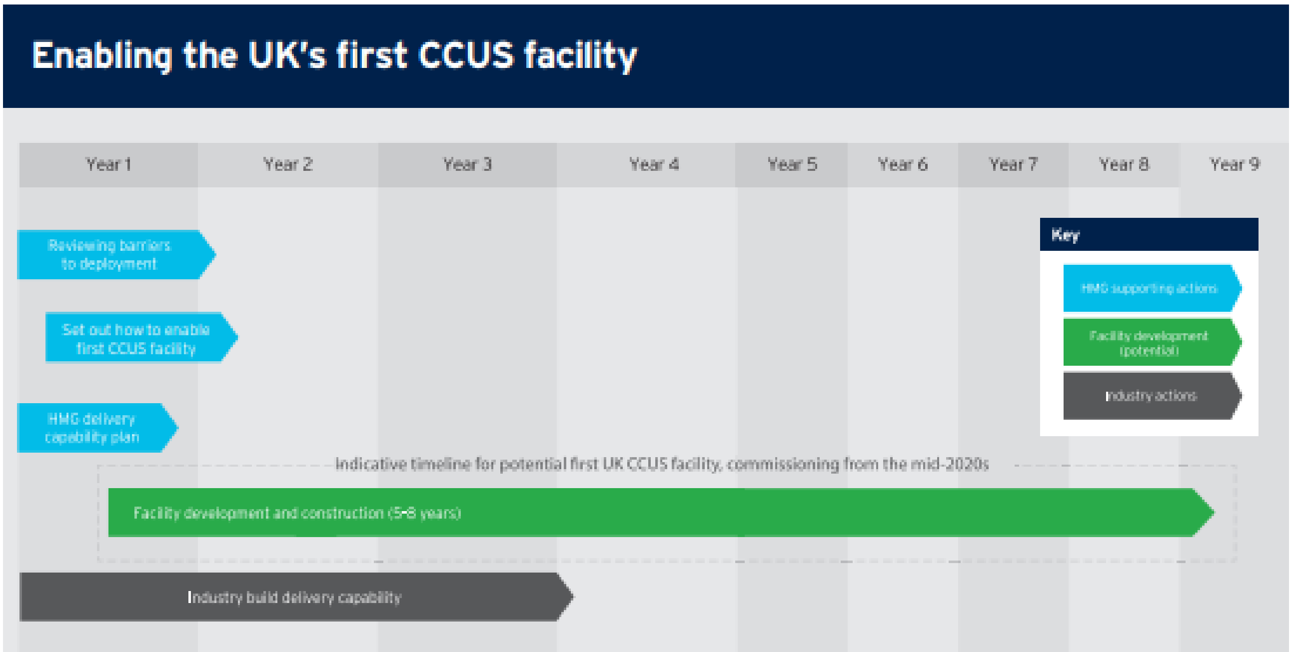
[2] Clean Growth Strategy: https://www.gov.uk/government/publications/clean-growth-strategy
[3] The UK carbon capture, usage and storage (CCUS) deployment pathway: an action plan - https://www.gov.uk/government/publications/the-uk-carbon-capture-usage-and-storage-ccus-deployment-pathway-an-action-plan

domestic deployment of CCUS subject to cost reduction. The UK CCUS Action Plan is designed to enable the UK's first CCUS facility to be commissioned from the mid-2020s, moving the UK to a deployment phase for CCUS and as an important first step to meeting the Government's 2030s ambition.

The key messages from this included:

- Creating a supportive business environment that delivers a cost reduction trajectory for the CCUS industry
- A shift in approach to focus on domestic CCUS deployment by continuing to work with industry to identify cost effective private sector-led ways of developing, financing and delivering CCUS

Exploring investable commercial models for those wishing to develop CCUS Figure 5: Timeline for first CCUS facility



Source: UK CCUS Action Plan (2018)

This report seeks to specifically address one of the key parts of the action plan that seeks to address the policy barriers, with a review of delivery and investment frameworks, including for power CCUS:

- *We will, through joint working with industry, keep under review the role of power CCUS and examine how it can provide the greatest value to the electricity system and support wider decarbonisation. We will consult on emerging findings, including potential market-based frameworks for power CCUS in 2019.*

This report focusses specifically on CCUS in the power market, in particular the role of CCUS in power sector decarbonisation. At the same time there are two other studies taking place simultaneously as part of the review of delivery and investment frameworks that consider the other elements of CCUS, including commercial models for industrial carbon capture and CO_2 transport and storage infrastructure.

While this report is focussed on CCUS for a power station, we have considered where there is overlap with industry or CO_2 infrastructure (such as the T&S charge the plant would need to pay).

2.4 CCUS Technologies

This section describes the three primary carbon capture technologies that could be utilised for power CCUS CfD:

- Post-combustion Capture
- Pre-combustion Capture
- Oxyfuel Combustion

For each technology the impact on power plant performance in terms of cost, efficiency, reduced operational flexibility and increased operational risk are considered.

Technologies considered are Combined Cycle Gas Turbine (CCGT), coal and biomass plant. Broad analysis is available for CCGT and coal plant. Biomass technology and efficiency parameters are similar to that of coal, especially for retrofit projects, and so efficiency analysis for coal is considered analogous for biomass plant in this section. However, a key difference with Biomass is the CO_2 capture element, once operational, has advantages over coal and natural gas fired CCGT with the fuel source potentially allowing for negative emissions. This advantage is considered in the conclusions.

Open Cycle Gas Turbine (OCGTs) were originally considered as part of this study, however, they were not included in our assessment of the models. This is due to the ramp up of OCGT plant being quicker than current capture technologies, and the run times of the plants typically being short, meaning the peaking nature of the plant could see the plant shut down again before steady state carbon capture was achieved. Additionally, the lower efficiency of OCGT assets means they would be more costly to operate than a CCGT option over longer running periods. However, it is accepted that OCGT CCUS could be viable in future.

2.4.1 Post-combustion capture

Overview

In post-combustion capture, fuel (natural gas, coal, biomass) is combusted in an essentially conventional power plant such as a pulverised solid fuel-fired plant or a CCGT.

The flue gas leaving the power plant is fed to a capture unit which separates CO_2 from the flue gas. CO_2 present in the flue gas can vary between 3% - 5% by volume in a natural gas power plant to around 10% - 15% by volume for a coal fired power plant.

Currently the best available technology for post combustion capture is chemical absorption using an amine-based solvent. It is the most advanced method due to considerable industrial experience with similar processes for gas separation and purification in the natural gas treatment and process industries. CO_2 is absorbed from the flue gas in a separation tower using the solvent, which is then regenerated by heating in a recovery column at temperatures over 100˚C. Low pressure steam from the power cycle can be utilised as the heating medium in the regeneration column reboiler.

In addition to amine-based solvent systems, a range of other post-combustion capture technologies are under development. These include the use of alternative liquid solvents such as those based on ammonia, solid adsorbent technologies, membrane separation and chilling the flue gas stream to freeze-out the CO_2. Each of these technologies has the potential to reduce the costs, improve the efficiency and improve the flexibility of operation of post-combustion capture. However, none of these alternatives have yet to be demonstrated at large industrial scale, so further research, development and demonstration is required before they become commercially available. Amine-based solvent are therefore regarded as the current state-of-the-art.

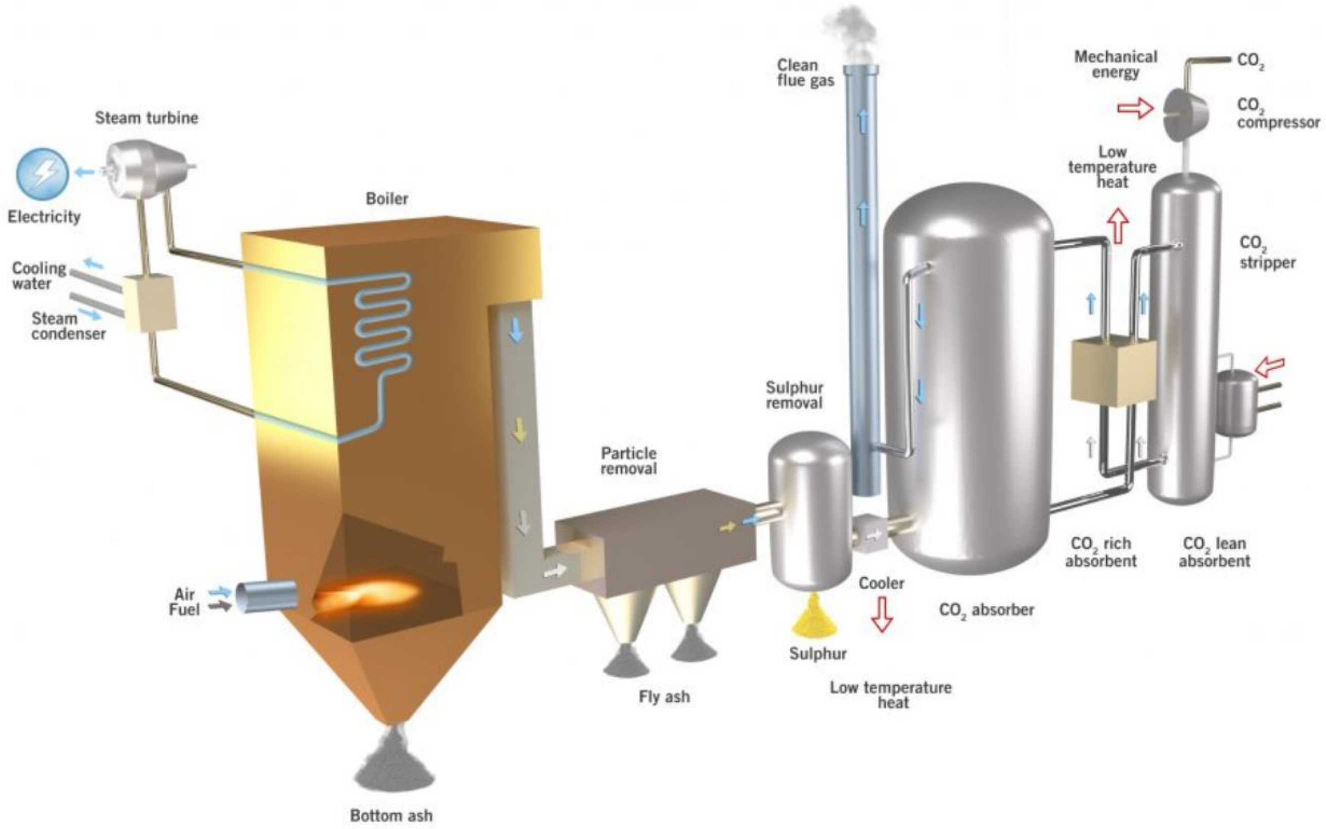
With best available existing technology (in standard configuration), post-combustion carbon capture plants typically require 1-2 hours from a cold start to reach steady-state operation after receiving heat to the regeneration column[4]. An extended start up sequence may therefore be needed at present to ensure low-carbon operation. Alternatively, an initial period of increased CO_2 emissions may need to be tolerated, if the start-up time of a capture plant cannot match that of a CCGT. However, it is important to note that alternative capture plant configurations and operating strategies have been tested and are being actively developed to accelerate the start-up process and overcome this issue[5].

Figure 6: Post-combustion provides an illustration of the end to end process for an amine-based post combustion capture facility.

Figure 6: Post-combustion

[4] Marx-Schubach, T. & Schmitz, G. "Optimising the start-up process of post-combustion capture plants by varying the solvent flow rate", Proceedings of the 12th International Modelica Conference, May 15-17, 2017, Prague, Czech Republic

[5] Ceccarelli, N. et al "Flexibility of low-CO_2 gas power plants: Integration of the CO_2 capture unit with CCGT operation" Energy Procedia 63 (2014) 1703 – 1726



Source: Global CCS Institute

Performance impact

Post-combustion capture has a number of performance impacts depending on technology. These are highlighted below.

Figure 7: Post-combustion performance impact[6]

Technology	Post-combustion performance impact
CCGT	• Reduced plant efficiency with a 12% impact on net power output • Increases capital costs by 45%, taking into account plant efficiency this translates to a ~65% increase in the capital cost per MW of net capacity • Cost per MWh generated depending on prevailing carbon prices, however excluding the carbon price the increase is ~50% • 1-2 hour start up time of capture plant with current best available technology and standard configuration is longer than the typical 30-60 minute fast start capabilities of new CCGTs. An extended start up sequence may therefore be needed to ensure low-carbon operation, or

[6] BEIS/Wood, "Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology Benchmarking State-of-the-art and Next Generation Technologies" Document Number: 13333-8820-RP-001, 20th July 2018

	alternatively, an initial period of increased CO_2 emissions may need to be tolerated, if the start-up time of a capture plant cannot match that of a CCGT. Alternative capture plant configurations and operating strategies are in development which could mitigate or eliminate this issue.
Coal / Biomass	• Reduced plant efficiency with a 22% impact on net power output • Capital costs per MW of net capacity increased by around 65% • Post combustion start times broadly in line with solid fuel plant start up due to pre-burning process

Advantages and disadvantages

Figure 8: Advantages and disadvantages of post-combustion capture

Advantages	Disadvantages
• Ability to typically capture 90%-95% of the CO_2 in the flue gas	• Could limit plant flexibility during start up
• Separation of processes between power station and equipment reduces risks if CCUS equipment has an outage	• Cost and efficiency penalty vs. unabated thermal plant. These disadvantages could potentially be mitigated through technological improvements
• Technology can be relatively easily applied as a retrofit to existing plant vs other CCUS technologies	
• New plant design can incorporate both steam and heat requirements of CCUS, facilitating operational flexibility and improving plant efficiency	
• Lowest impact on efficiency of any of the major CCUS technologies and cheapest to install	

2.4.2 Pre-combustion capture

Overview

Pre-combustion capture requires the conversion of the power plant's fuel to synthesis gas (syngas). This conversion process can be in the form of gasification of coal, biomass or other solid or liquid feedstocks or steam-methane reforming of natural gas.

Gasification / reforming involves the reaction of the fuel with steam and/or oxygen in sub-stoichiometric quantities, so that partial oxidation occurs, producing a pressurised syngas stream consisting primarily of carbon monoxide and hydrogen. This syngas stream then undergoes what is referred to as the water-gas shift reaction, to convert the carbon monoxide to CO_2 and additional hydrogen through reaction with steam.

This mixture is then separated into a stream of H_2 and a stream of CO_2 utilising a physical solvent-based adsorption process such as Selexol or Rectisol.

Pre-combustion capture can capture close to 100% of the CO_2 in the fuel with a dry, high purity CO_2 stream recovered from the regeneration column which can then be compressed for export via pipeline to storage. The pre-combustion capture technologies are well established for syngas processing in other applications such as chemicals production, SNG production and Fischer-Tropsch Synthesis fuels production.

The hydrogen stream is then utilised as the fuel gas in a CCGT power plant, where the gas turbine has been specifically designed or modified for hydrogen combustion[7]. Typically, diffusion burners must be utilised to deal with the high flame speed of hydrogen, with nitrogen dilution utilised to limit flame temperatures and NOx formation.

Pre-combustion capture offers the potential to decouple syngas production and CO_2 capture from power generation. By including hydrogen storage, e.g. as pressurised gas in salt cavern storage or in pressure vessels, then flexible power generation is possible long with steady-state, continuous CO_2 capture. However, the addition of hydrogen storage would incur additional capital cost, and so the benefits of increased flexibility would need to be balanced against the cost impact.

Pre-combustion systems equipped power plants utilising coal or biomass are generally termed as Integrated Gasification Combined Cycle (IGCC) plants. However, it should be noted that IGCC plants that do not incorporate CO_2 capture are also in operation.

Figure 9: Pre Combustion below provides an illustration of the end to end process of an IGCC with carbon capture.

[7] With hydrogen-fuelled turbines, hydrogen obtained from other sources can also be utilised to generate decarbonised power. For example, the hydrogen could be produced from renewable electricity via electrolysis during periods of low power demand, with the hydrogen stored and utilised for power generation during peak demand periods.

Figure 9: Pre Combustion

Source: Global CCS Institute

Performance impact

Pre-combustion capture has a number of performance impacts depending on technology. These are highlighted below.

Figure 10: Pre-combustion performance impact[8]

Technology	Pre-combustion performance impact
CCGT	• Reduced plant efficiency with a 30% impact on net power output • Increases capital costs by 87%, taking into account plant efficiency this translates to a ~176% increase in the capital cost per MW of net capacity • Cost per MWh generated depending on prevailing carbon prices, however excluding the carbon price the increase is ~110% • Without hydrogen storage, reduced flexibility as start-up and ramp rates are dependent upon the rates associated with the reforming / gasification plant
Coal / Biomass	• Reduced plant efficiency with a 22% impact on net power output • Capital costs per MW of net capacity increased by around 90%

Advantages and disadvantages

Figure 11: Advantages and disadvantages of pre-combustion capture

Advantages	Disadvantages
• Pre-combustion capture can capture close to 100% of the CO_2 - the most efficient of all the major technologies	• Costs are prohibitive compared to post-combustion technologies and against the non CCUS status quo
• Potential for hydrogen use from electrolysis in the future – limiting carbon impact • Potential for hydrogen import or export, allowing flexible power generation with steady state operation of the upstream gasification/reforming plant	• Limitations for retrofit plant due to process complexities. While an existing CCGT could be retrofitted with pre-combustion carbon capture, it would require modification to the power island and significant additional investment in the upstream process units.
• Relatively mature industrial processes incorporated into the design of the system	• Direct interaction between power station and capture. Unless the CCGT has the flexibility to operate on natural gas (i.e. without carbon capture) or from a buffer store of hydrogen, plant start-up and load following will be dependent on the operation of the upstream processing units

[8] BEIS/Wood, "Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology Benchmarking State-of-the-art and Next Generation Technologies" Document Number: 13333-8820-RP-001, 20th July 2018

2.4.3 Oxy-fuel combustion capture

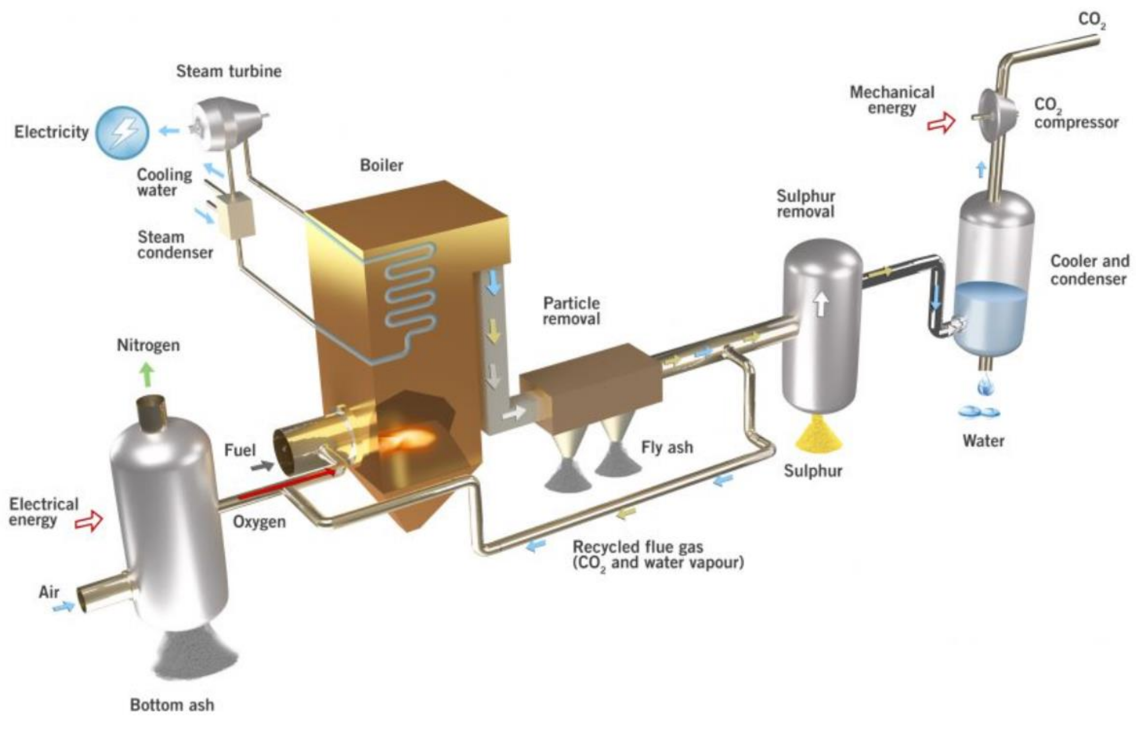
Oxy-fuel combustion uses pure oxygen, diluted with recycled CO_2, instead of air as the oxidant for the combustion process. This results in a flue gas which has CO_2 concentration as high as 75% by volume. The water vapour present in the flue gas can be removed by cooling and compressing the gas stream. Further treatment of the gas stream, typically involving an auto-refrigeration/distillation process rather than the use of a solvent, is generally required to remove residual gases before compressing the captured CO_2 for storage.

Oxy-fuel combustion system requires a cryogenic Air Separation Unit (ASU) which produces 95%+ pure oxygen from air but also consumes a major portion of power output generated by the plant.

Oxy-fuel combustion can be utilised on both solid fuel-fired and natural gas-fired plants. Retrofit of existing plant to oxy-fuel operation is potentially possible, but would require plant modifications in addition to the requirement to install the ASU and CO_2 purification unit. Figure 12 provides an illustration of this end to end process.

The Allam Cycle is an oxy-fuel technology utilising high-pressure CO_2 as the working fluid in place of a conventional steam cycle for power generation from natural gas fuel. This technology is a fundamentally different configuration from that of an unabated CCGT, and therefore it would not be possible to retrofit to an existing plant. The Allam Cycle can operate on both natural gas fuel or syngas produced from an upstream gasification plant

Figure 12: Oxy-fuel combustion capture



Source: Global CCS Institute

Performance impact

Oxy-fuel combustion capture has a number of performance impacts depending on technology. These are highlighted below.

Figure 13: Oxy-fuel combustion capture performance impact[9]

Technology	Oxy-fuel combustion performance impact
CCGT	• Reduced plant efficiency with a 15% impact on net power output • Increases capital costs by 46%, taking into account plant efficiency this translates to a ~72% increase in the capital cost per MW per MW of net capacity • Cost per MWh generated depending on prevailing carbon prices, however excluding the carbon price the increase is ~70% • Longer ramp-up times than typical CCGT, reducing operational flexibility • This may be mitigated through the addition of buffer oxygen storage, which can be drawn down to give a faster start to the power plant
Coal / Biomass	• Reduced plant efficiency with a 22% impact on net power output • Capital costs per MW of net capacity increased by around 50% • Longer ramp-up times than typical coal-fired station, reducing operational flexibility
Allam Cycle	• Novel technology currently at demonstration scale only • Potential for high plant efficiency compared to other power CCUS technologies, comparable with efficiency of non-capture conventional CCGT

Advantages and disadvantages

Figure 14: Advantages and disadvantages of Oxy-fuel combustion capture

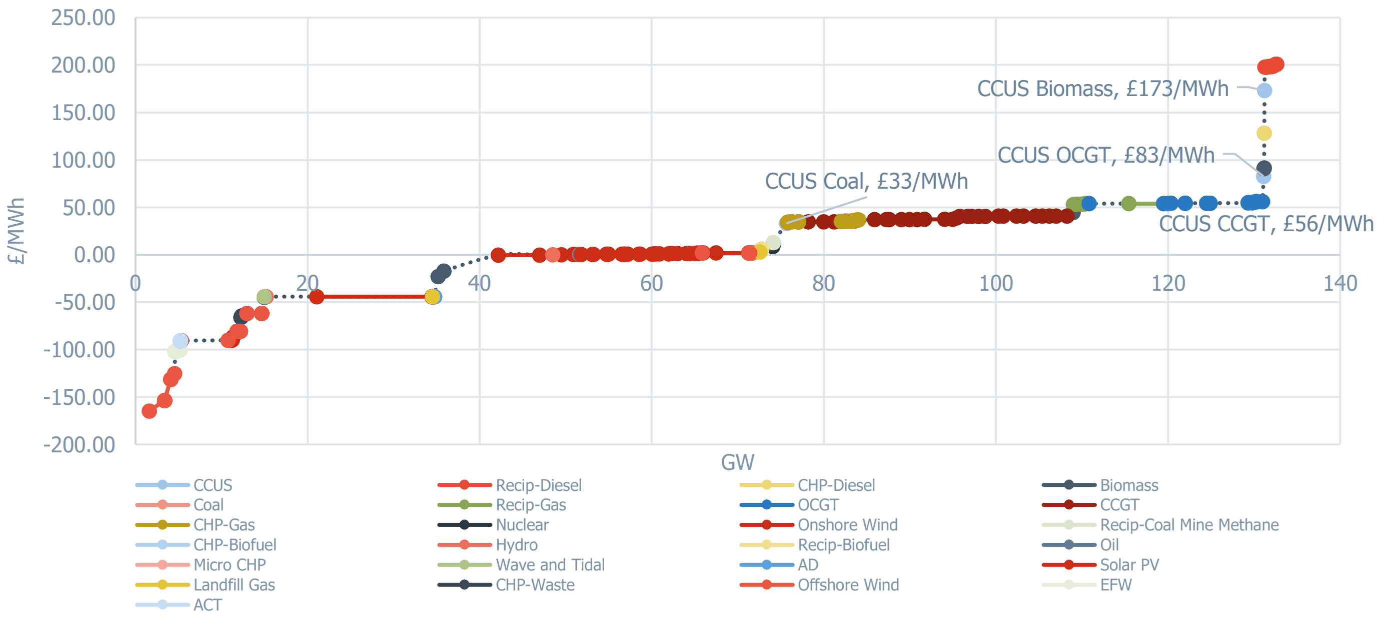
Advantages	Disadvantages
• The addition of oxygen storage allows the plant to give a temporary boost to the net power output during periods of peak demand	• Retrofit is complex and requires higher combustion temperatures
• Cryogenic ASUs are conventional well-established technologies in other sectors	• Lower CO_2 concentrations in product CO_2 stream than pre and post combustion technologies, requiring additional CO_2 purification stage
• Allam Cycle could provide a high efficiency solution, but the technology is currently at demonstration scale only	• Limitations on plant flexibility from oxy-fuel start up times
	• Oxy-combustion aspect of design not an established technology, downstream purification has also not been commercially proven at scale

[9] BEIS/Wood, "Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology Benchmarking State-of-the-art and Next Generation Technologies" Document Number: 13333-8820-RP-001, 20th July 2018

2.5 Running profile

Power stations will have different running profiles due to their changing position in the merit order during any given settlement period in the day. This is based on the Short Run Marginal Cost (SRMC) of that plant, which itself is a combination of the technical characteristics of the plant such as efficiency as well as fuel costs, carbon costs and fixed operational expenditure. In addition to SRMCs power plants will also face additional costs from general degradation in plant equipment from start ups and ramping which will depend on how often this has occurred and the amount of time the plant has been offline.

Figure 15: Cornwall Insight merit order stack in 2030 based on the SRMC running at baseload (real price, 2018)



Source: Cornwall Insight

As part of this study Cornwall Insight have sought to include arrangements for the following types of merit order running profiles when looking at different funding arrangements. These are set out below:

- **Baseload –** Similar to the existing CfD arrangements. This would provide limited flexibility response with the same £/MWh strike price in any period, but like under the current CfD the asset would have the requirement to participate in the Balancing Mechanism and respond to periods of negative prices
- **Hybrid –** A mid-point between baseload and peaking assets, with the potential to run "baseload" at a minimum level, such as at its stable export limit. This would provide a greater level of flexibility response when prices rise in peak periods
- **Flexible –** the asset would only provide output when in merit to produce

Based on the assessment principles discussed earlier, only the flexible solution is able to fully meet the objective of ensuring Power CCUS is 'correctly' situated in the dispatch merit order. As discussed in section 4.4.2, under this solution running profiles and technical carbon capture potential could be subject to some uncertainty.

A key consideration for the running profile of the power station will be the underlying commodity price of the input fuel of the plant, relative to the wholesale power price in that period. While there are correlations between commodities, the exact price of that commodity may determine if the plant is 'in merit' (the SRMC is below the power price and in theory should run and lock in a spread or profit) or 'out of merit' (the SRMC is above the power price and in theory shouldn't run) for any given traded period in the wholesale market. However, there is the risk that a plant will switch between being in and out of merit in any given period based on macro-economic developments to commodity and carbon prices. Coal or gas assets are subject to this type of effect. Biomass is much less subject to such changes because it is a less freely traded globally and often the power station may sign long-term fixed contracts for fuel or own the feedstock supply chain themselves.

Therefore, any market based framework would need to consider whether it is incentivising generation from a certain technology type which would otherwise be out of merit if CCUS equipment was not installed. If it does do this, then this could be argued as a market distortion.

2.6 Key CfD assumptions for a CCUS CfD

Taking into consideration the objectives of this study and the policy intentions for CCUS, as well as the technical considerations and potential market interactions for any project, Cornwall Insight has set out some key assumptions to guide this assessment.

These assumptions have been used in assessing adaptations for applying a CfD to power CCUS projects and creating appropriate model CfD frameworks. These assumptions are:

- **CCUS CfDs will be bilaterally negotiated in the first instance:** It's assumed that initial contracts will take the form of a bilateral negotiation between projects and BEIS. This is in line with current legislation as any CCUS CfD can only be awarded on the direction of the BEIS Secretary of State and cannot, currently, enter allocation rounds.
- **Market indexation will be to wholesale power:** Payment incentives will be based around the production of clean electricity from the CCUS power plant. This is to seek to ensure incentives can be aligned to positioning in the merit order to try and minimise distortion for other low carbon generation. Additionally, power markets provide more investor certainty than other payment forms, such as carbon savings, through the maturity of the market and investment precedents.
- **Carbon incentives would be penalties based:** The incentive to ensure carbon sequestration is based on non-payment against power output which is not associated with CCUS. CfD payments would only be made against the low carbon electricity generated and CO_2 stored (or transferred to the CO_2 transport and storage operator), which would need to have a contract design feature around the metering and measurement of CO_2 capture and storage. Any residual emissions would be subject to carbon pricing.
- **Technical feasibility of CCUS capture is assumed to be in line with current best available technology:** to accurately assess capabilities the technical parameters of capture plant are assumed to be similar to today and do not consider technological advancements of today's current technology nor new technologically becoming commercially available. Model designs could incorporate features that incentivise improved capabilities over time, this is discussed in section 4.
- **New build and retrofit CCGT, coal and biomass are the technologies considered:** This is to reflect the current technical potential and fuel inputs likely for a CCUS plant. Coal has been included, as the Government has committed to remove unabated coal generation from the electricity system

by 2025, and new build or retrofit of coal plants with CCUS may be a possibility. Open Cycle Gas Turbines (OCGT) have not been considered in assessing the models as their running profile means capture opportunities would be limited with current capture plant technology, but could be viable in future.

- **T&S usage costs would be pass-through fees:** CCUS power plants are assumed to pay T&S fees for use of the T&S infrastructure. This fee could be charged per unit of CO_2, or on a capacity basis (this decision is outside of the scope of this work). It has been assumed that this mechanism would sit outside of the CfD arrangement, possibly being a direct agreement between the power station and T&S owners. However, the cost of this fee to the power plant would be incorporated into a strike price. It is assumed the CCUS power plant has firm access 24/7 to the T&S infrastructure, regardless of the output profile of the CCUS power plant. The CCUS CfD would still need to incorporate features to mitigate interface risk, these are covered in section 3.6.
- **All plant will be subject to decommissioning requirements:** CCUS plant will have decommissioning requirements either at the end of the CfD contract or asset life, and there may need to be regulatory or other provision to avoid unabated running of the power plant post-CfD term.

3 Identification of adaptations for a CCUS CfD

To understand the applicability of the CfD contract to CCUS, Cornwall Insight has undertaken detailed research into the current CfD contracts and their key parameters. This section covers the key areas where adaptations may be needed to the CfD to ensure suitability for CCUS projects, which will help to shape the Model options. The end to end analysis of a project and CfD interactions has been categorised into the following sections:

- Planning
- Construction
- Operations
- Technical requirements
- Commercials
- Decommissioning and termination
- Broader linkages to other infrastructure for CCUS – Transport and Storage

In addition Cornwall Insight has considered other elements from the bilaterally negotiated Hinkley Point C and contracts awarded to biomass plant under the FIDeR process as these are relevant case studies for CfDs for fuelled and thermal stations.

Each area for adaptation identified within the current CfD contract has been given a Red Amber Green (RAG) status indicator based on two key factors, the commercial importance of the adaptation to CCUS for power projects for their deployment and the applicability of the current CfD and degree to which adaptation might be needed, if possible, to suit CCUS project requirements.

The RAG status for each is outlined below for the **commercial importance to CCUS for power**

- Green – little or no risk that would impact the deployment of a CCUS for power
- Yellow – some or moderate risk to the deployment of a CCUS for power
- Red – high or significant risk to the deployment of a CCUS for power

The RAG status for each is outlined below for the **applicability of the current CfD**

- Green – requires little or no intervention for CCUS for power CfD to be adopted
- Yellow – requires some intervention to manage for CCUS for power CfD to be adopted
- Red – requires significant alteration to the existing scheme or may not make it viable for CCUS for power CfD to be adopted

Figure 16: Identification of adaptations – RAG status provides a RAG summary for all the issues identified.

Figure 16: Identification of adaptations – RAG status

CfD feature	Commercial importance to CCUS	Current CfD applicability and degree of change needed
Planning: Supply Chain Plan	🟢	🟢
Planning: Eligibility Requirements	🟡	🟢
Construction: Contract Milestones	🟡	🟡
Construction: Contract flexibility and delivery timescales	🔴	🟡
Construction: Phased projects	🟡	🟡
Operations: Delivery of Capacity	🟡	🟡
Operations: Maximum Contract Capacity	🟡	🟡
Operations: Metering	🟡	🔴
Commercial: Fuel Inputs	🔴	🔴
Commercial: Reference pricing	🔴	🔴
Commercial: Contract Term	🔴	🟡
Commercial: Merit Order implications	🔴	🔴
Commercial: Flexibility revenues	🟡	🔴
Decommissioning	🔴	🔴
Termination	🟡	🟡
Transport and Storage links	🔴	🟡

Source: Cornwall Insight

3.1 Planning

3.1.1 Supply chain plans

The current CfD regulations stipulate projects with a generating capacity of 300MW or more are required to provide supply chain plans. These are first approved by the Secretary of State (SoS) and then required by the EMR Delivery Body for eligibility purposes. A plan is submitted to the SoS during a supply chain plan window which typically occurs before an Allocation Round.

The supply chain plan must show how the project is facilitating open and competitive supply chains in its industry with the aim to encourage the effective development of low carbon supply chains in the UK. The supply chain plan is monitored throughout the lifetime of the project (if successful in an auction) to ensure delivery.

The requirement for a supply chain plan is a feature of the standard allocation process under the CfD Allocation Regulations (2014)[10], which nuclear and CCUS projects are excluded from as they require SoS approval. However, for the bilaterally negotiated Hinkley Point C CfD, a bespoke supply chain plan was created based around procurement parameters from the wider supply chain, rather than on the project itself. This was in line with the wider programme of the Nuclear Advanced Manufacturing Research Centre (NAMRC) of which the project sponsor EDF Energy was already a member.

To align to the policy objectives of being a global leader in CCUS deployment, a similar process could be used for any CCUS CfD arrangement to that of Hinkley. The overall aim of the supply chain plan could be replicated for CCUS in power, but specific policy and technology changes may need to be considered such as:

- The appropriate MW threshold for delivery of a plan and whether all CCUS projects should provide supply chain plans
- Whether a wider canvas for the plan, including links to transport and storage infrastructure and industrial usage of carbon, is needed
- Whether a wider supply chain plan which places emphasis on contractors rather than the project, as is used for Hinkley Point C, is desirable

Figure 17: RAG status of Supply Chain plans

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Supply Chain Plan	●	●

3.1.2 Eligibility requirements

Eligibility requirements under the current CfD are designed to meet wider policy objectives of securing new low-carbon generation at least cost to consumers. Requirements therefore look to mitigate against speculative bidding from projects without the necessary maturity by having criteria such as planning permission approval and confirmed grid connection dates.

[10] http://www.legislation.gov.uk/ukdsi/2014/9780111116777/contents

In respect of each allocation round, BEIS will determine an Allocation Framework which sets out the specific checks that the EMR Delivery Body must carry out in order to assess eligibility.

Broadly, these requirements are:

- Relevant planning permissions (including offshore leases if applicable)
- Grid connection agreements
- Supply chain plans for 300MW+ projects (as per Section 3.1.1)
- Applicable low-carbon technologies not already in receipt of subsidy
    - Must be a new project that hasn't commissioned
    - The project cannot also receive Capacity Market payments
- Relevant target commissioning date for the allocation round
- Proof of company address and incorporation

CCUS is an eligible technology under CfD legislation[11] defined as a "complete CCS system". However, these projects can only be awarded a CfD by direction of Secretary of State, being excluded from the allocation round process.

CCUS technology coming forward is likely to be first of a kind and more immature in its project and technological development. Therefore, criteria linked to obtaining planning and grid connection agreements in place before negotiating a CfD may need to be amended as investors may need greater certainty of support through a CfD before committing to the costs of achieving planning consent and grid connection.

Power CCUS also necessitates additional "grid" connection to ensure suitable transport and storage solutions are in place for the CCUS plant to operate and capture carbon. Eligibility criteria and checks would also need to incorporate how the power station will link to the total CCUS solution and whether securing a T&S deal is a project risk or if it is facilitated by policy of government backing.

To ensure minimum standards and ensure CfDs secure best in class technology, a definition of what constitutes CCUS, or what the policy aims want from CCUS technology, may be required to ensure eligibility is suitably qualified.

Figure 18: RAG status of eligibility requirements

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Eligibility requirements	● (amber)	● (green)

3.2 Construction

3.2.1 Contract milestones

The CfD has a number of contractual milestones at certain points in project development which incentivise projects to show commitment, provide evidence of commissioning or start full operations. Overall, these

[11] The Contracts for Difference (Allocation) Regulations 2014: http://www.legislation.gov.uk/ukdsi/2014/9780111116777/pdfs/ukdsi_9780111116777_en.pdf

milestones could be utilised for a CCUS CfD to ensure the right delivery incentives are in place. However, Figure 19 details some of the interactions with CCUS which, if left unchanged, could create issues.

Figure 19: Identification of adaptations for contract milestones

Milestone	CCUS interactions	CCUS applicability
Milestone Delivery Date (MDD) - evidence of project commitments 12 months from contract signature	Question for CCUS would be whether 12 months is an applicable period to meet commitments. Maturity and conditionality of finance arrangements are factors to consider. The definition of pre-commissioning costs is important for a CCUS project as high spend may be attributed to R&D work in the early stage of the project by the developer. Additionally, under the current CfD, network and grid reinforcement and development works are excluded from this evidence. This definition could be extended to T&S infrastructure for a CCUS project or could be excluded	Question on length of time, project maturity and what CCUS costs should be included if the milestone was used (e.g. T&S links)
Operational Conditions Precedent (OCP) – commissioning requirements to meet before a start date can be issued to receive payments	There are a number of requirements under the CfD and more so for fuelled projects (metering, BM units, grid connection, Fuel Measurement Sampling (FMS) and Combined Heat and Power Quality Assurance). CCUS for power commissioning requirements may need to include a carbon capture quality standard to ensure a high degree of capture and efficiency. Alternatively, equivalents to current CfD standard FMS procedures could be used to agree measurement of carbon and power outputs once operational	CCUS quality standard or amended FMS procedures may be needed to apply the OCP in the same way
Target Commissioning Window (TCW) – commissioning window for the project	The TCW for projects is 12 months under the CfD depending on technology. For CCUS the TCW could provide a clear incentive on build times and project completion	Framework could apply to CCUS – although specific timelines needed
Longstop Date (LD) – end date for commissioning of capacity and meeting OCP	The Longstop Date would be applicable under a CCUS CfD to ensure the right for termination from a CfD counterparty in the event of non-delivery of capacity or project milestones by a set date. In the standard CfD the Longstop Date is typically 12-24 months from the end of the TCW for other technologies, but will need to be set appropriately to deal with the CCUS for power construction profile. Additionally, consideration would need to be made for plant such as CCGT which could be viable without CCUS and may look to operate	CCUS would need to consider whether this timeline is enough of a "buffer" against delays

	outside of their CfD arrangement if it is terminated at the Longstop Date.	

Figure 20: RAG status of CfD contract milestones

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Contract Milestones (overall)		

3.2.2 Contract flexibility and delivery timescales

The generic CfD has provisions for some limited flexibility over completion timelines and potential delays for projects. These provisions include:

- **Relevant Construction Event clause:** which can be used if an event occurs which renders development, completion, construction, conversion, installation or commissioning of the Facility to meet the Installed Capacity Estimate (ICE) uneconomic. The criteria for this are strict, being a geological condition or physical constraint on delivery. Projects that have this clause approved then have the ability to reduce their Installed Capacity Estimate
- **Grid delay extensions:** The CfD provides day for day extensions to a project which suffers a grid delay, so long as the delay impacts on stated project milestones, the MDD, TCW and LD, and was due to the network company not carrying out works in a timely manner and not the fault of the generator from negligence or avoidable circumstances
- **Force Majeure:** provisions in the CfD allow relief from liability against CfD obligations and milestones for the affected party in a force majeure event. The definitions of force majeure include Change in Law provisions and omissions by third parties, such as the CfD Settlements provider, which impact the party's obligations to meet contractual requirements and were beyond their control. It is worth noting that meeting force majeure criteria under the CfD comes with strict defined criteria
- **Permitted capacity reductions:** Projects are permitted at certain milestones in the contract to reduce their Initial Installed Capacity Estimate (IICE) set at the time of application. By the MDD projects are permitted up to a 25% reduction, which then becomes the Installed Capacity Estimate (ICE). From this point onwards the CfD states that generators must commission between 85% and 95% of the ICE, depending on technology. It is worth noting that capacity changes are only ever downwards and are entirely at the generator's discretion at certain contract stages

Whilst these features could provide some flexibility for CCUS plant in ensuring project development and providing some comfort for investors and developers if unforeseen events occur, they are not directly transferrable to CCUS power project.

Construction events for CCUS may be more material than established low-carbon technologies and therefore the current clause may need to be amended to provide more protection than just capacity reductions and delays to milestones to provide comfort to developers. Additionally, the grid delay extensions for current CfDs do not directly mirror across to CCUS as there are wider delay risks due to the multifaceted delivery streams of such a project. Issues could result from commissioning delays either with the power station or the T&S infrastructure. Any delay provisions in a CCUS for power CfD may need to account for the impacts on the wider project delivery and risk sharing between the different strands of CCUS development, such as grid delay and Force Majeure provisions against T&S delays.

Figure 21: RAG status contract flexibility

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Contract flexibility		

3.2.3 Phased projects

The current CfD permits up to 3 phases for offshore wind projects. This is designed to allow for large scale project development over a longer period than the standard contract allows through the TCW and LD timelines. The structure also potentially allows for divestment of phases whilst others are under development.

Under the current phased CfD rules:

- There is a maximum combined capacity of 1,500MW over the three phases (cap not applicable to single phase projects)
- 25% of the capacity needs to be commissioned in Phase 1
- Each phase must be at least 5MW in size
- The Strike Price is the same throughout all phases
- The Target Commissioning Date (TCD) of the final phase must be within 24 months of the TCD of the first phase

Generators opting for phased project CfDs choose between two templates which are distinct due to metering requirements, the single metering CfD and the apportioned metering CfD.

- Single Metering CfDs effectively measure and apportion output for each phase as part of the wider project. Each phase must have at least one exclusive BM unit with a separate phasing agreement to measure output
- Apportioned Metering CfDs allow for metering to be split in line with ownership and power offtake structure for the project. There are metering and monitoring obligations with this approach and generators may design their metering system to record the net metered output for the project as a whole. The apportioned metering approach is typically used by joint venture or multi-owner projects to apportion volumes by ownership structure

The scale of potential CCUS projects means that they could benefit from a phased CfD approach to help de-risk elements of project milestones for investors and developers. This is especially true if CCUS equipment is applied to Combined Cycle Gas Turbines (CCGTs) with multiple gas or steam turbines. Apportioned metering may also benefit joint venture CCUS projects.

However, the applicability of the specific phasing requirement for CCUS will need to be adapted to account for their probable scale and any timing of CCUS phasing.

Figure 22: RAG status phased projects

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Phased projects		

3.3 Operations

3.3.1 Performance and capacity

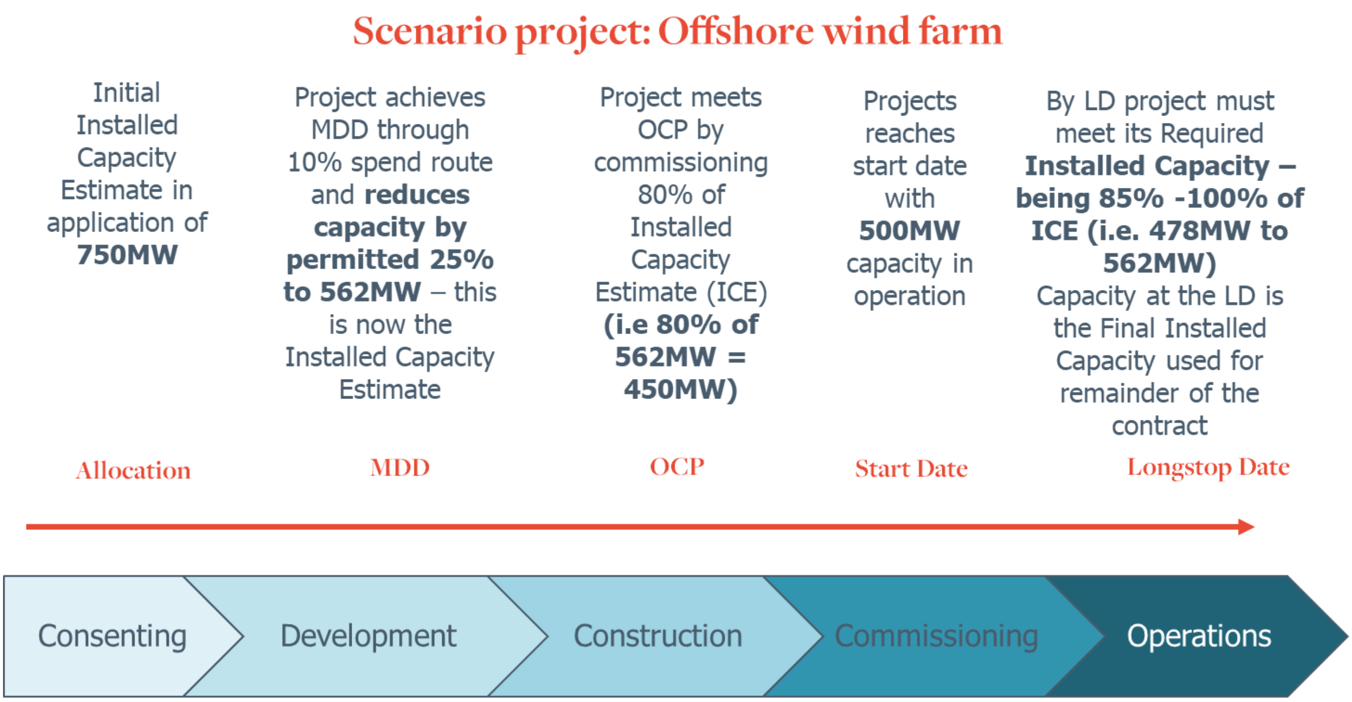
For both delivery and operations, the CfD has strict requirements around the capacity of a project.

Delivery of capacity

The CfD sets out clear requirements on the delivery of the Initial Installed Capacity Estimate (IICE), with the aim to ensure that capacity is achieved in line with budget allocation. There is some flexibility on this delivery, but it is not a desirable outcome for projects as under some circumstances it reduces payments against contracted capacity and ultimately revenues on the project. A Required Installed Capacity (RIC) is also set out in the contract to incentivise generators to meet minimum capacity requirements, being 85% of the ICE for offshore wind and 95% for all other technologies. The RIC needs to be met through commissioning by the Longstop Date, or generators face termination.

Figure 23 provides an indicative example of the current process for capacity for an offshore wind farm in the existing CfD to give comparison of the scheme requirements.

Figure 23: Installed capacity flexibility scenario



Source: Cornwall Insight

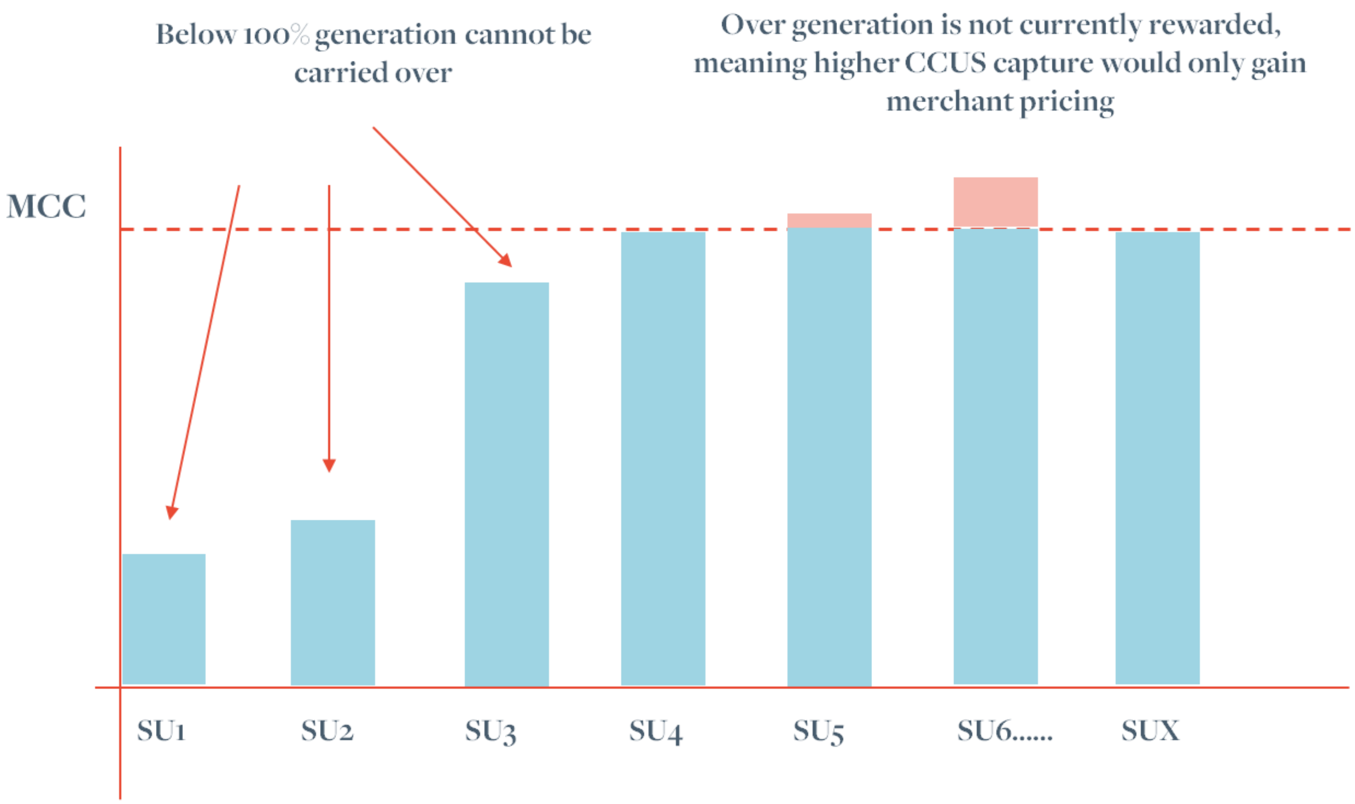
Importantly under the wider scheme, there is no provision for any "spare" capacity not delivered in contracts to be re-utilised or recycled to other projects under the same allocation round or in the future. This could be an issue for BEIS, where the policy imperative of carbon sequestration could be less successful if projects downgrade their capacity/ carbon capture levels during construction. Although payments are only made on clean electricity, lower capacity delivery by generators could be an issue for BEIS against any set policy objective for carbon sequestration or CCUS output expected or targeted. It could also impact on T&S network utilisation and revenues if higher carbon flows were previously expected.

A power CCUS CfD may need to factor in penalties for non-delivery of carbon capture, if projects built have lower installed capacities than those initially stated at the time of CfD award. This could potentially be through carbon offset penalties on the plant or alternatively budgets allocated for stated capacity could be re-allocated to future CCUS plant to ensure any potential carbon sequestration targets are met.

Performance and maximum contract capacity

Once a current CfD project is operational it will declare a Final Installed Capacity (FIC) through issuing a Final Installed Capacity Notice. For the purpose of operations and payments this is used to set a Maximum Contract Capacity (MCC) for the duration of the contract. The MCC effectively caps payments for each settlement period and over generation is not rewarded under the CfD and cannot be carried over to other settlement periods where generation is below the cap. A generator would still receive revenue for over delivery, however it would just be merchant power revenue sold into the wholesale market. The objective of the MCC is to ensure consumer costs under the scheme are managed and capped at expected levels. Figure 24 below provides an indicative example of this current approach.

Figure 24: Maximum Contract Capacity under the CfD



Source: Adapted from LCCC

A key consideration with thermal plant is their output correlation with weather factors including temperature, pressure and humidity. These all impact the MW output of the plant and mean that the actual generation and capture will vary. Whilst the CfD provides for the calculation of parasitic or auxiliary load of the plant in installed capacity calculations, adjusting views on the Maximum Export Limit (MEL) and plant output may be needed to account for weather impacts on large thermal plant.

Additionally, from a policy standpoint, if a CCUS project delivers greater clean electricity than expected it could be argued that this should be rewarded or compensated in some way as it is reducing emissions on power required to meet market demand. This incentive could also lead to more efficient running of the equipment to capture additional revenues. However, this additional payment coverage could also apply to modular technologies such as offshore wind and a precedent for wider lower carbon technologies may be set if this approach was applied to a CCUS CfD.

An additional element that emerged from previous bilateral CfD negotiations is the concept of applying a fixed MWh generation level for the plant over its CfD lifetime. This could be applied to CCUS, where an equivalent Maximum Contract Capacity is set at a MWh level for the contract duration as well as in individual settlement periods. Whilst this may control costs under the scheme, it could limit running hours for a flexible CCUS project if flexibility market requirements are greater at the start of the contract and limited hours are left towards the end.

Figure 25: RAG status performance and maximum contract capacity

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Performance and capacity		

3.3.2 Metering

To secure CfD payments current CfD projects must have a metering system that is compliant with the Balancing Settlement Code (BSC) requirements and those of the CfD. This includes relevant Code of Practice (COP) requirements. The metering must be exclusive to the CfD Facility output and account for losses to the distribution or transmission system connection. A project must also submit a copy of their Electrical Schematic Design to the LCCC to share information on the location of metering equipment. For private wire CfDs the BSC arrangements do not apply, but procedures are still agreed with LCCC around location and exclusivity of CfD output. Phased projects can opt for single or apportioned metering practices.

Metering is used to determine payments under the CfD, with generator output and payments calculated under the CfD on a Net Metered Volume basis. This is broadly defined as the gross generation of the site minus any parasitic load used by the generator and any losses up to the meter point, known as Loss Adjusted Metered Output (LAMO).Payments are made to generators for each Settlement Unit (SU), these are half-hourly in duration for baseload plant and hourly for intermittent technologies.

The CCUS CfD will need to ensure that both power and carbon are metered, for which the metering of carbon, while more challenging, already has internationally recognised standards.

There is no provision for the metering of carbon in the current CfD rules, creating issues for automatic applicability of the CfD to CCUS power projects. Carbon metering standards are not captured under the BSC and therefore new standards would be needed and required under eligibility rules. This links to the Operational Conditions Precedent issue highlighted in section 3.2.1 around a Fuel Measurement and Sampling (FMS) equivalent standard for metering carbon in a CCUS power plant.

Metering of CCUS under any CfD arrangements would need to consider:

- What is being metered for the purposes of verification and payments? Variables could include carbon measured at the point of capture from the power station, carbon measured as delivered to transport infrastructure or the proportion of carbon in storage following sequestration
- Over what timeframe CCUS is being measured? This could be from near real-time granularity out to seasonal variations

Figure 26: RAG status CfD metering

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
CfD metering		

3.4 Commercial

3.4.1 Fuel inputs

The current CfD has no requirement to account for the fuel input prices of generators. Although the CfD provides a fixed wholesale power value, a thermal or fuelled renewables generator still faces some degree of risk around their fuel input, for instance biomass pellets or waste for Anaerobic Digestion (AD). The variability on this price is currently seen as a commercial risk that generators need to account for in their Strike Price. For a CCUS project, the degree of fuel price volatility is likely to be greater with gas, coal, and biomass being the input fuels.

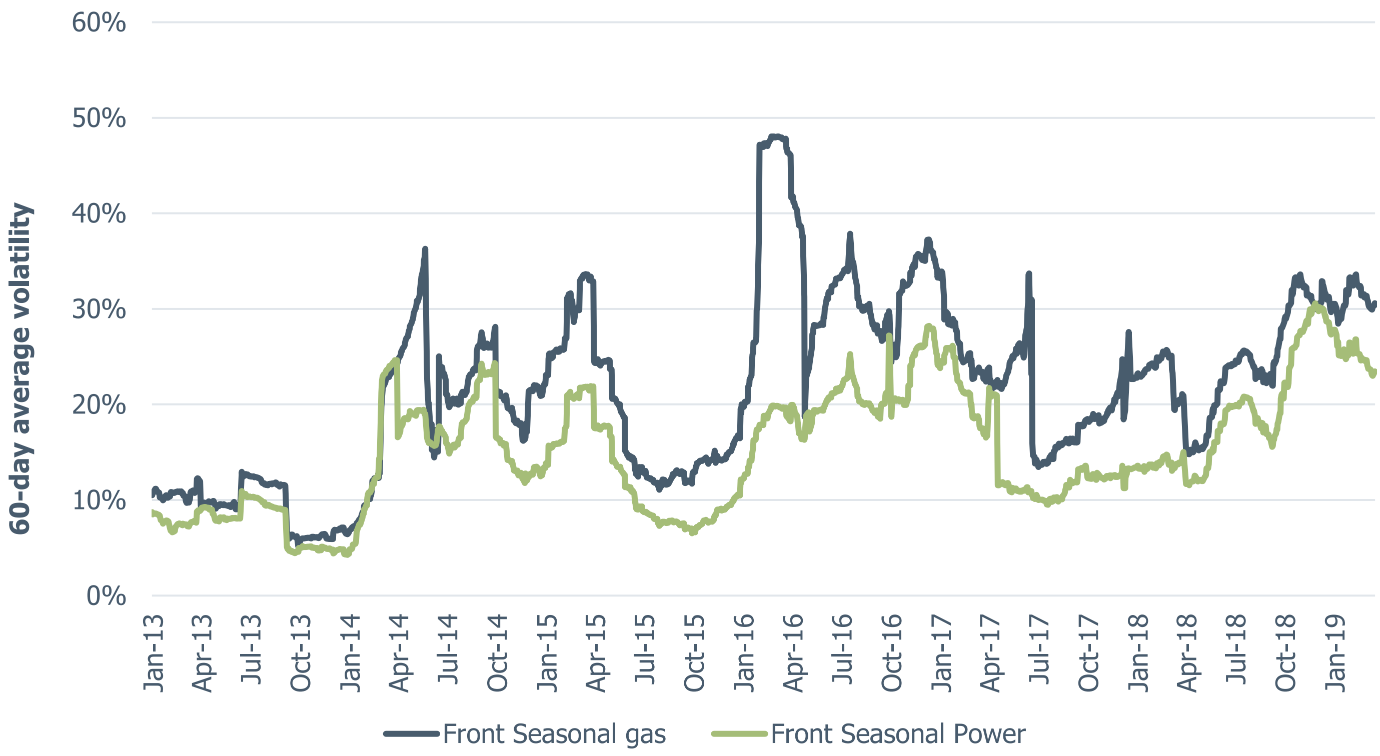
Figure 27 below shows Cornwall Insight analysis of the volatility of different tradeable commodities over the last 12 months as well as a comparison of season-ahead power and gas volatility. It shows that both the season-ahead gas and power contracts show variability in price of round 25% from the 60-day average. As an example, for a CCGT CCUS equipped plant, its fuel input and power revenues would have had a 25% swing around the mean price over the last 6 months. If linked to day-ahead prices this swing would have been 49% for gas inputs and 90% for power.

Figure 27: Commodity price volatility trends

Month	Day-ahead power	Front Season Power	Day-ahead gas	Front Season Gas	Coal	Oil	Carbon
Jan-19	90.6%	25.9%	49.3%	30.8%	39.8%	33.8%	69.5%
Feb-19	94.9%	25.5%	47.8%	32.5%	36.8%	32.6%	60.3%
Mar-19	77.1%	23.7%	41.6%	30.5%	28.8%	27.8%	55.8%
Last 6-months	73.5%	25.9%	46.9%	30.9%	29.9%	28.3%	63.5%
Last 12-months	86.2%	21.3%	75.4%	26.1%	25.6%	25.3%	52.7%

Source: Cornwall Insight

Figure 28: 60 day average volatility for gas and power



Source: Cornwall Insight

For CCUS projects there is a risk that under the current standard CfD a fixed strike price value may lead to a negative spread on carbon capture, disincentivising operations of the generating plant or CCUS equipment. The current generic CfD design does not allow for a re-negotiation of the strike price, only an adjustment by the LCCC on the grounds of changes to inflation to industry charges or in certain circumstances where there has been a change in law.

A reference price linked to the spread on fuel inputs, most likely to a clean spark spread for gas, may need to be incorporated into the CCUS CfD to ensure the power strike price does not limit operations in a scenario of high fuel input prices. However, the exact criteria for that fuel input, be it season ahead, quarter, month ahead or others would be very important. Any fuel product linkage will need to be aligned with the payments reference index for power under the CfD to ensure the generator can lock in a profit or margin above the SRMC of the plant. For example, if CfD payments for power are made against a season-ahead reference, the same or very similar metric for the fuel input would be needed to ensure a CCUS project can lock in a spread.

However, there are concerns around profiteering by generators under a CfD arrangement which is linked to a set product. Many large thermal power stations are delta hedged up to 3 years ahead of time. Delta hedging is an options strategy that aims to reduce, or hedge, the risk associated with price movements in the underlying asset, by offsetting long and short positions. Any link to underlying products such as season, will need to ensure there is adequate liquidity to enable large plants to trade in the market and provide a cost-reflective market price.

However, even assuming the fuel input and power reference pricing (section 3.4.2) are aligned, there remains the risk that other carbon emitting plants may operate ahead of the CCUS plant because the underlying input commodities favour alternative fuels. This has occurred frequently in the GB market with gas and coal switching in the merit order due to the underlying commodity value. Whilst this specific example may no longer be an issue from 2025 with the planned unabated coal phase out, in future there may be higher carbon intensity technologies which may run ahead of CCUS if it is aligned to the merit order. This is especially true of biomass CCUS with its relatively high fuel prices and overall Levelised Cost of Electricity. The exact nature of this impact will vary by time and the relative input fuel cost required to deliver the MWh and represents a material risk to revenue security.

Figure 29: RAG status fuel inputs

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Fuel price volatility	●	●

3.4.2 Reference pricing

Current CfD reference prices are linked to wholesale power prices, with the broader incentive being the delivery of low carbon power. Two different market reference prices are currently used, intermittent and baseload, depending on the technology. These are designed to link CfD generators to wider wholesale market pricing and trading structures. Ultimately, generators are incentivised to trade against reference prices to ensure full top-up payments to their strike price.

To incentivise CCUS in the power market, a similar £/MWh structure could be used. However, the current generic CfD is not directly applicable for reasons including:

- **CCUS eligible power and capture rates:** A CCUS CfD would need to only pay for the 'clean electricity' produced from the plant. The current CfD has no provision for this in its measurement of payment. Currently, fuelled generators under the CfD have a Renewables Qualifying Multiplier (RQM) which is used to determine the renewable and sustainable content of fuels used to generate power. This could be adapted across as a payment mechanism for CCUS payments but would need an agreed structure and industry standard approach to measurement and reporting on capture levels and how this maps across to the relevant payment multiplier
- **Market reference price:** The current CfD pays generators against either an hourly day-ahead (for intermittent plant) or season-ahead (baseload) reference price. Depending on the desired run-time of CCUS plant these references may not be appropriate. For instance, if the CfD design for CCUS ensures the plant runs more of a peaking profile so as not to displace renewable technologies, a baseload season-ahead reference price would not be appropriate as it may disincentivise response to market signals and likely limit the returns and investability of the project
- **Alternative or additional reference prices:** The current CfD reference pricing is solely based around the power market. For a CCUS CfD, there is the added element of emissions savings and carbon which may need to be incorporated to address policy objectives. Alternatively, a carbon reference price could be used to penalise a CCUS CfD generator if they are running without CCUS in place. However, fossil fuel generators already pay for carbon when running in the market and therefore this could create a double charge for a CCUS plant running in non-capture mode. Pricing carbon emissions is already occurring in many developed energy markets, with the EU ETS trading scheme and Carbon Price Support currently used in GB. However, the schemes as they currently operate may not directly be applicable to CCUS payments due to:
    - The use of the "polluter pays" principle to charge for emissions rather than reward savings. For CCUS a reward or payment would be needed for the opposite function to incentivise CCUS utilisation
    - The volatility of carbon pricing under the EU ETS scheme, which has seen values range between €4.0/tonne and €25.4/tonne over the last 5 years

- Uncertainty around the future of UK carbon trading in light of Brexit
- The policy objective of CCUS to ensure a direct power market indexation link for any CCUS plant

Reference pricing is of material importance to a CCUS CfD, as prospective investors and developers will use this to forecast revenues and assess their potential earnings under the contract. Uncertainty around future carbon pricing may limit the degree to which a clear investable reference can be made for CCUS plant. A solution to both power and carbon reference pricing ultimately depends on whether the CCUS plant is expected to operate as a baseload or peak running asset.

Figure 30: RAG status reference pricing

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Reference pricing	●	●

3.4.3 Contract term

The current generic CfD contract is a 15-year agreement with the LCCC. There are exceptions to this, with Hinkley Point C having a bespoke CfD agreement which is 35 years in duration, while the Drax and Lynemouth biomass conversions have 11 year contracts to take into account the retrofit aspect of the project and the policy decision to end support for biomass conversions in 2027.

The generic CfD contract of 15 years has been determined through modelling and analysing the typical useful asset lives of low carbon technologies, the required payback periods to ensure desired rates of return and beat hurdle rates and the net present value for consumers of spending on the CfD contracts over different durations.

For CCUS, similar analysis would need to be taken to determine what contract term is best suited to meeting these aims. Analysis would need to cover:

- Useful asset life of CCUS – including the differences between new build and retrofitted equipment
- Re-use of CCUS equipment at different power stations if asset life is beyond that of a thermal power station
- Whether the project is a new build power station or is retro-fitting CCUS equipment
- Hurdle rates for CCUS technology and potential debt recovery timelines
- The ability and desire of lenders to finance at 15-year durations or longer
- The net present value of CCUS to consumers against alternative options over the asset lifetime

From a developer perspective, the more certain revenues are under the contract the more likely a longer-term financing arrangement can be made. Therefore, if the CCUS CfD plant was operating at baseload levels with a set strike price, funding could be extended closer to 20 years. Alternatively, a peak running plant with less certainty on running hours would likely be granted much shorter financing terms or low debt leverage against the overall project value.

These conclusions are based on general energy project finance trends, but an allowance needs to be made for the risks around first of a kind (FOAK) technology and contract deployment for a CCUS CfD contract. Where there is no proven track record of lifetime operation, a lender may want loan repayment before the end of the CfD, to mitigate the potential risks of debt service shortfalls from the project. Although this could be mitigated by providing a floor payment, which is discussed in section 4.4.

Ultimately, the CfD contract tenure for CCUS may have to match the lending horizons necessary to make the investment viable overall, rather than being linked to the generic 15-year approach or typical asset lifetimes.

Figure 31: RAG status contract term

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Contract term		

3.4.4 Wholesale market interactions and merit order

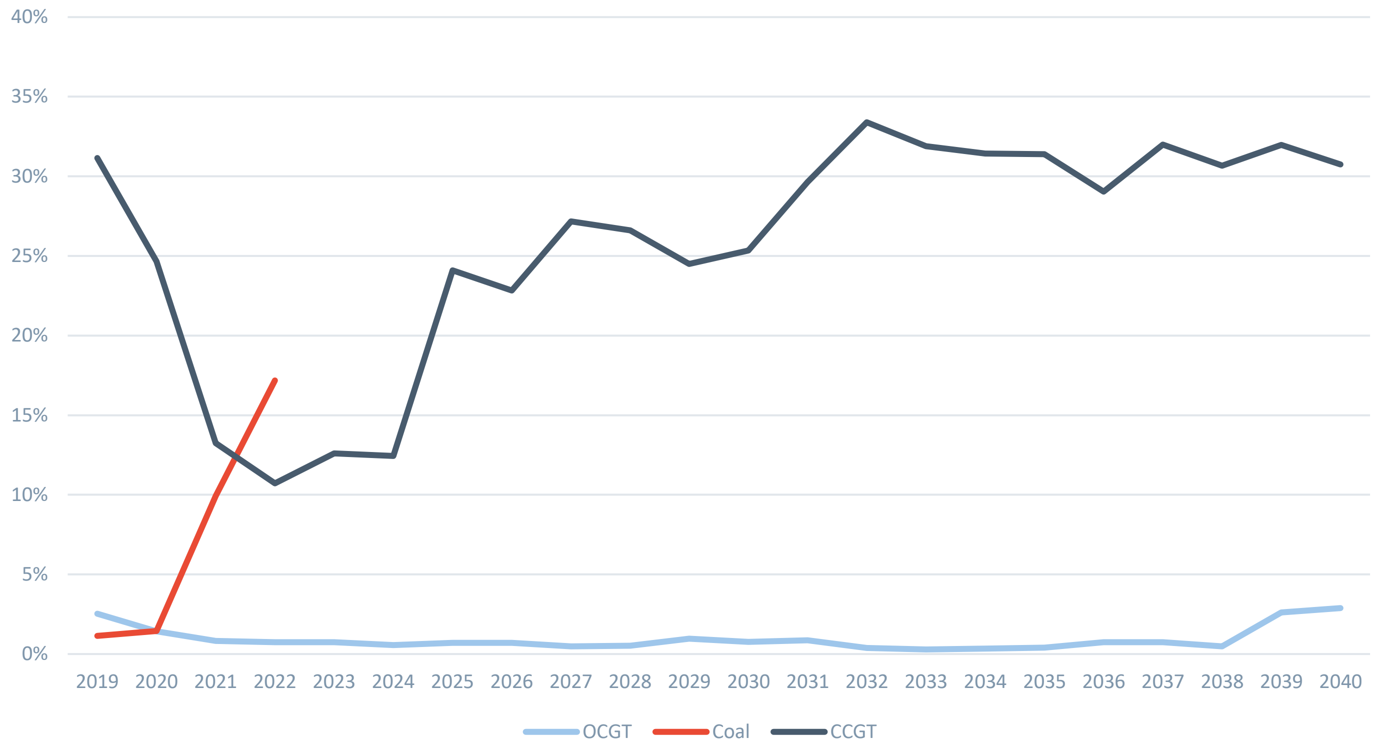
The current CfD pays a fixed £/MWh value on all volumes generated by a project and does not change this level if underlying market prices vary during times of system shortage or surplus. The only exception to this is the negative price provision in the CfD, introduced for AR2 generators onwards, where no CfD payments are made if the within-day market has 6 consecutive hours of negative pricing during the payment period in question. So far under the CfD this provision has not been triggered.

Barring this exception, this means that CfD generators are incentivised to maximise generation, within stable operational limits, to earn higher revenues under their agreements regardless of wider wholesale market conditions. This is an issue for CCUS CfD projects, especially in the context of the policy aims to ensure that CCUS does not run before renewables in the merit order.

The merit order in any given half hour will determine the wholesale market load factor and therefore the amount of time the plant will be operational. Figure 32 shows the estimated future load factor based on Cornwall Insight modelling under National Grid's Community Renewables scenarios and shows that the estimated load factor of an existing CCGT is expected to be approximately 30% or less of the time annually, while coal will have to come off the system by 2025 as part of the Coal Closure Policy the Government has committed to[12].

[12] To note this is subject to SoS approval: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/672137/Government_Response_to_unabated_coal_consultation_and_statement_of_policy.pdf

Figure 32: Coal, CCGT and OCGT wholesale market load factor – Community Renewables Scenario



Source: Cornwall Insight

As an example, a CCUS CfD with a fixed strike price for all hours of operation would be incentivised to run at high output levels regardless of the wholesale electricity price. Whilst other CfD-supported assets also have this incentive (so long as prices do not drop to negative levels), future unsubsidised renewables do not have this incentive and would be dependent on the market price being at a certain level to ensure returns. The higher the number of standard CfD projects which distort the merit order through running regardless of market signals, the greater the degree of price cannibalisation impacts on future unsubsidised renewables. This could ultimately impact investment cases for such assets.

This is a material issue for the structure of the CCUS CfD to ensure market interactions have the desired policy outcomes. Potential solutions are discussed in the model section of this report.

Figure 33: RAG status merit order interactions

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Merit order impacts	●	●

3.4.5 Flexibility revenues and incentives

National Grid as the System Operator procures a number of flexibility services over a range of timescales to ensure system security is maintained. Broadly, the two options National Grid has are the Balancing Mechanism (BM) and balancing services contracts.

The BM is mandatory for all licensed generators in GB, including any licensed generators who have a CfD. Under the CfD contract, generators must have BSC approved metering equipment and a Balancing

Mechanism Unit (BM Unit) if they are participating. Through the BM National Grid can bring on, turn up or turn down plants to manage both energy and system imbalances. Actions are determined on a cost basis and in consideration of system or locational constraints, the pricing for this is determined by generators themselves and is separate to the merit order of the wholesale market. A merit order in the BM will exist for generators of all technologies based on their plant characteristics, commercial arrangements and any support scheme payments they receive. As an example, nuclear BM units will bid and offer to National Grid at very high levels, effectively pricing themselves out of the BM merit order as curtailment for a nuclear plant would likely mean an extended period offline, creating commercial and technical issues for the plant.

Overall, generators will determine how to price based on their wholesale market operations, fuel costs and their technical ability to meet short-term system needs.

CCUS CfD plant provided with the same generic CfD structure would have a very limited incentive to be flexible than they would have otherwise by operating in the market without a CfD. Additionally, if BM prices spiked to very high levels CCUS plant have the technical capabilities to ramp up and meet system shortages. This could lead to super normal profits for the project as the BM price received would be separate from the CfD wholesale market reference price. From a technical perspective, the plant may also ramp up in this time without CCUS equipment yet in operation.

National Grid also procures balancing services to meet specific system needs. These include frequency response and reserve services with the majority provided by thermal plant. Currently under the CfD most assets do not provide balancing services either because they are wind or solar technologies, or, if fuelled either have no direct incentive or lack the informational requirements needed (such as the delay to Power Available project) to respond to National Grid requests.

For CCUS projects, the technical parameters of the power station, likely a CCGT plant or biomass, would be able to offer significant capabilities to National Grid. This would include mandatory Fast Frequency Response, wider frequency services and potential reserve requirements if the plant was operating on a peaking basis. This would also include free inertial response when generating. These revenues are outside of those provided by a CfD in the wholesale market and may impact the running order of the plant in the market. Although BM and balancing services revenues would need to be factored into any CfD arrangement for CCUS, because of their extrinsic nature and uncertainty on delivery they would not be considered bankable revenues by the investor community. Therefore, simply reducing strike prices to account for a modelled estimate of these additional revenues would not be a "like for like" approach as the power and balancing revenues have a different risk profile amongst lenders.

Figure 34: RAG status flexibility revenues

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Flexibility revenues		

3.5 Decommissioning and termination

3.5.1 Decommissioning requirements

For all CfD projects except Hinkley Point C, there are no decommissioning requirements or obligations within the CfD contract. Following the 15-year CfD term, it would be prudent to assume that a typical asset would have a useful asset life of a further 5 to 10 years and would likely operate as a merchant project in the wholesale electricity market. Typically, lending arrangements for the project match the CfD tenure, but for a CCUS project this may not be the case.

Hinkley Point C has many decommissioning criteria related clauses wrapped into the CfD agreement. The CfD is for 35 years, but a useful asset life of around 60 years could be expected, with decommissioning not taking place until perhaps 2100. The CfD for Hinkley Point C is aligned to the Energy Act 2008, which legislated that operators of new nuclear power stations must have a Funded Decommissioning Programme (FDP) to ensure financing arrangements are in place to meet the full costs of decommissioning and their full share of waste management and disposal costs. The FDP is a pre-requisite before nuclear-related construction can begin.

Hinkley Point C's FDP was conditionally approved in October 2015, with waste and decommissioning costs accounted for with a £2/MWh allowance in the strike price. The operator, EDF Energy, will pay a higher proportion of the strike price into the FDP if decommissioning costs rise but also benefit if they can mitigate these costs. A Funding Arrangements Plan (FAP) is also in place as a formal contract between EDF Energy and an independent fund company set up to hold money for the decommissioning phase.

Importantly from an investment view, decommissioning costs have a statutory priority over both debt service costs and shareholder dividends under the financing structure.

For CCUS plant there may need to be regulatory or other provisions to avoid any incentive for a fossil fuel powered station to continue operating after its CfD without CCUS equipment.

The current generic CfD is therefore not suitable as it provides no decommissioning requirements or criteria. However, Hinkley Point C may provide a useful model of how to incorporate CCUS decommissioning costs into a bilaterally negotiated contract for both strike price adjustments and financing arrangements.

This is also the case for T&S infrastructure, where the fee placed on the CCUS plant and potential other users may need to account for the decommissioning costs. Therefore, any strike price for a CCUS plant would likely need to incorporate decommissioning costs for the plant as well as relevant T&S fees, which may also include a decommissioning factor within this. Careful consideration needs to be made to ensure double counting of fees, or payments, is not being made or unbearable risks are being taken by project investors.

Figure 35: RAG status decommissioning requirements

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Decommissioning	●	●

3.5.2 Termination events

The CfD has several termination criteria which are used by the LCCC to incentivise delivery and prudent operation from projects, halt payments and postpone any future commitments if projects are in breach of their agreement. These termination criteria are broadly aligned to the policy objectives of ensuring timely project delivery, accurate and truthful reporting of low-carbon output and maintaining investor certainty for those prudently operating. Criteria broadly cover:

- Failure to meet contract milestone requirements in full and by the stated deadlines
- Insolvency of the generator

- Non-payment by the generator the LCCC
- Fraudulent activity by the generator
- Failure to declare transfer arrangements
- Failure to comply with metering arrangements

Importantly, termination events that occur after the Start Date of a project may require payment from the project to the LCCC. This is typically equal to the amount the project would have paid in difference payments over the remaining life of the contract had the CfD not been terminated, subject to the application of a formula.

The broad criteria here could be applicable to a CCUS CfD as they provide a final end point if a project fails to meet criteria, potentially limiting wasteful consumer spend on a failed project. An issue arises around how strictly these criteria may be applied to CCUS as the volatility of fuel inputs and wholesale prices may put a higher probability of termination on a CCUS project particularly around non-payment. Additionally, the current criteria only cover the "CfD Facility" itself i.e. the generating station. For CCUS, issues may arise due to aspects outside of the CCUS power station equipment including transport and storage links. Defining what constitutes a termination on the CCUS equipment is therefore critically important. Events linked to transport and storage issues could be outside of the CCUS power stations control and may be considered force majeure under the CfD definitions.

Figure 36: RAG status termination events

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
Termination events	●	●

3.6 Transport and storage links

One potential policy option being considered by BEIS is for T&S infrastructure and any CCUS power plant to be separately contracted for, which could automatically raise issues of interface risk between these two strands of CCUS infrastructure. This has already been seen to some extent in the full chain CCS Competition projects This interface risk is not currently accounted for in the standard CfD terms.

A CCUS CfD may need to incorporate a number of features to ensure T&S interface risks are adequately accounted for in the contract and also take account of any risks or interdependencies between the two project aspects and their respective regulatory regimes.

Figure 37: T&S infrastructure links and potential risks below provides a summary of the key risks for a CCUS power stations links to T&S and the potential mitigation through a CfD contract.

Figure 37: T&S infrastructure links and potential risks

Transport and Storage link risks	CCUS interactions	CfD contract mitigation
What if the T&S infrastructure is delayed beyond the start date of	The CCUS plant would not be able to operate with carbon capture if such carbon cannot be transported	Permissible TCW and longstop date extension in the contract could be linked to T&S start dates and any uncontrollable changes to this. A

the CCUS power plant?	and stored, potentially impacting CCUS eligible CfD payments	deadline of extensions may be needed before payments/ damages are paid to the CCUS power plant
What if the CCUS plant is delayed beyond the T&S start date?	The CCUS power plant may face contract erosion if the start date for it and the T&S are aligned and then subsequently missed	Contract erosion should provide a good incentive for the CCUS plant to limit these impacts. The contract may need to incorporate payments/damages in return to the T&S infrastructure if project delays persist over a long duration (+12 months)
What if the T&S infrastructure does not have sufficient capacity to serve all customers at peak CO_2 capture?	There are risks for the CCUS plant in ensuring access to T&S infrastructure when required. This would likely need to be the equivalent of firm access 365 days a year	The CfD contract itself may not be the right tool to mitigate against this risk for the project. Instead, an agreement between the CCUS project and T&S infrastructure may be needed to confirm access arrangements, charges and usage limitations
What if the CCUS power plant runs significantly fewer hours than expected (thereby capturing lower volumes of CO_2)?	There is risk for the power CCUS project that if it is not running frequently in the power market, for instance if operating as a flexible asset, that it does not utilise as much capacity in the T&S infrastructure as expected. This could lead to high unit costs to the power CCUS project if the price to use the T&S is on capacity basis rather than per unit	The CfD contract could opt for minimum as well as a maximum power output and CO_2 capture levels to ensure T&S usage. However, this will depend on whether the asset is running baseload or peak

Figure 38: RAG status transport and storage links

CfD feature	Importance to CCUS project	CfD applicability and degree of change needed
T&S linkages	●	●

4 CCUS CfD Models

4.1 Introduction

Following identification of areas for adaptation, Cornwall Insight has created archetype models which could be addressed CCUS projects.

Three models are presented:

- A baseload incentivised CCUS plant with limited flexibility
- A hybrid CCUS plant with lower baseload output and more flexibility
- A flexible CCUS plant with a running profile determined by the merit order

Each CfD model is detailed below with an overview given of the potential contract features.

The key differences between each model mainly cover the commercial incentives and operating criteria placed on the CCUS plant. For each model, we broadly envisage wider CfD contractual factors such as contract milestones, contractual flexibility, operational requirements and eligibility criteria can be mapped across to a CCUS CfD. Albeit, this would need to incorporate adaptations to meet some of the specific CCUS adaptations highlighted in section 3 of this document.

The three models have been reviewed against key objective criteria to ensure consistency when evaluating the different model options.

- **Investability -** CCUS must be an investable proposition to a variety of lender and investor types. In particular, this must remain the case in the event of cross-chain risks being realised
- **Merit-order position -** At the plant level, CCUS facilities should operate efficiently without distorting market signals or the merit order and should not deter renewables dispatch (baseload vs flexible generation)
- **Cost reduction -** Any framework for power CCUS must support a cost-reduction trajectory for both levelised costs of electricity of the plant and in ensuring consumer costs are minimised. This is key to achieving the ambition set out in the CCUS Deployment Pathway.

Consideration is also given to the technical parameters of CCUS projects against these incentives, the potential capture efficiency and overall capture levels and onward implications for the T&S infrastructure with the different model running profiles.

In addition to Cornwall Insight's review, interviews with independent investment advisors have been conducted on the proposed models and alternative options available. This has included Peter Atherton and Andrew Buglass.

Peter Atherton has been an Equity Analyst since 1996 when he joined Kleinwort Benson to cover the UK utility sector. In 2000, Peter joined Citigroup where he was Head of Pan European Utilities Sector research. Whilst at Citigroup he was regularly ranked No.1 in both the Extel and Institutional Investor surveys.

Andrew Buglass has been funding and developing global energy projects exclusively since 1992, under senior roles with leading companies such as Royal Bank of Scotland, PowerGen plc and Unocal Corporation. He also has a role as Co-Chair of the Low Carbon Finance Group, which brings together senior energy investors across debt and equity and has been a respected voice in dialogue with policy makers since its formation in 2009.

To note, all numbers used are for representation only and should not be considered an assessment of typical values for a CCUS project.

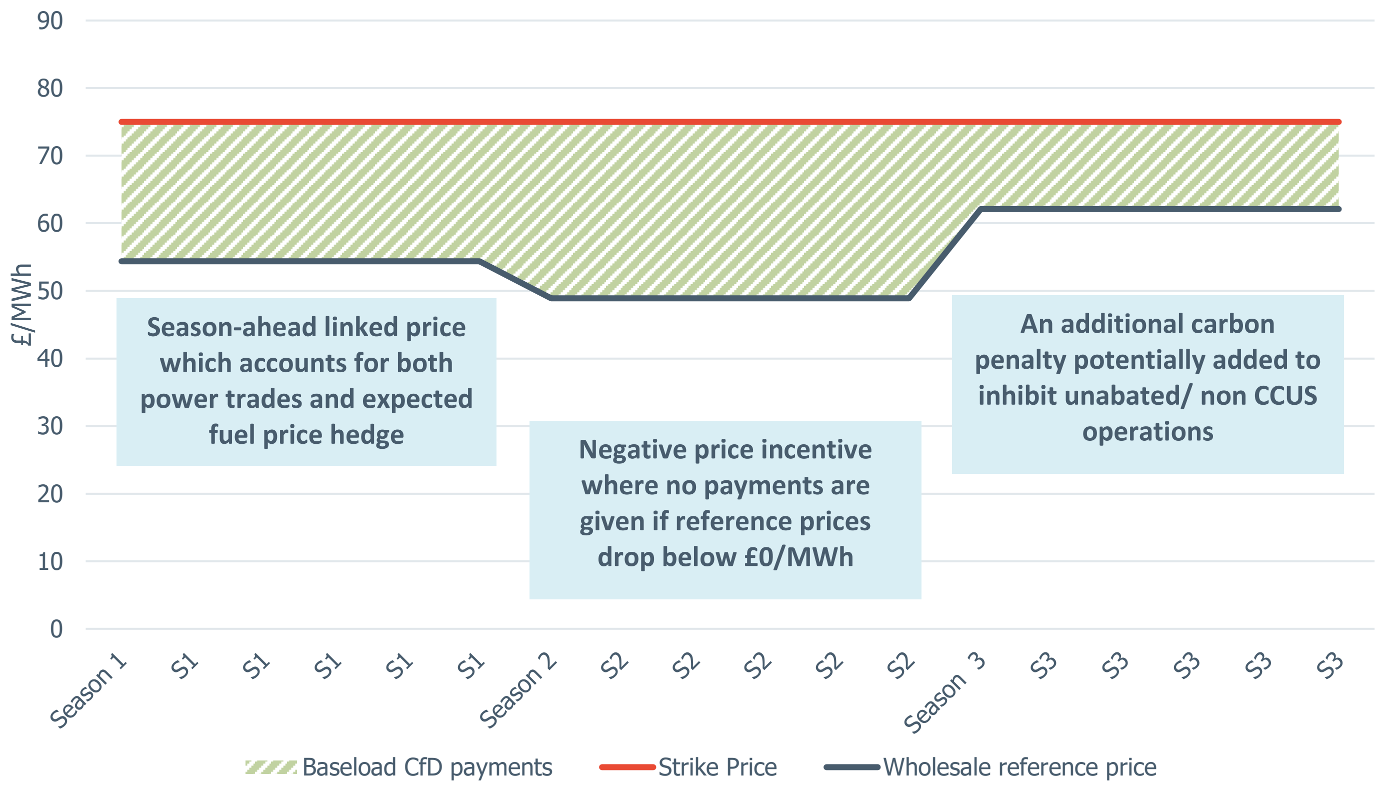
4.2 Option 1: Baseload CCUS plant CfD

4.2.1 Option overview

This first model option is the closest in alignment to the current standard CfD and would reward a power station on the power generated with CCUS capture at a fixed £/MWh strike price. The strike price would incorporate the LCOE of the technology type when fitted with CCUS equipment, the relevant T&S user fees and any associated decommissioning costs, which would be ringfenced. Payments could be measured through appropriate metering practices on carbon to assess volumes delivered to the T&S operator during power production, in an equivalent to the current RQM procedures under the CfD. The strike price would need to be set at a level to ensure the plant is only incentivised to run with CCUS equipment in operation. Incentives could also be added to dissuade running the project unabated, including additional emission price penalties for non-CCUS generation.

An alternative to this structure outlined in Figure 39 could be a strike price adjustment to the market spread rather than the actual traded price. This would likely provide greater security over the running profile and the investability of the plant versus other thermal generation. This could be done through a pre-determined calculation to the market spread but would represent a different approach to existing CfDs which have been based on £/MWh.

Figure 39: Option 1 baseload CfD example



Source: Cornwall Insight

Figure 40: Option 1 baseload contract overview

Contract feature	Model 1 design: Baseload CfD
Contract term	**10 to 20 years in length** based on the incorporation of a tail for investors to the estimated life of the plant of 25 years
Pricing arrangement	**A £/MWh strike price.** Market Reference Price for power would need to be linked to an equivalent metric for the fuel price hedging to ensure alignment on positive spread. The most suitable being a season-ahead or year-ahead reference price
Fuel price provisions	**Fuel price adjustments** may be required to ensure that the spread of the unit with the adjustment results in a positive cashflow and therefore stable baseload running patterns. This may require a fuel price adjustment and / or a spread adjustment to align with other plants in the market to guarantee running
Flexibility incentives	**Very limited** with £/MWh payment incentive. Altered negative price provision where no payments are made if the reference price of power drops below £0/MWh, rather than as currently after 6 consecutive hours, should deter running in these circumstances
Contract milestones	Broadly mirrored across from generic CfD. **Specific adaptations would be needed** to incorporate: • The expected construction timelines of CCUS against the current delivery milestones under the CfD i.e. specific CCUS extensions may be needed to the Target Commissioning Window and Longstop Date to ensure the correct balance of risk for developers • The milestone requirement (MDD) to prove project development could be extended to allow for longer duration CCUS construction milestones and financial close • An extended remit on delivery obligations to cover not only installed capacity but also minimum carbon capture rates
Contractual flexibility	Broadly mirrored across from generic CfD. **Specific additions to account for T&S delays** and interactions would be needed including: • Specific T&S delay criteria which would ensure that any delays outside of the CCUS power projects control would be accounted for in contract milestones and general contract term extensions
Transport and storage links	**The baseload structure provides the most certainty of any model structure for T&S infrastructure links** as the CfD structure would provide a clearer signal to the T&S provider on expected usage patterns. This certainty could also make a T&S payment structure more simplistic, with a £/tCO_2

	equivalent being used. This cost could then be wrapped into the CCUS power projects strike price, removing uncertainty around T&S payments for the CCUS power station
Decommissioning	**This can be accounted for in strike price given to the power project**. Taking the example of Hinkley Point C, a ring-fenced function under the contract could be utilised to ensure value is set aside for any decommissioning requirements

Source: Cornwall Insight

4.2.2 Option appraisal

Principles

Figure 41 assesses the baseload model option against the CCUS Action Plan objectives.

Figure 41: Option 1 appraisal against CCUS policy objectives

Objectives	Overview
Investability	This option is most aligned the to the current CfD and the fixed strike price across all periods would support price certainty for investors. However, the certainty of running is not guaranteed depending on the relative spread of other plants and input commodity prices, this could potentially be managed through fuel price adjusters to ensure baseload running patterns regardless of fuel spreads
Merit order position	Baseload operational incentives would the mean asset runs ahead of some newer subsidised renewables (AR3 onwards) and new subsidy free assets
Cost-reduction	All models could feasibly provide cost reduction trajectories if the right tendering frameworks and contract incentives are in place. For the baseload CfD an assessment would need to be made on the overall CfD spend on any projects against the strike price. As while the £/MWh figure is likely to be lower than the hybrid or flexible CfD scenarios, increased run time would likely lead to higher costs overall. However, the increased running times could provide for quicker technology learning and improvements for future projects. To make this investable the contract also needs to incorporate fuel price/spread risk that will likely result in a higher cost of capital than the current standard CfD

Other considerations

An adequate fuel price hedge would need to be in place to de-risk input price volatility. It is possible to create an adjustment for the fuel input within a short run marginal cost calculation to ensure the plant can operate and maintain a stable revenue stream.

There are a number of ways this could be achieved with the most appropriate market linking the power market reference price, being season or year ahead, to an equivalent fuel contract to allow for equivalent hedging. Season ahead hedging for baseload thermal assets is a common practice across the sector.

However, there is a risk that a CCUS power station may not be able to lock in a margin this far ahead if spreads are negative. Therefore, a fuel price adjustment or reimbursement ex-poste to ensure a positive spread on power generation or providing an additional top-up on the £/MWh strike price may need to be added. This would ensure the power station is compensated for high short-term commodity volatility and has the certainty to remain operating at baseload even in times of negative spread.

Whilst this maintains certainty for investors, it would expose the Low Carbon Contracts Company and ultimately suppliers and consumers, to potentially large-scale swings in global commodities and short-term price spike impacts. Consumers do bear this risk generally with wholesale market price fluctuations, but this model effectively locks in this risk for one commodity when in normal market circumstances exceptionally high pricing would see fuel switching in the generation mix.

However, it should be noted that in the reverse situation where fuel prices dropped significantly then the fuel price adjuster could be lowered to ensure that generators are not over rewarded (and consumers not exposed) to unnecessarily high CfD payments.

This model would provide comfort to onward T&S infrastructure owners, as carbon levels could be forecast against expected running patterns and load factors. It would also allow for a more simplistic "pay per tonne" carbon tariff which could be forecast against expected running patterns.

From a technical standpoint this approach also has advantages. As discussed in section 2.4 the most mature and commercial power CCUS technology is post-combustion capture. With best available existing technology in standard configuration, post-combustion carbon capture plants typically require 1-2 hours from a cold start to reach steady-state operation after receiving heat to the regeneration column. An extended start up sequence may therefore be needed at present to ensure low-carbon operation. Alternatively, an initial period of increased CO2 emissions may need to be tolerated, if the start-up time of a capture plant cannot match that of a CCGT. A CCUS power station with post-combustion capture under this model would have the lowest likelihood of non-capture or lag as the number of starts and ramping activities in a year would be very limited compared to a more flexible asset. The total amount of carbon capture and the proportion captured against total power output is likely to be highest under this model

One potential major drawback of this structure is its position in the merit order and incentive to be flexible. The fixed strike price across all periods would incentivise baseload operations and could in future distort merit order functions to the detriment of renewables assets.

As discussed in section 3.4.4, whilst other CfD-supported assets also have the incentive to operate whenever possible to capture a fixed strike price, or under the RO a certificate value, future unsubsidised renewables would be dependent on the market price being at a certain level to ensure returns. Under this model if prices dropped to very low levels unsubsidised renewables would likely be incentivised to lower or completely stop generating whilst a baseload CCUS plant still operates to capture its full strike price. This could be an issue for potential subsidy free projects developing in the 2020s and mature RO projects which will start to roll out of the scheme from 2027. Ultimately, the higher the number of baseload CCUS CfD projects which distort the merit order through running regardless of market signals, the greater the degree of price cannibalisation impacts on future unsubsidised renewables.

Some degree of flexibility could be provided through amending the current negative price provision in the CfD and ensuring that in any periods when wholesale market reference prices go negative that the project is not topped up to its strike price. However, this may be difficult if the asset is linked to a season ahead price in order to lock in fuel spreads as this market contract would be very unlikely to witness negative prices. The negative price provision could link the contract to day-ahead or within-day indices for this element of the contract only, as is done with more recent baseload assets under the current standard CfD.

One further aspect of consideration for this model is the degree to which this contract type would be rolled out into the market. As the contract could be supported by investors, it should attract interest and development under the right market conditions and provide an example of CCUS development. If this contract was limited to a handful of projects, it could act as a catalyst for wider adoption of CCUS and a general building of investor confidence in the technical and commercial feasibility of the projects. Later projects could then receive a contract more in line with model options 2 and 3 to ensure less risk of merit order distortion and potentially lower consumer costs. However, this multiple investment model approach may create uncertainty for investors and its attraction to policy makers would depend on BEIS' policy objectives of the wider role of CCUS in the power sector.

Figure 42: Option 1 advantages and disadvantages

Advantages	Disadvantages
Alignment to current CfD – less risk for investors and scheme management practices	Lack of flexibility in running – high output incentivised
Known and investable contract structure – limited changes from existing CfD	Could run ahead of newer renewables CfD contracts (due to higher strike price) and unsubsidised renewables in the merit order
Easier integration with T&S infrastructure – known payment terms and likely carbon levels	Fuel price hedge effectively locks in consumers to swings in global commodities regardless of merit order
Market indexation and wholesale trading integration	

Source: Cornwall Insight

Investor review

In discussion with investors this option was seen as being closest to the existing CfD structure, but with added complexity due to the specific arrangements to manage fuel input and merit order risks. The strengths of this scheme included:

- Closest structure to the existing CfD and therefore the existing knowledge of investors with regard to similar investments
- Seeks to encourage a baseload operation which is easy to model, and affords stable and bankable revenue streams through the 'intrinsic' nature of the plant

Concerns with this option included:

- Basis risk on the traded market reference price and ensuring offtake agreements. Risks around aligning offtake agreement with hedging strategy
- Risk of negative prices in the market and continued maximum generation of the plant
- Complexity when moving to a spread approach to account for fuel input volatility and the risk that it does not work in practice
- Political sustainability of maintaining large-scale baseload CCUS contracts if the system becomes more decentralised
- T&S interface risk allocation in construction and in operations critical to bankability and regardless of the payment model will need to be dealt with

4.3 Option 2: Hybrid CfD

4.3.1 Option Overview

The overall incentive of this structure is to ensure some baseline stability on output and payment for the generator, which can then underwrite investment, whilst introducing a degree of flexibility to operations and responsiveness to the wider market.

This model approach would seek to compensate a project based on a scaled payment system, with different £/MWh top-up payment rates at different output levels linked to wider wholesale market prices and the short-run marginal costs of the plant. This would ensure that the generator is only incentivised to increase output in response to wholesale market prices and CfD payments being sufficient to cover short run marginal costs. The scaled payments would be based on power plant output with CCUS capture in any given settlement period.

However, to ensure some guarantee of operations a level of "full payment" strike price would be given up to a set output of the plant, with the Stable Export Level (SEL) a good criterion to set this against as the plant would be unable to operate below this level. However, it is possible for a power station to reduce their SEL and so the criteria for this level will need to be set in advance. The running at this defined baseload level would be guaranteed through a relevant strike price payment and any fuel price adjusters to ensure a positive spread on operations.

Above the SEL, a generator would be incentivised to increase the output of the plant to capture higher payments if wholesale reference prices rose above a defined SRMC trigger. In essence, a generator would be incentivised under the contract to increase output of the plant to capture the higher top-up payments.

Rises in wholesale reference prices above the SRMC would trigger increasing output, but the top-up payments for flexible running would be the same for all volumes, i.e. a higher reference price would be awarded to all output not just for the increase. This is because a link to a reference price, likely day-ahead power for trigger payments, would mean the generator has already traded output into the market of that same value. A cap could also be set on top-up payments once a certain market reference price is reached where top-up payments revert to zero.

For the baseload element of the plant a similar fuel price adjuster to model 1 could be used to incorporate a hedge on this proportion of the plant's output. Season or year ahead reference pricing could be used with a relevant ex-poste adjuster if fuel prices spike.

The scaled payment triggers would require a different "dynamic SRMC" assessment to ensure the plant responds to short-term market conditions and triggers. This could reflect a day-ahead reference SRMC for both the power and the fuel input, with current day-ahead auctions clearing the day before delivery providing time for the power station to align expected output to price triggers incentivised in the contract. Each day the dynamic SRMC would be adjusted to reflect fuel input prices and therefore a wider fuel price adjuster would not be needed for this aspect of payment reference.

In certain circumstances where the dynamic SRMC is lower due to falling fuel prices then the asset could be running in a baseload style throughout the day, and in other circumstances higher SRMC would see the plant operating only at its Stable Export Limit throughout the day.

Whilst this provides some flexibility in running patterns, the addition of different reference prices and triggers creates more of an administrative burden for any counterparty in this model than both the baseload and flexible model options.

Any generation without CCUS capture would not receive the scaled payments and like option 1 an additional carbon penalty could be added to the contract to further disincentivise unabated generation. However, allowance may need to be made to take into consideration ramping periods and capture profiles under flexible operating patterns. A mechanism to account for any delays in capture against plant ramp-up could be added into this arrangement, but ultimately CfD payments would only be made against clean electricity volumes.

Figure 43: Option 2 example running pattern against market prices provides an overview of how plant operations could map wholesale reference price triggers.

Figure 43: Option 2 example running pattern against market prices

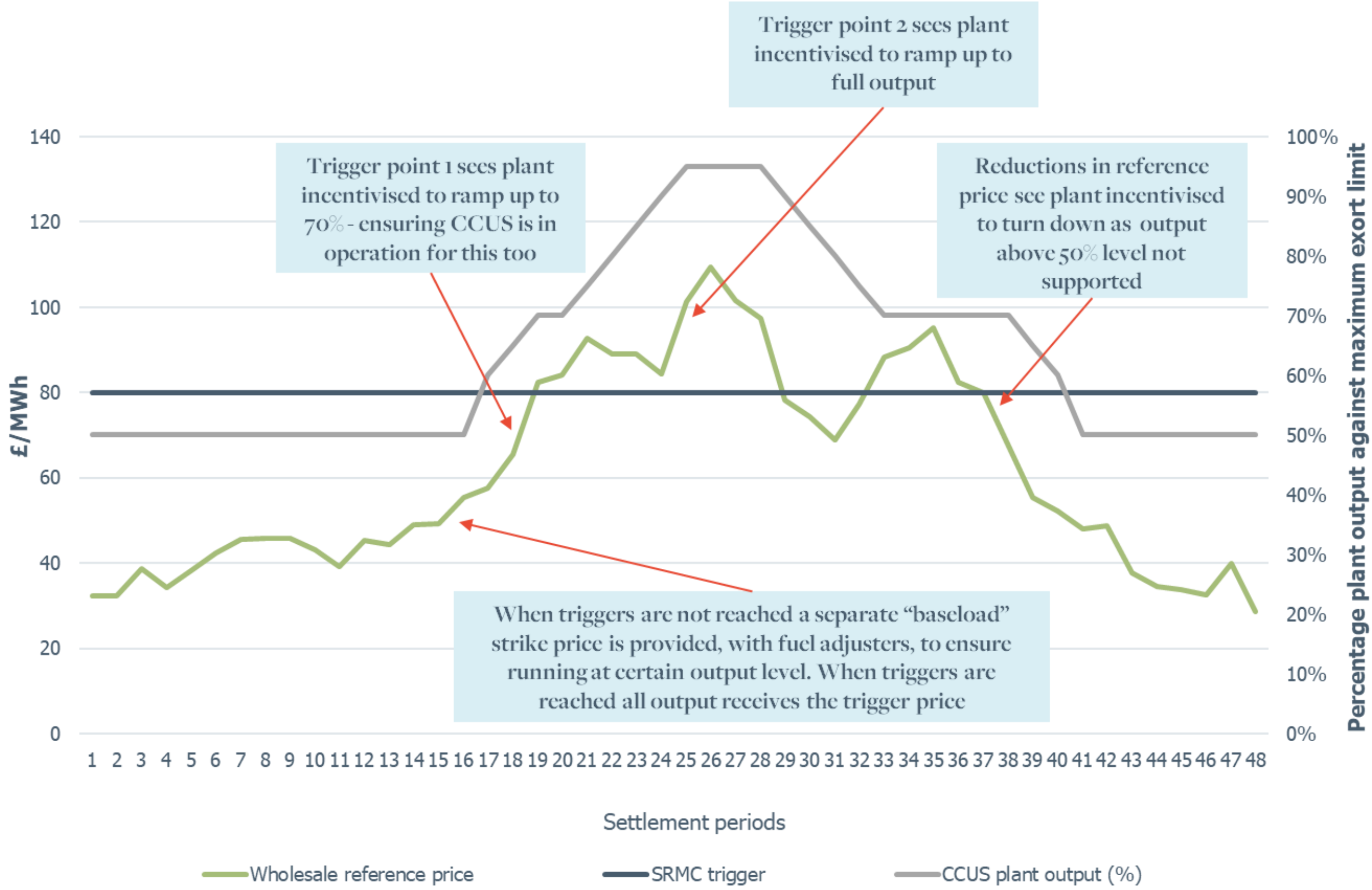


Figure 44 below provides an indicative example of how these triggers could work in practice. These numbers are for example only and the parameters are:

- A 200MW plant
- A SRMC of £80/MWh
- Trigger levels are shown which are indicative of the wholesale price levels at which the generator would be obligated to increase output. Three are set
    - When prices are below £80/MWh the generator is obliged to run at its SEL, assumed at 100MW (50% output). A strike price is provided here to ensure running and provide value above SRMC levels
    - When prices rise above £80/MWh the plant should ramp up from 100MW (50%) of output to 150MW (75% of output)
    - When prices rise above £100/MWh the plant should ramp up from 150MW (75% of output) to 200MW (100% output)

- Whilst an obligation is in place to run with the price trigger, the earnings highlighted below show the financial incentive for the generator.

Three trigger levels are shown and calculated which incentivise the generator to increase output to capture additional revenues, a further trigger is also shown as an example of when the plant would be incentivised to switch off.

Figure 44: Option 2 example earnings and output

Trigger level	SRMC (£/MWh)	Market Reference Price (£/MWh)	Top up Payment/strike price (£/MWh)	Max output in trigger level (MW and % of max)	Earnings above SMRC (£)	Earnings above SMRC (£/MWh)
A	**B**	**C**	**D**	**E**	**F =** (C – B+D) x E	**G =** C-B+D
1	80	80	50	100 (50%)	£5,000	50
Total earnings (Trigger 1)					£5,000	
2	80	100	25	100 (50%)	£4,500	45
2	80	100	25	50 (25%)	£2,250	45
Total earnings (Trigger 2)					**£6,750**	
3	80	115	5	100 (50%)	£4,000	40
3	80	115	5	50 (25%)	£2,000	40
3	80	115	5	50 (25%)	£2,000	40
Total earnings (Trigger 3)					**£8,000**	

Source: Cornwall Insight

Figure 45: Option 2 Hybrid CfD contract overview

Contract feature	Model 2 design: Hybrid CfD
Contract term	**10 to 15 years.** A shorter loan period or debt leverage level would likely be gained by this contract vs the baseload option as a lower proportion of revenues are guaranteed. This would likely mean lenders would prefer to have a much larger asset tail against loads synchronised with the end date of the CfD. It would also likely support a reduced level of debt leverage vs the baseload contract, potentially increasing build costs and equivalent strike prices
Pricing arrangement	**A split in payment structures to incorporate both the baseload and flexible aspects of operations.** Baseload output at or around the Stable Export Limit (SEL) could be linked to a season-ahead reference with fuel price adjusters to ensure a positive spread. Trigger points for flexible running would need a day-ahead reference to power and fuel inputs to ensure a dynamic aspect to the SRMC trigger for running at higher output.
Fuel price provisions	**Fuel price adjustment required for baseload aspect as per option 1.** This would likely need to include fuel price adjusters to ensure a proportion of the plant was always in merit
Flexibility incentives	**Some flexibility provision above a minimum export level**. The plant would be running inefficiently over long periods if not required in the market. Up to its minimum level, the plant would also be distorting the merit order as like the baseload options its price would be higher than subsidy free renewables and its incentive to turn down in periods of low prices is diminished
Contract milestones	Broadly mirrored across from generic CfD. **Specific adaptations would be needed** to incorporate: • The expected construction timelines of CCUS against the current delivery milestones under the CfD i.e. specific CCUS extensions may be needed to the Target Commissioning Window and Longstop Date to ensure the correct balance of risk for developers • The milestone requirement (MDD) to prove project development could be extended to allow for longer duration CCUS construction milestones and financial close
Contractual flexibility	Broadly mirrored across from generic CfD. **Specific additions to account for T&S delays** and interactions would be needed including: • Specific T&S delay criteria which would ensure that any delays outside of the CCUS power projects control

	would be accounted for in contract milestones and general contract term extensions • An extended remit on delivery obligations to cover not only installed capacity but also minimum carbon capture rates • Installed capacity delivery criteria in the contract would need to ensure generators are not incentivised to reduce delivery against stated levels in order to limit the number of MWs which would receive low or no CfD top-up
Transport and storage links	**The structure provides a degree of certainty to T&S links through the minimum output levels.** This could be used to calculate a floor of system usage. Above this level there is some uncertainty on use, but the power station would need firm access 24/7 to ensure delivery and carbon capture when power market conditions change
Decommissioning	**This can be accounted for in the strike price given to the power project**. Taking the example of Hinkley Point C, a ring-fenced function under the contract could be utilised to ensure value is set aside for any decommissioning requirements

4.3.2 Option Appraisal

Principles

Figure 46: Option 2 appraisal against CCUS policy objectives

Objectives	Overview
Investability	Investment case could be made against the minimum output level and revenue returns from this strike price. Above this level, output would be based against extrinsic market factors and would be subject to more risk. This will create the question of whether the level of debt would facilitate a viable internal rate of return for equity investors
Merit order position	A signficiant proportion of output has no flexibility incentive which would likely impact the merit order. The scaled aspect of plant can be calculated to ensure merit order position is after renewables
Cost-reduction	All models could feasibly provide cost reduction trajectories if the right tendering frameworks and contract incentives are in place. The hybrid CfD however is likely more expensive compared to other alternatives as if this model was rolled out to a fleet of plants it would be less efficient and more expensive to consumers, on a relative basis, than the baseload model. Strike prices are also likely

	to be higher due to the less certain run times and increased financing costs from lower debt leverage.

Other considerations

As this approach has a minimum export level which mirrors the operational patterns of the current CfD, contract features and practices could broadly be transferred across. Like the Baseload CfD model, several technology specific adaptations to the issues identified in section 3 of this analysis would be needed.

One specific issue relating to this approach would be how installed capacity estimates were delivered. There is the potential that projects may not deliver full capacity against stated levels if the scaling factors for payments do not incentivise output above certain levels. Under the current CfD permitted reductions of up to 25% are allowed to original estimates and this could potentially be gamed under this model by CCUS projects who save on building out capacity at lower scaled CfD payment levels which provide lower returns per MWh. A solution to this would be to link any reductions in capacity to the scaled payments formula, so that they operate in lock step with one another if delivered capacity is lower than first estimated.

The current payment structure, based around a maximum contract capacity, may also need to be adapted. This is because this hybrid approach also encompasses a minimum export level for payment. A solution could be to create a minimum contract capacity, calculated against similar principles of a stable export limit, to ensure plant is operating at safe and reliable levels with CCUS in place before it receives CfD payment.

Whilst the approach provides some flexibility incentives, projects would have a distorted position in the merit order for their minimum export levels. For one CCUS CfD this would have minimal effects on the wider market, but a fleet of assets could substantially distort expected running patterns. The minimum export level strike price would likely be ahead of recent subsidised CfD projects and subsidy free renewables in the merit order as a result of this approach.

Additionally, the degree of this distortion is likely to be greater than the baseload CfD option as a strike price in any hybrid approach would likely be a higher £/MWh figure to take account of inefficient running patterns. This inefficiency could also mean that if output is incentivised at the stable export limit, say 50% of capacity, then a fleet of ten CCUS power plants with hybrid CfDs would be delivering the equivalent clean electricity of perhaps five or less baseload CfD plant but at a higher strike price. As the hybrid model does not deliver significant benefits for investors and may also have merit order impacts, then cost implications could be a limiting factor in evaluating the relative merits of this model.

The inefficient nature of operations would also have an influence on interface risks with T&S infrastructure. T&S providers would have a degree of certainty on usage with minimum export levels, however above this level the degree of usage would be unknown and subject to extrinsic wholesale power market drivers. The CCUS power plant would however need 24/7 access to the T&S infrastructure in order to ensure capture and sequestration when running above minimum levels. This situation would lead to either higher payments by the power station if a fixed charge was paid to the T&S infrastructure, or lower revenue for the T&S provider if CCUS power stations were charged on a usage basis, compared to the baseload model option. Consideration would need to be given under this approach as to the efficiencies of the T&S infrastructure and how payments for its use are recovered.

Figure 47: Option 2 advantages and disadvantages

Advantages	Disadvantages
Provides a degree of flexibility vs baseload CfD	Inefficient plant output – issues for both plant operations and consumer costs relative to other model options
Minimum output level could be invested against as more certain of running patterns	Most distinct from the current CfD – concerns for investors against existing contract with a high degree of change
	Fleet roll-out would see higher costs than equivalent power from baseload assets
	Increased administration and monitoring vs current CfD to determine and measure plant output and payments

Investor review

In discussion with investors this option was seen as being quite complex, but with some potential to encourage flexible operation. The positive signals identified by the scheme included:

- The link between plant costs and operation means some margin protection at flexible running patterns
- The sizing of debt based on the stable export limit of the plant (minimum MW) with upside for flexible running and responding to the market. The model was seen as a creative solution which could allow bankability without restricting running at baseload

Concerns with this option included:

- It felt too complex to get globally mobile investors interested in such a scheme design it would require additional education for investment and credit committees to get comfortable with
- Too distinct from the existing CfD arrangement that it might as well be starting again, and hence this model will take time to get investment or credit committees comfortable. Investors will only see this as worthwhile if there is a pipeline of expected projects
- Plant when operating at minimum load will be inefficient
- Investors were unlikely to link offer of debt to generation scaling above the minimum without an additional risk premium, likely increasing financing costs
- There is interface risk allocation on the construction and operations which is critical to the bankability
- The debt leverage levels may be too low to allow equity investors an attractive and viable Internal Rate of Return

4.4 Option 3: Flexible CfD with capacity payment

4.4.1 Option Overview

This model aims to align the operations of the CCUS plant to typical merit order characteristics while providing investor security with a capacity payment. The design would incentivise the plant to run based on the asset SRMC (the "dispatch SRMC") without CCUS in place to ensure a competitive position in the merit order ahead of or in line with non CCUS plant equivalents. A strike price top-up would then be awarded to represent the extra costs of the CCUS equipment when operational with an added acceptable return for the investors. When the plant is running, prices would be capped at this adjusted strike price level to protect consumers from excessive returns for flexibility provision at times of shortage or system stress. If market reference prices rose above this level, as under the current CfD the CCUS generator would pay back to the CfD counterparty. The most suitable reference price is likely the day-ahead market, which would allow suitable time to optimise plant output against market signals.

The flexibility incentive would need a reference plant to establish fundamental pricing in the market, the short run marginal cost and the generation output, with verification potentially provided by a valid party covering operational behaviour and pricing. The reference plant for the new build plant could be against the same technology without the CCUS element based on the technical parameters provided by the technology providers. Where an existing technology doesn't exist then an alternative reference plant without CCUS could be used also. For an existing plant any retrofit would likely require a different capacity payment and/or CfD flexibility payment to account for these arrangements. Like the other models, any generation without evidenced carbon capture would not be supported by additional top-up. However, a key difference for this approach would be incorporating incentives into floor price payments.

Although the reference plant calculation would require some detailed technical analysis, there are precedents in the market with similar methodologies utilised to set Administrative Strike Prices (ASPs) under the CfD and Net Cost of New Entry (net CONE) criteria under the Capacity Market in GB. Examples are also in place across Europe in assessing new entrant plant into various national capacity mechanisms. The GB Capacity Market and European schemes calculate SRMC as part of Net CONE assessments.

Similar to ASPs, the dispatch SRMC criteria for the CCUS plant could be set against the top quartile of most efficient equivalent plants in the market, based on the typical range of Levelised Cost of Electricity (LCOE). A similar assessment to BEIS' generation costs modelling[13] could be utilised. This level could then allow the most efficient and cheapest projects to agree a price at or below a set LCOE with BEIS. It could also be used to set a competitive top-up strike price for the additional CCUS equipment.

Importantly, the dispatch SRMC would be dynamic and change on daily basis to reflect fuel price inputs relative to the electricity price. This would ensure constant alignment with non-CCUS assets and also negate the need for longer-term fuel price adjusters as the plant would be referenced against the day-ahead value.

Due to the unknown running pattern of the flexible operation a capacity payment, effectively a floor price on returns for the asset, would be required to provide investors with a known minimum level of return that could be financed against. This would be a £/MW payment against plant capacity levels which delivery clean electricity, i.e. the abated plant capacity. This payment could be conditional on low-carbon generation only, with the plant subject to a penalty or claw-back if it operates without the carbon capture plant.

As part of this model structure there would be an obligation to provide clean electricity when the price in the market meets the dispatch SRMC trigger for the plant (based on SRMC without CCUS costs added). A

[13] https://www.gov.uk/government/publications/beis-electricity-generation-costs-november-2016

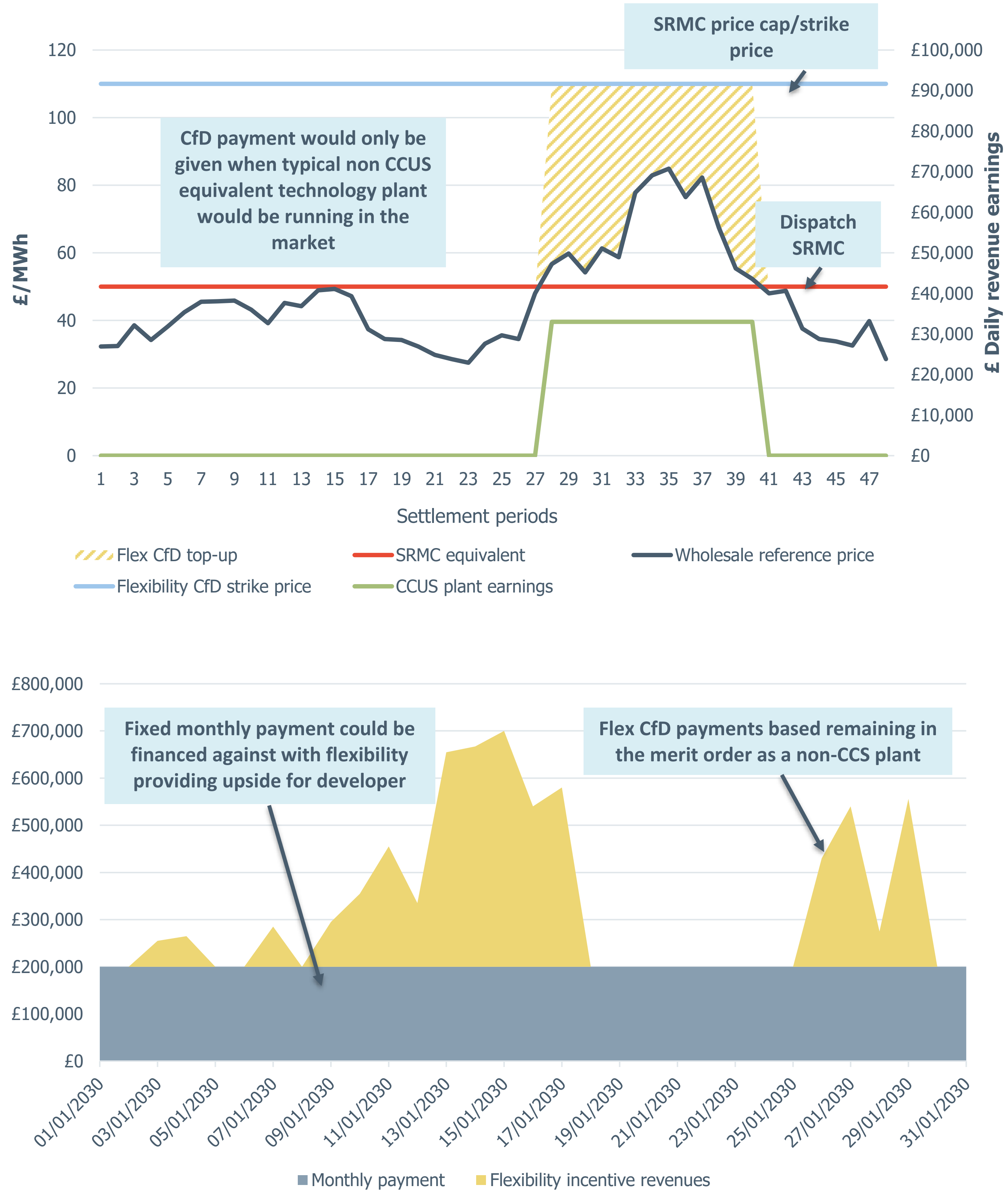
mechanism to account for any delays in capture against plant ramp-up could be added into this arrangement, but ultimately CfD payments would only be made against clean electricity volumes.

It would then be possible to implement a penalty scheme in the event the plant didn't meet its obligation to deliver or delivered energy without capture processes in place. This could be aligned to similar penalties currently implemented under the Capacity Market scheme to ensure delivery, but this will need to be set to avoid material impact on the annual payment to manage any debt repayments.

The capacity payment and the penalty structure would need to be carefully managed to ensure that it allows for appropriate financing arrangements to be put in place and did not create perverse incentives for the plant to operate in non-capture mode or not at all to game prices.

The creation of a dispatch SRMC (based on non CCUS plant) and SRMC price cap would ensure there is appropriate upside for equity and the consumer is protected from wholesale power market spikes and excessive payments to the power plant.

Figure 48: Flex CfD daily flexibility incentive and monthly payment profile example (indicative)



To note – the SRMC shown in Figure 49 would be dynamic and change on a day-ahead basis to reflect fuel input costs.

Figure 49: Option 3 Flex CfD contract overview

Contract feature	Model 3 design: Flexible CfD
Contract term	**10 to 15 years** due to the unknown running pattern and floor price providing minimum return levels
Pricing arrangement	**Capacity payment to provide safeguard on returns.** Flexible revenue linked to market price trigger, which would best be suited to day-ahead pricing to allow for triggers to be accommodated into running patterns. If price rises above SRMC trigger level, then plant is incentivised to run to earn market revenue and CCUS top-up. An obligation to run in these periods and produce clean electricity could further incentivise this
Fuel price provisions	**There is no direct adjustment required under this approach** as the structure is replicating existing and new build assets through calculating a SRMC The SRMC would be dynamic for the trigger calculations and adjusted on a day-ahead basis to reflect fuel inputs
Flexibility incentives	**The SRMC calculation should provide a merit order position above that of renewables**. Direct incentive to provide flexibility when market price signal is in place
Contract milestones	Broadly mirrored across from generic CfD. **Specific adaptations would be needed** to incorporate: • The expected construction timelines of CCUS against the current delivery milestones under the CfD i.e. specific CCUS extensions may be needed to the Target Commissioning Window and Longstop Date to ensure the correct balance of risk for developers • The milestone requirement (MDD) to prove project development could be extended to allow for longer duration CCUS construction milestones and financial close
Contractual flexibility	Broadly mirrored across from generic CfD. **Specific additions to account for T&S delays** and interactions would be needed including: • Specific T&S delay criteria which would ensure that any delays outside of the CCUS power projects control would be accounted for in contract milestones and general contract term extensions • An extended remit on delivery obligations to cover not only installed capacity but also minimum carbon capture rates • The potential addition of non-delivery penalties on plant when SRMC calculations suggest it should be

	operational. These could be akin to those used under the Capacity Market scheme
Transport and storage links	**The most uncertain delivery and utilisation of the archetype models owing to the flexible output of the plant.** The power plant would also need firm access to the T&S infrastructure to ensure offtake
Decommissioning	**This can be accounted for in strike price given to the power project**. Taking the example of Hinkley Point C, a ring-fenced function under the contract could be utilised to ensure value is set aside for any decommissioning requirements

4.4.2 Option Appraisal

Principles

Figure 50: Option 3 appraisal against CCUS policy objectives assesses the flexible CfD option against the CCUS Action Plan objectives.

Figure 50: Option 3 appraisal against CCUS policy objectives

Objectives	Overview
Investability	So long as a floor price is set at the correct level this contract would be investable. Sophisticated flexibility asset developers and operators would also be attracted to the optimised nature of the contract
Merit order position	SRMC calculation would ensure running after renewables
Cost-reduction	All models could feasibly provide cost reduction trajectories if the right tendering frameworks and contract incentives are in place. If a fleet approach was taken with this model then lower floor and top-up prices could be set over time to encourage cost reduction. The level of strike price would likely be higher than the baseload model owing to uncertain run times and limited hours of potential operation. Reduced running times could limit or slow technological learnings of early stage projects relative to baseload model

Other considerations

Like the other model structures, the CfD contract features can broadly be mapped across to this design with specific CCUS adaptations on milestone timings, T&S interface and delays. One potential addition is the non-delivery penalty feature.

Debt raised on the contract would likely only be secured on the floor price element of the contract. This is especially true of project financing arrangements as flexibility revenues would be uncertain in terms of volume and timing. Therefore, the level of this floor would need to be set in the context of providing an applicable level of debt for the project and at a level that it allows for equity hurdle rates for a first of a kind technology to be met.

From a flexibility and merit order standpoint, the model reflects the closest alignment to a reference plant without CCUS in the market. The linkages to the market and dynamic SRMC calculations also limit the need for calculating and executing fuel price hedges as under the baseload option. The dynamic nature of the SRMC also ensures that if the plant is out of merit on price due then it is not still in operation, unlike the hybrid option which would still impact the merit order even if SRMC levels do not secure a positive spread.

In contrast, there may be a higher administrative burden in forecasting and measuring trigger levels for flexible operations and the updates to SRMC levels. This is likely to occur daily and would need sophisticated information sharing systems to operate. Whilst this already occurs in the market through National Grid dispatch requirements and trading activities, a secure and separate route may be needed for these CfD contracts which is set to defined standards.

As dispatch would be market-driven, run times over the asset life of a CCUS power plant under this model would be subject to considerable uncertainty. If in the future, as more renewables come onto the electricity system, run times are expected to reduce (i.e. less than 4 hours), then limited or no CO_2 may not be captured to expected levels during these periods using today's standard configuration of technology (as described in section 2.4). Further analysis will need to be conducted to understand how different types of CCUS power plant may behave operationally in the future and what effect, if any, this has on CO_2 capture rates. This analysis could be used to further refine this model to incentivise developers and technology providers to improve capture rates through alternative technologies, plant configurations, and operational practices. However, this may not be an issue if under this model the market drives plants to dispatch for longer periods.

To fully understand the impacts of this, detailed scenarios would need to be modelled to assess the levels of carbon capture by different CCUS technologies under different future market conditions. Once parameters of existing and future plants are analysed, BEIS could set ramp-up and capture parameters to levels which ensure capture rates improve over time against current technology parameters. If transparent and provided to the market in good time, this could provide a signal for the market to achieve technical improvements.

Figure 51: Option 3 advantages and disadvantages

Advantages	Disadvantages
Provides some minimum certainty for investors	Higher administrative burden in forecasting and measuring output and determining SRMC levels
Ensures flexibility from CCUS	Technical characteristics of the plant could add complexity – somewhat uncertain levels of carbon capture in certain cases when the asset is operating as a flexibility provider
Aims to maintain typical merit order operations	Running profile uncertain – will it only attract higher costs of capital equity investors
Capturing of commodity price volatility in SRMC calculation – lower administrative burden than other two contracts for fuel price calculations and adjustments	

Investor review

In discussion with investors this option was seen as being positive for investor interest because of the following:

- Predictable cash flow through the capacity payment
- Incentive for equity to capture upside from flexible operation. The mechanism should attract typical equity investors who operate in the flexible energy asset space
- Simplicity of underlying floor or capacity payment instrument for debt is akin to their funding model
- Open to equity and debt accordingly
- Tenor of loan closely linked to the capacity payment and length of agreement

Some of the key risks or uncertainties that would need to be addressed include:

- Proportionality of the penalty regime for failure to deliver that maintains incentive. Stop loss limits on these penalties would need to be applied and if set high would result in higher risk premiums
- Setting the level of floor or annual payment for setting the downside case, accounting for penalties
- Flexibility arrangements would need to be clear to ensure enough carbon capture
- Different from other existing CfD investment structures, creating a need to educate and inform credit and risk committees of lender banks

4.5 Model comparison

A summary of the model options are outlined below. Based on the three criteria for this study, indicative assessments show that the flexible CFD with capacity payment appears to meet more of the objectives outlined. However, this may change with additional or alternative criteria which may be assessed in the future which could include total emissions reductions or net emissions reductions depending on policy objectives.

Figure 52: Model comparison

Objectives	Option 1: Baseload CfD	Option 2: Hybrid CfD	Option 3: Flexible CfD with capacity payment
Investability	• Most akin to current CfD, although fuel price hedging adjustments and protections would be key to investability	• Investment case could be made against the minimum output level and revenue returns from this strike price. However, significant divergence from current CfD and lack of precedents.	• So long as a floor price is set at the correct level this contract would be investable. Upside may attract certain equity investors
Merit order position	• Largest merit order impact with the plant running ahead of new and some existing renewables. A fleet of baseload assets would have a considerable market-wide impact	• Signficiant proportion of output has no flexibility incentive which would impact merit order	• SRMC calculation would ensure running after renewables and negate need for long-term fuel price hedging

Cost-reduction	• Potential adjustments over time to strike price levels. Likely to provide the cheapest £/MWh strike price, but also the highest overall costs through increased run times. Arguably, higher run times could allow technology cost reductions to be achieved more quickly	• Potential adjustments for top-up levels over time to incentivise improvements. Ineffeicicent nature likely more expensive than equivalent baseload option and debt leverage would be lower	• Floor prices and SMRC triggers could be adjusted over time to incentivise improvements. Likely higher strike prices and payments than baseload option and short run times may limit technology improvements and cost reductions relative to the baseload option

4.6 General investor feedback

During the investor review of the model options, a number of issues or concerns where identified that related to all the options outlined and included:

- Desire to keep the structure of the arrangement as simple as possible to minimise the risk of not getting internal buy in from investment and credit committees in lender organisations
- Investment will examine the risks set against a known investment such as offshore wind, onshore wind or solar PV
- Additional risk compared with other CfD projects due to the fuel input volatility and potential merit order position
- First of a kind technology risk will result in higher risk premium, versus other CfD technologies, regardless of other risks
- Infrastructure risks for the technology is likely to be significant
- There is the potential need for buy-out arrangements to protect the investor from first of kind, infrastructure risk and government changes that may result in disruption
- Investors are now comfortable with the risk associated with pay when paid of the Low Carbon Contracts Company

4.7 Alternative market-based options for CCUS in power

Outside of the Contracts for Difference Scheme there are a number of alternative options for financing of energy related projects which have been used for a variety of energy infrastructure projects. A summary of the key alternatives to market-based mechanisms are outlined below:

- Cost plus open book
- Regulated Asset Base
- Tradeable tax credits
- Tradeable certificates with obligation
- Cap and Floor

All numbers used in this section are for illustration only and in no way a representation of the values that may be used in the future.

The detail provided in this section is a high-level headline assessment of alternatives. Whilst each support model is credible for CCUS power projects, they all contain significant disadvantages over the adaptation of an existing instrument like the CfD in achieving investable low-cost solutions that, if adapted correctly, do not distort merit order functions.

4.7.1 Regulated Asset Base (RAB)

A RAB model values existing assets used in the performance of a regulated function, for example electricity or gas markets, and sets tariffs to pass the costs of these assets on to consumers. Great Britain developed the RAB to provide comfort to investors in privatised network utilities such as electricity, natural gas, railways, telecoms, transport and water that their investments would not be treated unfairly. RABs were initially developed in the early 1990s for UK infrastructure industries by Ofwat (the economic regulator of the water industry in England and Wales). Ofwat created the first infrastructure RAB for the purpose of setting its five-year price limits in 1994. They continue to be used, with the most recent example being the Thames Tideway sewage tunnel. BEIS is currently considering the feasibility of a RAB model for new nuclear projects.

The RAB model mitigates the construction risks of projects by enabling investors to receive returns before they have been completed. For CCUS this would require a regulator to issue a licence to the CCUS project developer, outlining the levels of revenue and returns that the investor would receive.

Adjustments to the RAB model to allow for incentives on operation of the plant would be required if the plant was to operate flexibly in the market.

Figure 53: Advantages and Disadvantages of RAB

Advantages	Disadvantages
Ensures certainty of cashflow	Requires a large-scale transfer of value and high levels of consumer spend before operations
Reduction in the cost of capital	Impact on competition within the market
User prices are regulated	Cost of regulatory function. The administrative work involved is high for the potential scale of CCUS investment across a fleet
Equity and project finance have a role	Normally used for public goods or must run infrastructure. Difficult to transfer this model if a flexible style CfD model was chosen

Protection from market uncertainty	Inconsistent with how power stations are typically financed

Figure 54: RAB appraisal against CCUS objectives

Objectives	Overview
Investability	The RAB model is widely used in utility investment. For a first of a kind CCUS project the early payment structure during construction could reduce investor risks on project delivery and expected returns. However, the RAB model is not widely used in the power generation investment community and may limit the appetite of typical developers
Merit order position	The typical RAB model of guaranteed unit payments or lump sums based on continued operations would limit the incentives on a CCUS project to provide flexibility. The model is suited to a baseload or must run infrastructure projects
Cost-reduction	Uncertain if the RAB model delivers savings against equivalent non CCUS running plants with a flexible running profile

4.7.2 Cost plus open book

This mechanism involves direct operational payments from the government to cover all properly incurred costs annually, on an open book basis, with an addition of agreed margins provided to the project. The contract has been widely used in other sectors such as logistics, transport and some infrastructure development. In this mechanism, the majority of the risks are borne by the public sector as increases in project costs are accounted for in the open book. In a CCUS context this would mean that increased development costs would be borne by the consumer who would effectively be paying more for no increase in MW capacity or carbon sequestration.

For CCUS, adjustments to the cost-plus model to allow for incentives on operation of the plant would be required to ensure it remains flexible in the market.

Figure 55: Advantages and Disadvantages of Cost plus open book

Advantages	Disadvantages
Guaranteed payments	Limited certainty on what the costs may be
Clear relationship to investment costs	Ongoing administration and high costs of if CCUS deployment is limited
Protection from market uncertainty	Default solution doesn't optimise plant in markets
Ability to integrate project finance	For the developer there is a lack of incentive to reduce costs

Figure 56: Cost plus open book appraisal against CCUS objectives

Objectives	Overview
Investability	Cost plus open book approach provides guaranteed returns for developers and investors above their cost base. The model has not widely been used in energy investment however its structure would fit with the risk profile in typical energy project finance arrangements
Merit order position	Without adjustments to revenues based on output levels or time of delivery, both generation levels and flexibility could be limited by this approach. For example, if returns are purely linked to MWh output then the plant would operate on a baseload basis
Cost-reduction	The approach does not incentivise cost reductions as these can be recovered through the open book. The approach is more suited to projects where delivery of quality is more important than cost. For example, a CCUS project which incurs higher costs to install and run sequestration equipment which is of higher quality can simply pass this through to the government or consumers

4.7.3 Tax credits

Tax credits are reductions in the tax liability of a firm if it meets certain requirements. This could be applied to the output of the CO_2 or the initial capital expenditure.

The tax credits themselves would not encourage the flexibility in the market of the CCUS power station if on the CO_2 savings as it would encourage maximum generation.

Figure 57: Advantages and Disadvantages of tax credits

Advantages	Disadvantages
No upfront support required	Complexity of company tax arrangements being unknown
Widely used approach in USA and other developed energy markets	Difficult in linking tax with benefits
	Default solution doesn't optimise plant in markets
	Difficult to bring in project finance

Figure 58: Tax credits appraisal against CCUS objectives

Objectives	Overview
Investability	If the benefit approach is solely tax credits then a generator would still be exposed to the uncertainty of market revenues and fuel prices. Additionally, tax credits under a traditional energy project finance structure would be difficult to account for and share as they could be received at earlier or later stages in a project when debt is more or less prevelant in the project
Merit order position	Tax credits would likely incentive baseload operations in order to ensure higher output to recover the credits against
Cost-reduction	The approach also does not incentivise cost reduction on specific projects. For example, if tax credits are applied on a set percentage or value basis then higher costs for the project would simply be accounted for in tax credit calculations, unless a staged or tiered approach was used. For example a CCUS generator which incurs higher construction costs would be able to account for these in any tax credit offset calculation

4.7.4 CCUS certificates

Tradeable CCUS certificates combined with an obligation to decarbonise could be adopted as a market-based option. CCUS certificates are typically awarded per tonne of CO_2 abated and emitters are obligated to ensure a certain amount of CO_2 is captured.

The certificates themselves would not encourage the flexibility for the CCUS power station, as if they are paid on a tonnes per CO_2 captured basis the plant would be incentivised to produce at maximum generation.

Figure 59: Advantages and Disadvantages of CCUS certificates

Advantages	Disadvantages
Ongoing payments during operation	Uncertainty in future carbon price and certificate volatility
CCUS can be linked to ongoing carbon pricing arrangements	Difficult in linking tax with benefits
	Default solution doesn't optimise plant in markets
	Difficult to bring in project finance

Figure 60: CCUS certificates appraisal against CCUS objectives

Objectives	Overview
Investability	Unless an obligation was placed on industry or energy suppliers, there is a risk under this approach of a lack of buyer. Without large-scale CCUS roll-out certificate prices would likely be volatile

Merit order position	Certificate awardings would likely incentive baseload operations in order to ensure higher payments. A teared certificate price could incentivise flexiblity if linked to wholesale power prices, but would make returns for investors uncertain
Cost-reduction	Uncertain if the CCUS certificates deliver savings against equivalent non CCUS running plants with a flexible running profile

4.7.5 Cap and Floor

Cap and floor contracts can be used to hedge against volatility in power or carbon prices in order to ensure guaranteed returns.

The floor is the minimum amount of revenue that an asset can earn. This means that, if an asset does not receive enough revenue from its operations, its revenue will be 'topped up' to the floor level. The funds will be transferred from the consumer to the asset owner. It is valuable in raising debt.

The cap is the maximum amount of revenue for an asset owner. This means that, should an assets revenue exceed the cap, the CCUS project will transfer the excess revenue to the consumer. For consumers, the cap on revenues provides benefits in return for their exposure in underwriting the floor. It is valuable in capping equity returns.

The model has been used for interconnection in GB, and this general approach does not typically incentivise flexibility as the asset is in near constant operation.

Figure 61: Advantages and Disadvantages of Cap and Floor

Advantages	Disadvantages
Clear range in returns for asset owner	Uncertainty for end consumer in cash flows
Ability to bring in project finance	Administration to manage payments and receipts

Figure 62: Cap and floor appraisal against CCUS objectives

Objectives	Overview
Investability	Guaranteed floor on returns ensures certainty for investors and reduces risks. The approach would likely attract a wide range of investors due to this lower risk approach
Merit order position	The general approach favours baseload or constant running. However, an adapted approach where payments are set against peak for flexible plant could provide a floor for investors to mitigate against concerns on running profile whilst incentivising generation at peak times t
Cost-reduction	Uncertain if the Cap and Floor delivers savings against equivalent non CCUS running plants with a flexible running profile

4.8 General investor feedback

The investors have also provided general feedback to the alternative market-based options which included:

- RAB model received mixed reviews of suitability for this type investment. It would likely be attractive to an investor, with a low level of risk. Some felt it wasn't a RAB style investment as the technology is not predictable or long-term like other assets such as nuclear or network infrastructure.
- Cost plus open book has some good case studies globally with the ability to share savings from improved delivery/timeliness that can be passed back with uncertainty
- Tax credits have good case studies in countries like the United States, but would require substantial complexity to the scheme, with less tax capacity, i.e. tax reduction capabilities, in GB to support significant investment levels
- CCUS certificates have good case studies from similar schemes such as the Renewables Obligation scheme, but there is significant uncertainty for the price of carbon to set a long-term scheme that investors would be comfortable with. There was also concern around the liquidity of such certificates and the potential buyers if only a small number of CCUS plants were built
- The cap and floor scheme provided the greatest level of simplicity for investors to manage risk, but was potentially better suited to assets/infrastructure in which revenue and incentives are based on availability such as an interconnector rather than assets that are dispatchable and controllable with less certain running and usage patterns.

Overall, critical issues from investors related to what was the lowest cost model to deliver the early high risk plants, driven by technology and infrastructure concerns. In order to minimise the additional risk premium it would need to ensure a level of simplicity to attract investors.

5 Conclusions

This study has demonstrated how the broad structure of the CfD contract could be adapted to become a market-based incentive for CCUS power projects. In comparison to alternative investment models which were assessed at a high level, the CfD has more suitability when adapting for potentially flexible running patterns than models such as RAB and Cap and Floor and is more understood and trusted in the investment community than options such as tax credits or certificate schemes.

However, there are a number of areas in which the design of the CfD would need amending for the CCUS asset type. These adaptations broadly cover:

- **CCUS technology aspects –** including defined contract milestones, T&S interface risk, metering arrangements and accounting for carbon measurement and incentives
- **CfD payment aspects –** including how and what is being paid for (wholesale power or carbon offset), managing the volatility in fuel price inputs, linking the CfD mechanism to potentially flexible running patterns and how strike price adjustments may be treated

Whilst Cornwall Insight believes that the majority of adaptations could be integrated into the contract through redesign and amendments, payment aspects may be more difficult as they would need to be more carefully designed around investor requirements, risk profiles and wider wholesale market interactions.

Overall Cornwall Insight views option 3, the flexible CfD, as the model which most aligns with assessment criteria and investor requirements. This is due to its minimal merit order impacts and investability despite changes from the current CfD design. Whilst the baseload design is an investable format in the views of investors and Cornwall Insight, its disruption to the merit order (i.e. running regardless of market signals) may increase the degree of price cannibalisation impacts on future unsubsidised renewables

The flexible CfD would limit merit order impacts due to dispatch SRMC levels responding to market conditions and fuel price changes. As a result, the flexible CfD approach could see plants playing different roles over their projects lifetimes based on the wider market and the relative roll-out of further renewables capacity. For example, under a system with a moderate level of intermittent renewable generation (such as in the 2020s), a power CCUS plant could play more of a "baseload" role under this model, providing consistent clean electricity when renewables and nuclear do not meet demand. As further intermittent renewable generation is added throughout the 2020s and 2030s, this role may change, with power CCUS plants seeing lower load factors and moving to mid-merit operation, only providing generation in periods of relatively low supply or high demand. This makes option 3 more adaptable than the baseload CfD, which would effectively lock-in CCUS generation to the market regardless of the wider system changes and potentially significantly impact the merit order.

There are potential technical limitations to the flexible CfD approach in terms of levels of capture, especially for post-combustion technologies, that could arise if the plant has frequent cold starts and very short running periods (i.e. less than 2 hours) if today's standard configuration of technology is used (see section 2.4). Further analysis will need to be conducted to understand the future running patterns of different types of CCUS power plants as greater capacities of intermittent renewables are added to the system and what effect, if any, this has on CO_2 capture rates.

Whether or not this is the case, there are a number of approaches which could improve capture plant flexibility, and the final model could include provisions designed to incentivise improvement of capture start up and ramping times against current technology. This could incentivise developers and technology providers to find technological and/or operational solutions to this, so long as the contract being awarded was seen to reward these efforts commensurately.

An approach to which contract is most suitable will also ultimately depend on the aims for BEIS around deployment of CCUS and potential strategy for any "fleet" of assets.

- **To prove CCUS commerciality –** a baseload CfD option may be more suitable for the first CCUS plant(s) in order to prove technical capabilities of the technology and to allow CCUS power projects to provide economies of scale to a wider T&S system where industry also locates
- **To ensure minimum power sector disruption and provide flexible back-up for low carbon power –** then a flexible CfD option is more appropriate to ensure that CCUS plant does not run ahead of other low carbon assets, especially future subsidy free renewables, and provides low or zero carbon flexible back-up

While providing a baseload option to earlier contracts may help catalyse the development of a wider CCUS industry, this would materially limit flexibility from these plants. To secure investment they would also need to be "grandfathered" for the contract duration, likely 10 years or more. This would potentially lock in assets which have no incentive to provide flexibility. Further assessment may be necessary to discern the impact this may have on dispatch of future generation capacity, such as subsidy free renewables or CCUS power plants with a lower CfD strike price or flexible CfD.

Additionally, providing two contracts to the market with baseload contracts to earlier projects and flexibility contracts to later ones may create uncertainty around investment and push certain investors towards their preferred option. Setting clear timelines or deadlines on the type of contract could help but would also lock government policy into a structure which may need to be adapted after implementation.

Therefore, a more rational approach may be to opt for one type of CfD and adapt the contract for new assets over time as the technology matures. If option 3, the flexible CfD was chosen, this could include:

- The floor payment being set to higher levels in early contracts to provide more investor certainty on returns for First Of A Kind (FOAK) assets. As CCUS technology matures this could be lowered to shift revenues more towards capture in operations
- The trigger point for operations against a defined SRMC could be set at lower levels for earlier contracts to ensure a greater period of operation. This could allow for earlier projects to prove technical feasibility but does carry the risk of creating merit order distortion if trigger levels are set artificially low
- Strike price levels for CCUS top-up could also be amended for contracts as levelised costs of the technology fall or are incentivised to fall to meet future strike prices
- A commissioning window could be provided to FOAK projects that allows for a period of baseload operations to account for testing, feasibility and snagging. This could be akin to some of the time-based windows given in the current CfD with a set time provided to run at baseload and prove operations. However, this would need to be carefully managed to ensure minimal merit order disruption when running baseload, clear criteria on when this period would end and the correct incentives to not over reward on payments in these periods

Overall, providing a single CfD structure to the market and amending this overtime to suit technical requirements and incentivise cost reductions should prove an investable format. It also allows the sector to get comfortable with the terms provided, as has happened with the existing CfD, instead of adapting to different structures, i.e. baseload to flexible contracts, as the technology matures.

Annex 1 - Acronyms and defined terms

AD	Anaerobic Digestion
ASP	Administrative Strike Prices
ASU	Air Separation Unit
BEIS	Department for Business, Energy and Industrial Strategy
BMRP	Baseload Market Reference Price
BSUoS	Balancing Services Use of System
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture Usage and Storage
CO_2	Carbon Dioxide
CfD	Contracts for Difference
CHPQA	Combined Heat and Power Quality Assurance
CHPQM	Combined Heat and Power Qualifying Multiplier
COP	Code of Practice
CPI	Consumer Price Index
DSR	Demand Side Response
EII	Energy Intensive Industry
EIS	Enterprise Investment Scheme
EMR	Electricity Market Reform
EMRDB	Electricity Market Reform Delivery Body
EPC	Engineering, Procurement and Construction
ESC	Electricity Settlements Company
EU ETS	European Union Emissions Trading Scheme
FAP	Funding Arrangements Plan
FCM	Financial Commitment Milestone
FDP	Funded Decommissioning Programme
FFR	Fast Frequency Response
FIC	Final Installed Capacity
FIDeR	Final Investment Decision Enabling Renewables
FiT	Feed In Tariff
FOAK	First of a Kind
FY	Financial Year
GW	Gigawatt
ICE	Installed Capacity Estimate

IICE	Initial Installed Capacity Estimate
IGCC	Integrated Gasification Combined Cycle
IMRP	Intermittent Market Reference Price
kW	Kilowatts
LAMO	Loss Adjusted Metered Output
LCCC	Low Carbon Contracts Company
LD	Longstop Date
MCC	Maximum Contract Capacity
MDD	Milestone Delivery Date
MW	Megawatt
MWh	Megawatt hours
NDD	Non Delivery Disincentive
OCGT	Open Cycle Gas Turbine
O&M	Operation and Maintenance
OCP	Operational Cost Payment
OFGEM	Office for Gas and Electricity Markets
PPA	Power Purchase Agreement
RAB	Regulated Asset Base
RO	Renewables Obligation
RPI	Retail Price Index
RQM	Renewable Qualifying Multiplier
SCLP	Settlement Costs Levy Paid
SEL	Stable Export Level
SF	Settlement Final
SoS	Secretary of State
SRMC	Short Run Marginal Cost
TCW	Targeted Commissioning Window
TF	Termination Fee
TLM	Transmission Loss Multiplier
T&S	Transport and Storage
TRA	Total Reserve Amount
WD	Working Days

Annex 2 – CfD Overview

CfD scheme design

The Contracts for Difference (CfD) scheme is the government's flagship policy for incentivising investment in low carbon electricity generation. The scheme was launched through the Energy Act 2013 as part of a policy programme known as Electricity Market Reform (EMR). EMR aimed to encourage additional investment in the GB market to meet stated policy objectives of increasing the amount of low carbon electricity on the system, improve security supply and ensure affordability for consumers. The design of the scheme, and importantly for this analysis the design of the contract, is based around the overarching EMR objectives of:

- **Decarbonisation**
    - By 2050, GB is targeting an 80% reduction in carbon emissions (across the economy) on 1990 levels (the Climate Change Act, 2008)
    - By 2020, GB is mandated to source 15% of total energy consumption from renewable sources. The electricity element of this is estimated at ~30% (up from 7% when EMR objectives were set in 2010)
- **Security of supply**
    - Electricity demand may double by 2050 (according to DECC in 2010 when EMR objectives were set)
    - We require diverse, reliable and resilient supplies to keep the lights on
    - Ensure an "adequate safety" cushion of capacity as the amount of intermittent and inflexible low-carbon generation increases
- **Minimise costs to the consumer**
    - Minimise cost to the consumer and keep energy bills down whilst attracting the necessary investment

CfD scheme design

To meet objectives set out under EMR, the CfD scheme has been specifically designed around ensuring low carbon generation at a lower cost to consumers.

Key design features are:

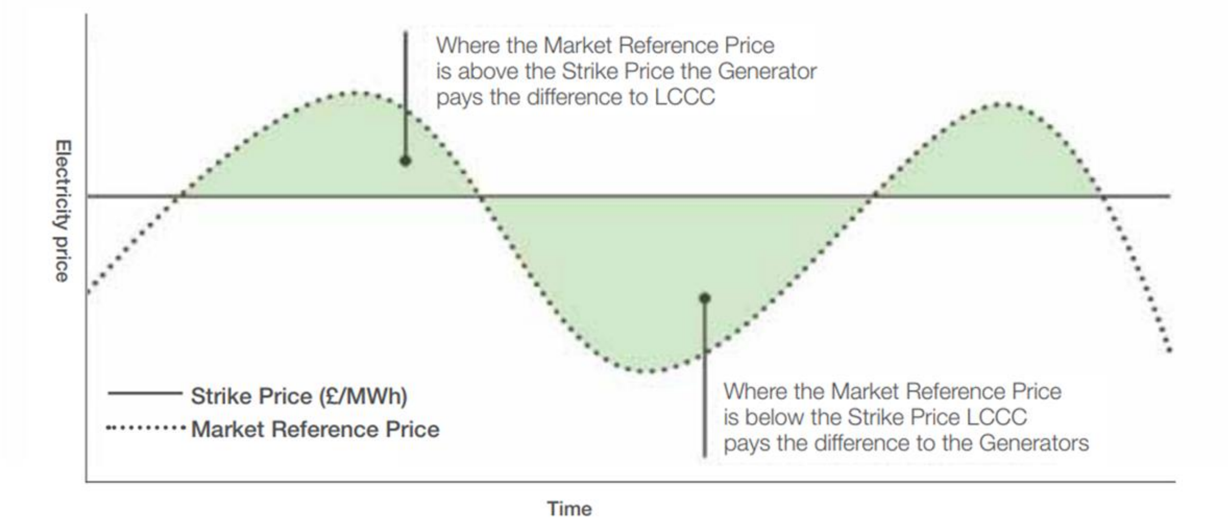
- **Price stability:** The contract offers price certainty for the 15-year tenure (plus a defined time allowance for construction) by awarding projects based on a £/MWh Strike Price. This price is determined through bidding in the allocation process and is guaranteed for the 15 years with a link to CPI inflation. Projects receive difference payments under the CfD based on the difference between the set Strike Price and a wholesale Market Reference Price (MRP). Importantly, if the MRP is above the Strike Price then the project pays the difference back. This effectively caps consumer costs and limits "windfall" returns for projects in times of high wholesale electricity prices. This is detailed in figure 4

- **Wholesale Market Referencing:** The contract references a wholesale MRP for technology types to link difference payments to wholesale traded values. This ensures projects are aligned to the wider market value for power. Additionally, the CfD only provides for these difference payments, meaning generators need to trade their power in the market in order to meet the MRP. This ensures CfD generators are not adversely impacting wholesale market functionality and liquidity

- **Competitive Allocation:** CfDs have generally been allocated on a competitive basis through a sealed-bid pay as clear auction. This approach serves two purposes for meeting objectives. Firstly, competitive tension should lead to price discovery as a limited auction budget drives cost reduction and efficiencies from projects in order to secure contracts. Secondly, allocation through specified auctions, known as Allocation Rounds, allows for some budgetary control and a clearer view of potential project deployment. There are exceptions to this competitive allocation practice, with both Hinkley Point C and the Final Investment Decision Enabling for Renewables (FIDeR) contracts being bilaterally negotiated with government

- **Private Law contract:** Successful projects sign a CfD with the Low Carbon Contracts Company (LCCC), who are the CfD counterparty. The contract is a private law arrangement and provides significant protection against Force Majeure events and change in law. Unlike some policy schemes which are written into statute, and can therefore be modified and re-designed through legislation, the CfD provides a more water-tight private contract.

Figure 63: Contracts for Difference overview



Source: LCCC

The CfD is also designed with recognition to the previous large-scale renewables generation scheme in the UK, the Renewables Obligation (RO). The RO was openly administered, often termed a "built and accredit" model, with lower budgetary control mechanisms. It was written into statute rather than being a private law agreement and accredited projects were subject to both wholesale power and certificate (subsidy) price volatility.

It was recognised that a large proportion of the investment community, particularly lenders, would be willing to finance CfD projects at lower rates than the RO if revenue streams had less downside risk and volatility associated with them. The ability of the CfD design to reduce cost of capital requirements for projects and increase the variety of investors is in direct recognition that this should lead to lower £/MWh bids under the CfD and reduced costs to consumers compared to other designs such as the RO.

Roles and responsibilities

The Energy Act (2013)[14] and the Contracts for Difference (Allocation) Regulations 2014[15] grant the Secretary of State (SoS) powers to run CfD allocation rounds but do not oblige that they happen. Thus, CfD allocation does not follow a pre-determined schedule and does not occur at regular or fixed intervals.

The CfD is a levy funded scheme for low carbon generation, and so spending falls under the umbrella of the Levy Control Framework (LCF), and latterly the accounting Control for Low Carbon Levies introduced in late 2017. This has implications for how the allocation of CfDs takes place.

When a CfD allocation round does take place, the allocation phase currently utilises "technology pots" to segment applicants by the maturity of low carbon technology. When a CfD allocation round is announced, BEIS will set out its intentions regarding the budget envelope and the specific delivery years for the technology pots it wishes to make the subject of the allocation round. This is done via a Budget Notice.

National Grid are the CfD Delivery Body[16] and administer the allocation phase. If the value of applications exceeds the budget allocated to a given technology pot then an auction will arise. In an auction, projects will compete on a strike-price basis with other projects in their technology pot. The auctions for each pot will be conducted on a "pay-as-clear" basis. Bids received by National Grid are stacked in the relevant technology pot in order of strike price, cheapest to most expensive, regardless of delivery year or capacity. National Grid will then value bids in that order, starting with the cheapest strike price bid, against a specified budget envelope for delivery years in the allocation round.

There is a strike price established for each designated delivery year. Subject to maxima and minima rules and the impact of Administrative Strike Prices (ASPs) capping prices for specific technologies, the marginal project to clear the auction in each year sets the price for that year in the technology pot.

Successful projects are awarded a CfD contract which is signed with the LCCC. This includes the strike price awarded to the relevant project, the initial installed capacity estimate and the target commissioning window. The LCCC funds payments to participants using a levy on all licensed electricity suppliers. The levy rate is set quarterly using forecasts of generation and demand. It is billed to suppliers daily based on their gross demand.

Figure 64: CfD Scheme summarises the key roles and responsibilities of the parties involved in the CfD scheme.

[14] http://www.legislation.gov.uk/ukpga/2013/32/pdfs/ukpga_20130032_en.pdf
[15] http://www.legislation.gov.uk/uksi/2014/2011/contents/made
[16] And also the delivery body for the Capacity Market. They are commonly known as the EMR Delivery Body in Statute

Figure 64: CfD Scheme

Allocation round set up and parameters	Qualification and allocation	Contract signature and management
BEIS	**National Grid**	**LCCC**
• Responsibility for over-arching policy objectives • Determines budgets and auction parameters including technology pots, ASPs and eligibility criteria • Rules for the Allocation Round, set out in the Allocation Framework • Reviews Supply Chain plans for above 300MW CfD projects • Modifications and rule changes undertaken between Allocation Rounds	• Known as the EMR Delivery Body • Main role to administer the allocation process • Undertakes qualification and eligibility assessments • Administers sealed-bid auction process and determines awarding and Strike Price levels	• The CfD contract counterparty • Private Limited company wholly owned by BEIS • Signs contracts with successful projects following allocation • Manages projects through the CfD contract and relevant milestones towards operations • Payment counterparty for generators – provides CfD payments through collecting levy on electricity suppliers in the GB market

Source: Cornwall Insight

CfD contract parameters

For those successful in being awarded a CfD, the contract signed with the LCCC is formed of two parts:

- **The CfD agreement**: This is a shorter project specific document which details key aspects including the awarded strike price, technology class, installed capacity estimates and relevant contract milestones and start dates for the project

- **The CfD terms and conditions (T&Cs)**: This is a much longer document which is generic for all technologies and successful projects. It details conditions under the agreement and the rights and responsibilities of parties

Collectively these are usually termed the "CfD contract" and have been designed to cover a wide range of eventualities commonly associated with large scale infrastructure projects. Although the CfD T&Cs are the same for every project, there are some further bespoke aspects of the CfD agreement for phased offshore wind projects of up to the maximum CfD capacity of 1,500MW, private wire connected projects and unincorporated joint venture projects.

Once a project signs a CfD contract, a process is set in motion in which a number of key parameters must be met by the project to ensure progression towards operations and CfD payments. The parameters in place aim to ensure successful project delivery and link the contract to stated wider policy objectives of securing low carbon generation at the least cost for consumers. The parameters include:

- **Installed capacity:** The CfD has strict requirements around delivering capacity levels stated at the time of application. Although some flexibility is given to reduce capacity from initial estimates, projects are not rewarded for over delivery. This ensures generators meet minimum requirements but also that spending on contracts is not increased, and consumer costs impacted, due to greater project capacities

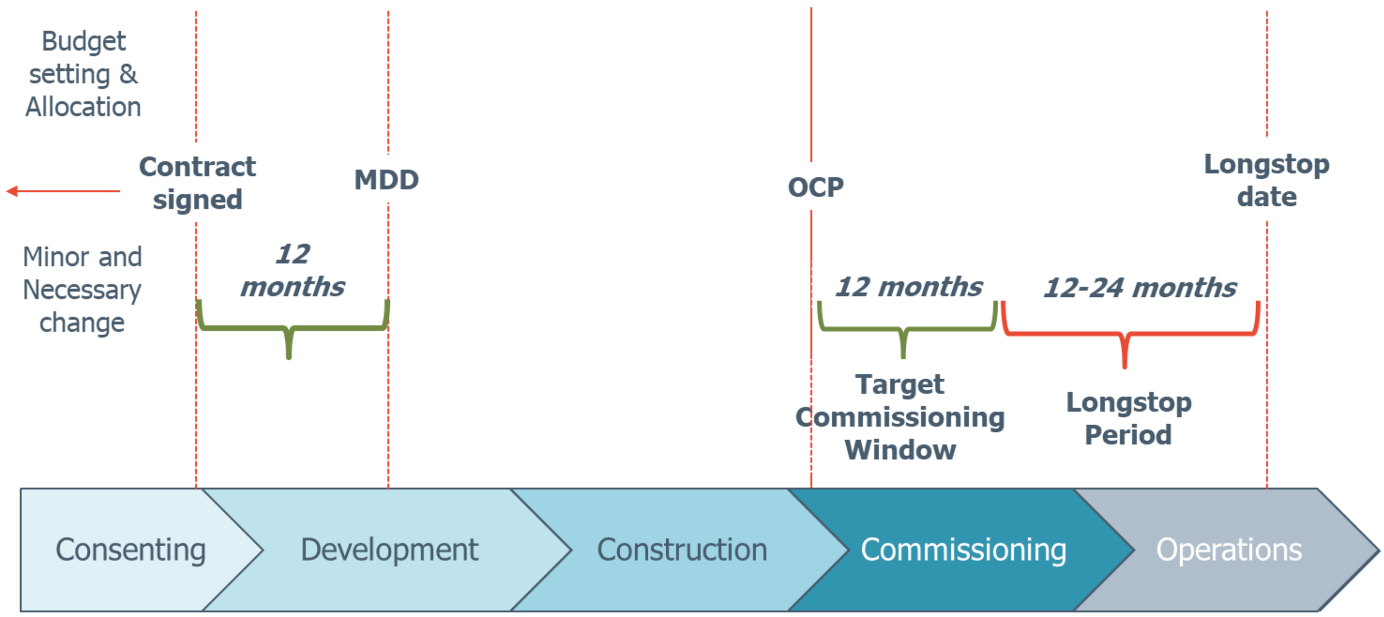
- **Renewable qualifying multipliers (RQM) and fuel measurement sampling (FMS):** To align with the policy aims of the CfD, fuelled technologies are only rewarded under the CfD for output produced from sustainable non-fossil fuel sources i.e. low carbon. Projects receive an RQM which determines how much of their output is eligible for CfD payment. The RQM is based around agreed parameters and procedures for fuel measurement sampling

- **Expected start dates:** Projects provide a target commissioning date at the time of application which is used to set a window for development of the project, known as the Target Commissioning Window. Under the contract a project must provide LCCC with monthly updates on expected start dates from contract signature until operations. This is to ensure LCCC can accurately track project milestones and predict consumer levies on CfD payments

- **Project milestones and conditions precedent:** There are a number of key milestones projects must pass in order to progress towards issuing a start date and receiving payments under the CfD. These are designed to incentivise the project to evidence commitments and commission the project within a set period, known as the Target Commissioning Window, to ensure the full 15-year tenure of CfD payments.

The milestones under the CfD are one of the key design features of the contract. Figure 65: CfD timelines below provides detail of these milestones alongside indicative project stages.

Figure 65: CfD timelines



Source: Cornwall Insight and LCCC

For each milestone there are distinct criteria that aim to ensure certain parameters in a contract are met. These are detailed below.

Figure 66: Key contract parameters

Contract parameter	Detail
Milestone Delivery Date (MDD)	The first major milestone of the CfD. By 12 months from contract signature projects must demonstrate commitments to delivering the project. This is evidenced through one of two routes – the 10% project spend route or project commitments route
Operational Conditions Precedent (OCP)	OCP requirements ensure certain criteria are met before a generator can issue a start date and receive payments under the CfD. OCP criteria include evidence of metering, grid connection, commissioned generating capacity and for fuelled plant criteria on Combined Heat and Power Quality Assurance (CHPQA) and Fuel Measurement Sampling (FMS) requirements
Target Commissioning Window (TCW)	The TCW is designed to ensure the delivery of a project in line with allocation results. It is the period in which generators are incentivised to agree a start date with LCCC and begin to receive payments under the CfD. Start dates cannot be issued before the TCW and if they are after the TCW the project will face contract erosion. This is due to the CfD tenure automatically starting at the end of the TCW regardless of the project's progress. The TCW does provide some flexibility in a project's start date as it is typically 12 months in length.
Longstop Date (LD)	This is the final date in the CfD contract by which projects can achieve their OCP criteria and issue a start date. This is also possible in the Longstop Period, being the time between the end of the TCW and the Longstop Date. A project must also have commissioned a minimum amount of capacity, termed the Required Installed Capacity, by this date. If this is not achieved the LCCC has the right to terminate the contract

Source: Cornwall Insight

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Control sheet

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