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Policy Mechanisms for Supporting Deployment of Engineered Greenhouse Gas Removal Technologies

A report for the

National Infrastructure Commission

NATIONAL INFRASTRUCTURE COMMISSION

Element Energy

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Executive Summary

Greenhouse gas removals (GGRs) are an integral component of reaching net zero

For the UK to reach net zero emissions in 2050, the Climate Change Committee (CCC) and others have identified that greenhouse gas removals (GGRs) will be critical to balance residual emissions from some of the most difficult to decarbonise sectors. The CCC estimate that between 44 and 112 $MtCO_2e$ of engineered GGRs could be required annually by 2050 – equivalent of up to around 20% of current UK emissions. This includes engineered GGRs such as Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS) which are consistently deployed in whole system energy models that achieve net zero by 2050, and are the focus of this report. BECCS and DACCS generate negative emissions by capturing CO_2 from the atmosphere and permanently storing it underground.

However, there are currently no engineered GGR technologies deployed at scale in the UK or globally. To accelerate GGR deployment, this will involve supporting 'first of a kind' (FOAK) projects to overcome the initially high investment costs and developing policy mechanisms that support deployment in the medium term and enable the sector to mature in the long term. The incentives needed to enable deployment of GGRs do not currently exist with a combination of market failures and project risks creating a situation which could result in suboptimal outcomes.

Deployment of engineered GGRs currently faces multiple market failures and project risks

The most important enduring market failure is that GGRs currently do not have a price incentive for the negative emissions they produce. GGR policy support will be needed to address this market failure, given that negative emissions will deliver direct benefits to corporations seeking to offset residual emissions from hard-to-abate sectors and will enable the UK to achieve net zero emissions by 2050. In addition, understanding the project risks associated with engineered GGRs will play a crucial role in designing effective policy support mechanisms. Figure 1 below summarises the six key projects risks that all GGR technologies face as they approach commercialisation and large-scale deployment.

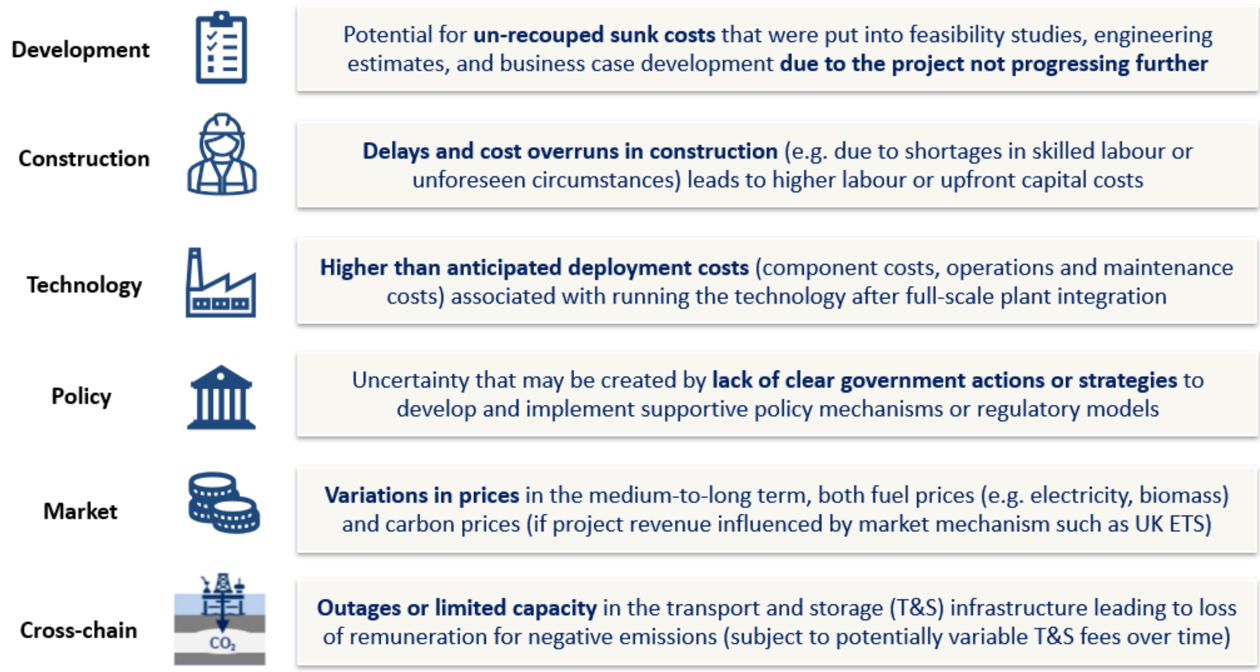

Figure 1: Project risks facing GGR technology developers

Policies to support GGRs can be market-based, contracted or government interventions

Known policy mechanisms exist which have supported other technologies' FOAK deployment, with some options applicable to GGRs already familiar to investors and developers. This study developed a 'long list' of policies which was derived from a comprehensive list of frameworks identified in literature and discussions with stakeholders. Table 1 below breaks down the long list by distinct categories, along with a core description of each policy mechanism. Many of the policies shown below are applicable to other sectors (e.g. carbon capture and storage) and well known to those seeking to invest in GGRs, including contract for differences, tax incentives or linkages with existing markets such as the new UK Emissions Trading Scheme (ETS). New mechanisms are also proposed in the 'long list', such as a standalone negative emissions (NE) service contract to directly subsidise each unit of negative emissions (£/tCO_2) produced by a GGR project.

Table 1: Long list of potential GGR policy mechanisms

Category	Policy Mechanism	Core Description
Market-based	**Negative Emissions (NE) Credits in UK ETS**	Integration of NE credits into UK ETS where emitters are able to purchase NE allowances sold by GGR developers
	Carbon Dioxide Removal (CDR) Market with Obligations	Mandate emitters to deploy or invest in a defined level of a GGR technology via obligation certificates (tradeable or not) or face penalties for non-fulfilment
Contracted	**NE Service Contract**	Government procurement of GGR technologies through a bespoke contract providing direct subsidies for negative emissions (£/tCO_2)
	Co-product Contract for Difference	Payment to generator/emitter for the difference between a contractual price and a market or reference price for a low-carbon product (e.g. electricity in £/MWh or manufactured goods in £/tonne)
	Dual Contract Subsidy	Subsidy for low-carbon product derived from GGR (e.g. power market contract for difference or low-carbon hydrogen - £/MWh) combined with service contract for negative emissions (£/tCO_2)
	Carbon Contract for Difference (CfDc)	Carbon contract for difference (£/tCO_2) with reference price linked to a carbon price or negative emissions market (e.g. NE credits in the UK ETS or new compliance market for GGRs)
Government interventions	**Tax Incentives**	Reduce the tax liability of businesses investing in GGR technologies, based on negative emissions (£/tCO_2) or upfront capital (£)
	Costs Plus Subsidy	Direct operational payments from government to cover all properly incurred costs annually, on an open book basis, with an addition of an agreed return on investment
	Public Ownership	Direct government ownership and operation of a GGR plant through a public company or similar
	Competitions	Grant funding to 'pull through' technologies in development phase across the commercialisation cycle

Two market-based and two contracted policies were shortlisted for detailed analysis

To support the development of both FOAK projects and a mature GGR sector, policies should ensure bankability, drive effectiveness, and be widely suitable. Assessment criteria focused on bankability were used to assess the ability of policy mechanisms to reduce revenue uncertainty and provide investor confidence. To evaluate effectiveness, criteria assessed a policy mechanism's ability to promote cost reduction and plant efficiencies, optimise project selection and whether it integrated the polluter pays principle. Lastly, in evaluating suitability, mechanisms were assessed on their adaptative capacity and applicability to both FOAK projects and a mature GGR sector. Table 2 provides an overview of the criteria used to assess the long list of policies.

Table 2: Criteria used for the assessment of the long list of GGR policy mechanisms

Category	Criteria	Description
Bankability	**Reduces revenue uncertainty**	Mechanism improves revenue certainty and predictability (e.g. generates sufficient demand for NEs or has successful track record)
	Provides investor confidence	Mechanism enables a balanced allocation of the key GGR project risks between the public and private sectors to ensure projects are investable for financiers and developers
Effectiveness	**Cost reduction promotion**	Mechanism promotes operational cost reductions and technology performance improvements over time
	Optimal project selection	Mechanism promotes innovation and competition, facilitates the selection of the lowest cost projects, and ensures future cost reduction and long term value for money
	Polluter pays principle	Mechanism enables costs to be distributed to emitters, particularly hard-to-abate sectors requiring offsets
Suitability	**Adaptative capacity**	Mechanism is flexible enough to operate effectively across a range of GGR technologies, able to transition between FOAK to mature projects, and able to meet varying levels of GGR demand
	FOAK applicability	Mechanism structure incentivises FOAK GGR projects and is implementable within the early timescales for FOAK GGR deployment (i.e. late 2020s/early 2030s)
	Mature sector applicability	Mechanism is capable of supporting a mature GGR sector with competing technologies and projects and most likely to be widely implemented from the 2030s/40s

The market-based policy mechanisms, along with the dual contract subsidy and the carbon contract for difference (CfDc), seem most promising to support GGR deployment in the UK. From the assessment of the long list against the criteria (results in Figure 7 in section 3.2) and further discussion with the NIC project team, four policies were shortlisted to be explored further in detailed analysis and design. The key strengths of these policies are outlined below:

- **Market-based options** ("NE Credits in the UK ETS" and "CDR Market with Obligations")
  - As a long-term policy approach to place costs on emitters via a market for NEs, both policies achieve this aim and have the potential to be applied across all engineered GGRs
  - Additional strengths and limitations of both market-based options are explored in detailed design and analysis (section 4)
- **Dual contract subsidy** (or "NE Service Contract" where no co-product is produced)
  - This policy mechanism effectively shields against co-product market price risks to ensure investor confidence along with the ability to be applied to all GGR technology solutions which are anticipated to receive low-carbon subsidies for their co-products
  - The payment mechanisms (for the low-carbon product subsidy and the NE service contract) are readily adaptable between FOAK and mature GGR projects with the ability to be administered via competitive auction-based allocations
- **Carbon CfD**
  - This policy mechanism builds on the UK government's proposed industrial carbon capture contract (CfD payment structure), providing a simplified contract structure that could be readily implemented and adapted between GGR solutions
  - By linking the payment mechanism to a market reference price for negative emissions (i.e. UK ETS or new compliance market), this policy has the ability to reduce costs borne by Government over time as the price for NEs increases as the UK approaches net zero

Both contracted policies have long-term potential to generate additional market revenue

In a mature GGR sector with a high NE market price, the CfDc policy mechanism could deliver significant value for money. Figure 2 below shows representative costs and revenue for a Nth of a kind (NOAK) DACCS plant receiving a CfDc subsidy in 2040. In the base case (15-year contract and central carbon price), a NOAK plant is likely to require no additional subsidies shortly after 2040 if base NE market prices increase in line with projections of economy-wide carbon prices. Increasing the contractual period from 15 to 20 years may reduce CfDc top-ups by a third. More significantly, under a low NE market price, top-ups may triple, with a high NE market price requiring the plant to pay its extra revenues back to the Government. In the long-term, CfDc contracts may not be needed and a standalone NE market could be preferred if projected revenues from a NE market are high enough to cover the full costs of a GGR plant.

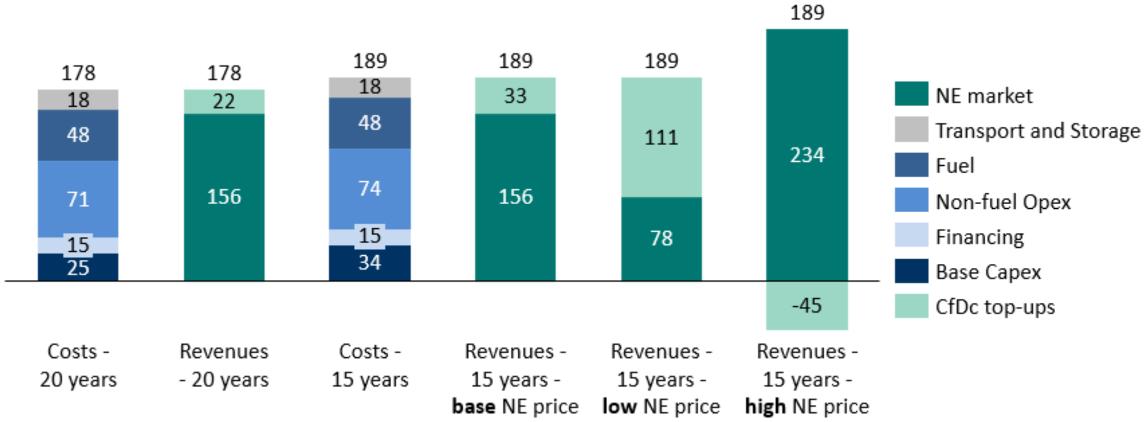

Figure 2: Costs and CfDc revenues required for removal of one tonne of CO_2 through NOAK DACCS under different incentive periods and base NE market prices (£/tCO_2)

The dual contract subsidy, which is not integrated with a regulated NE market, has potential to generate additional revenues from voluntary offset markets. Figure 3 shows an illustrative stacked revenue stream for a GGR plant receiving the dual contract subsidy. Two options are identified for integration with a private market for removals. One is for the GGR developer to own and sell its NE credits on a voluntary offset market, whereby Government could incentivise developers by allowing developers to keep a percentage of the revenue from the voluntary offset market. Alternatively, the Government could own and sell the NE credit on a voluntary offset market, allowing Government to recoup costs spent in procuring GGRs through the NE service contract. It may also be possible for future regulations to allow GGRs incentivised by a CfDc to opt-out of the contract should participation in a private market enable greater revenue potential.

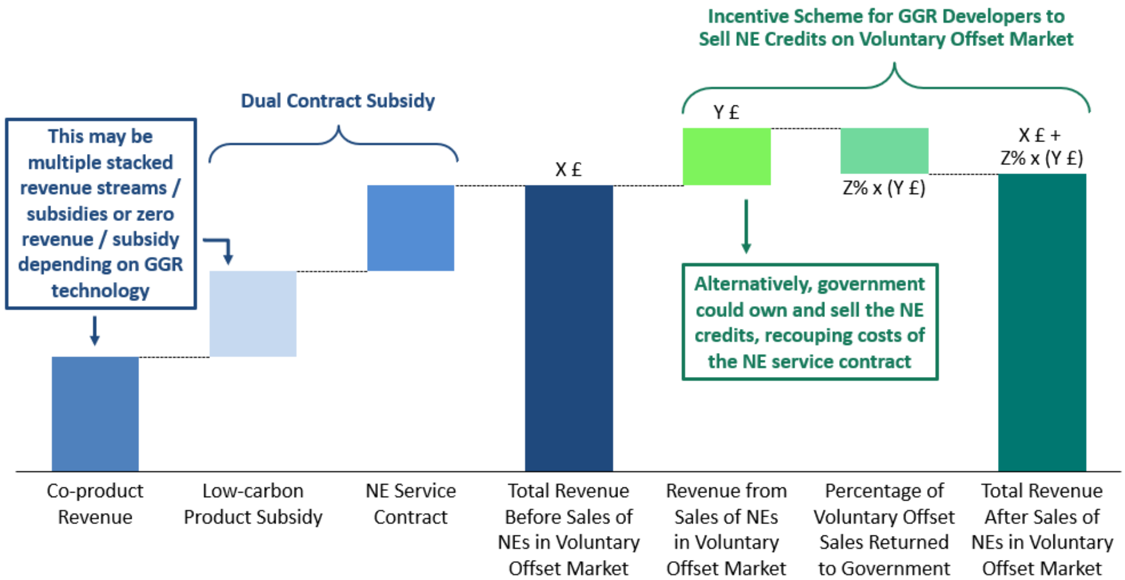

Figure 3: Potential incentive scheme for voluntary offset market integration with a GGR developer receiving the dual contract subsidy

Each shortlisted policy has key advantages and limitations for supporting GGR deployment

Regulated markets for GGRs could be the preferred long-term policy option to incentivise a maturing GGR sector and ensure hard-to-abate sectors are able to offset emissions. Of the two market-based policy mechanisms explored in this study, both achieve this outcome. In the long-term, standalone regulated NE markets could be preferred as they enable NE credits to be traded, driving efficiencies and cost reductions in a mature GGR sector. While both markets inherently follow the polluter pays principle and are able to pass on costs to emitters, standalone markets may be unable to provide sufficient revenue certainty and risk mitigation for investors, particularly for FOAK GGR projects. Furthermore, careful consideration to how both engineered and nature-based GGRs interact with the market will be key to managing any unintended consequences.

Combining a low-carbon product subsidy and NE service contract into a dual contract policy mechanism could kickstart a nascent GGR sector. Beyond its relative ease of implementation for FOAK projects, the dual contract subsidy is an attractive option for providing revenue certainty to investors given the long-term contract lengths. In addition, the dual contract subsidy policy option could adapt over time as the GGR sector matures, either by utilising competitive auction-based allocations or even replacing the NE service contract with a CfDc. However, there is greater complexity involved with this policy mechanism if used in a mature GGR sector, as competing GGRs would be receiving different low-carbon product subsidies.

Integrated with a NE market price, a CfDc policy mechanism would be a familiar and viable incentive to drive FOAK deployment and a maturing GGR sector. Similar to the dual contract subsidy, a CfDc would provide sufficient revenue certainty to investors over the lifetime of a GGR project. Moreover, its track record in the UK both for low-carbon power and for BEIS' proposed industrial carbon capture contract enable it to be a relatively easy to implement policy mechanism. In the long-term, an increasing NE market price would ensure value for money, since the subsidy is only paid on the difference between the strike price and market price.

In summary, while each policy mechanism offers advantages relative to the others, a clearer set of priorities for GGR deployment would be valuable to narrow down the preferred policy mechanism(s) for implementation. To support a preferred GGR policy approach, further work could focus on investigating the feasibility and timescales for implementing either regulated NE markets, complementary analyses on the funding routes for GGRs to evaluate distribution of costs and risk allocation, and refined analyses on the potential for revenue to be generated from voluntary offset markets.

Authors

This report has been prepared by Element Energy.

Element Energy is a strategic energy consultancy, specialising in the intelligent analysis of low carbon energy. The team of over 80 specialists provides consultancy services across a wide range of sectors, including the built environment, carbon capture and storage, industrial decarbonisation, smart electricity and gas networks, energy storage, renewable energy systems and low carbon transport. Element Energy provides insights on both technical and strategic issues, believing that the technical and engineering understanding of the real-world challenges support the strategic work.

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Acronyms

BECCS	Bioenergy with Carbon Capture and Storage
BEIS	UK Government Department for Business, Energy, and Industrial Strategy
CCC	Climate Change Committee
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation, and Storage
CDR	Carbon Dioxide Removal
CfD	Contract for Difference
CfDc	Carbon Contract for Difference
CfDe	Power Contract for Difference
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalents
DAC(CS)	Direct air (carbon) capture (and storage)
EfW	Energy from Waste
ETS	Emissions Trading System
FOAK	First of a Kind
GGR	Greenhouse Gas Removal
H_2	Hydrogen
Mt	Mega tonne
MRV	Monitoring, Reporting and Verification
NE	Negative Emissions
NIC	National Infrastructure Commission
NOAK	N^{th} of a Kind
R&D	Research and Development
T&S	Transport and Storage
TRL	Technology Readiness Level
UKGS	UK Guarantees Scheme
UKIB	UK Infrastructure Bank

Contents

1 Introduction

1.1 Context

For the UK to reach net zero emissions in 2050, the Climate Change Committee (CCC) has been clear that greenhouse gas removals (GGRs) will be required to balance residual emissions from some of the most difficult to decarbonise sectors. The CCC estimate that between 44 and 112 $MtCO_2e$ of engineered GGRs could be required annually by 2050[1] – equivalent of up to around 20% of current UK emissions. This includes GGRs such as Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS) which are consistently deployed in whole system energy models that achieve net zero by 2050.

However, there are currently no engineered GGR technologies deployed at scale in the UK or globally. To accelerate GGR deployment, this will involve supporting 'first of a kind' (FOAK) projects to overcome the initially high investment costs and developing policy mechanisms that support deployment in the medium to long term as the sector matures.

Currently there are a range of market failures and project risks that mean the incentives needed to enable deployment of GGRs do not exist, resulting in suboptimal outcomes. The National Infrastructure Commission (NIC) appointed Element Energy to analyse the policy mechanisms which can address these market failures and project risks in order to inform its advice and recommendations to Government on engineered GGR technologies. The findings of this research will feed into a broader study by the Commission scheduled to report in summer of 2021.

1.2 Objectives & scope

This research was commissioned as part of the NIC's wider study examining how emerging engineered GGR technologies can support the UK's climate ambitions.[2] Alternative nature-based GGR technologies which includes methods such as afforestation, peatland restoration, soil carbon sequestration or enhanced weathering are also being considered as part of a wider Government analysis of GGRs. These however fall outside the remit of NIC as they are not classified as economic infrastructure. From here on in this report, when referring to GGRs, this refers to engineered GGRs (i.e. BECCS and DACCS) unless otherwise specified.

The purpose of this research is to explore which policy mechanisms can address market failures and project risks hindering GGR deployment. This covers the early stages of deployment involving FOAK projects, through to the latter stages, representing the mature GGR sector which is likely to develop over the coming decades.

The analysis objectives were to:

- Review engineered GGRs performance and risks to understand barriers to deployment
- Understand the range of potential policy mechanisms to support FOAK GGRs and a mature GGR sector
- Complete a clear comparative assessment of the strengths and weaknesses of policy options
- Select a shortlist of promising policy mechanisms and complete more detailed analysis on their design
- Provide synthesised findings and conclusions

While important to consider for policy development for BECCS, biomass sustainability criteria and availability of biomass supply were not in scope for this study, as these are being investigated in parallel work by the UK Government's Department for Business, Energy, and Industrial Strategy (BEIS). In addition, a detailed assessment of the funding options for shortlisted policy mechanisms was not undertaken. The NIC are undertaking a separate study on who will pay for the large investment costs needed for deployment of GGR technologies.

[1] The Sixth Carbon Budget – Greenhouse Gas Removals (Climate Change Committee, 2020) [LINK]
[2] For further information on the NIC's study on GGR technologies: [LINK]

1.3 Methodology

This study was broken down into four key stages, as shown in Figure 4. In the first stage, the team undertook a literature review of policy mechanisms which could be used to support GGR technologies. This review was underpinned by an assessment of the market failures (analysed by the NIC) and projects risks facing GGRs, as well as technology specific policy considerations. Next, a long list of policy mechanisms was summarised, with some policies from the literature review excluded (rationales in Appendix 6.2). The second stage sought to assess the initial long list of policy mechanisms through a multi-criteria assessment. The assessment focused on key criteria which enabled the identification of each policy mechanism's strengths and weaknesses. The most promising policies from the assessment were then selected to be shortlisted for detailed design and analysis. In the third stage, the policy assessment and shortlisted policies themselves were taken through a review process. This was conducted via an internal workshop with the NIC and an external workshop and engagement with stakeholders from the investment and finance community. Lastly, stage four involved detailed analysis of the shortlisted policy mechanisms, taking a closer look at their key design features and their potential to transition from FOAK to a mature GGR sector. Further analysis was conducted on the market revenue potential for GGRs under varying policy scenarios, along with important complementary and enabling policies to support the primary policy mechanisms investigated.

Figure 4: Key stages taken in this study to review, assess, and analyse GGR policy mechanisms

1.4 Report structure

The report is structured into the following sections:

- **Section 2** covers the initial review of the engineered GGR sector (i.e. key characteristics of BECCS and DACCS technologies and the current risks and market failures), along with the initial long list of potential policy mechanisms.
- **Section 3** outlines the criteria used in the assessment of the potential policy mechanisms and the shortlisted policies mechanisms, with rationales highlighting their key strengths.
- **Section 4** contains the detailed design and analysis of the shortlisted policy mechanisms, including their key design features, potential transition from FOAK to a mature GGR sector, and additional complementary and enabling policies for the wider successful deployment of GGRs.
- **Section 5** discusses how the key insights can inform the potential adoption of the shortlisted policy mechanisms and presents conclusions from the detailed analysis.

2 Initial Review of GGRs and Potential Policy Mechanisms

This section covers the initial review of the engineered GGR solutions in scope. This includes a summary of the key characteristics of BECCS and DACCS technologies and the current risks and market failures facing GGR projects. The final sub-section provides an overview of the initial long list of potential policy mechanisms.

2.1 Overview of GGR technology solutions

As discussed in section 1.2, this study focuses on engineered GGRs, notably bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS). This study has focused on five distinct GGR solutions. These were chosen because of the different considerations that need to be made for each solution in assessing feasible policy mechanisms:

1. **BECCS Power**: CCS infrastructure attached to power plants which combust biomass feedstocks (typically imported wood pellets in the UK) to produce low-carbon electricity which can be sold to the electricity market.
2. **BECCS Energy from Waste (EfW)**: CCS infrastructure attached to EfW plants whose primary function is the incineration of waste (e.g. municipal solid waste). With the integration of CCS, EfW plants can be converted into BECCS due to the biogenic portions of waste in their feedstock. As a co-product, BECCS EfW plants would produce electricity which can be sold to the electricity market.
3. **BECCS Industry**: CCS infrastructure attached to industrial facilities which utilise biomass feedstocks as a low-carbon fuel. These could be sites currently using biogenic fuels or sites with the potential to switch to biogenic fuels. For either of these sites, CCS is a potential or preferred abatement option for deep decarbonisation or negative emissions (e.g. cement kilns).
4. **BECCS Hydrogen & Other Fuels**: CCS infrastructure attached to low-carbon hydrogen production (from biomass) or other biofuel production plants. For example, this includes application of CCS to plants which produce syngas via waste or biomass gasification technologies with subsequent conversion methods to products such as hydrogen or liquid biofuels.
5. **DACCS**: Technologies which directly remove CO_2 from the atmosphere, covering both chemical and physical processes, with captured CO_2 thereafter transported to permanent storage. Capture plants are likely best situated close to both availability of low-carbon and low-cost energy (e.g. renewables).

Engineered GGRs are at various stages of development, with a higher number in the early research stages and fewer approaching deployment and commercialisation. Furthermore, each solution has a wide range of abatement costs given that these are highly technology and project dependent and further impacted by site scale, location, and feedstock requirements. Table 3 below provides an indicative overview of technology readiness level (TRL) for each of the GGR solutions explored in this study.

In addition to their differences in TRLs, each engineered GGR solution also has distinguishing characteristics across their co-products[3], revenue streams and existing or planned policy support (shown in Table 4). These differences will play an important role in the applicability and design of future policy mechanisms to support GGR deployment, which may require adjustments across GGR solutions.

[3] Defined as the additional product(s) that a GGR plant produces in addition to the negative emissions that are generated.

Table 3: Estimated TRL and technology deployment stage for engineered GGR solutions

GGR	Estimated TRL and Technology Deployment Stage
BECCS Power	**TRL 6-7:** First large-scale plant now operational in Japan (2020).[4] Drax planning for commercial scale deployment in UK by 2027.
BECCS EfW	**TRL 6-7:** Norway's Northern Lights project aims to have a full-scale CCS equipped EfW plant by 2024. Only a few operational plants worldwide (e.g. Japan) with several under development in the Netherlands.[5] Commercial scale deployment in mid/late 2020s in the UK with support incentives in place.
BECCS Industry	**TRL 5-7:** Norway's Northern Lights project aims to have a CCS equipped cement plant by 2024.[6] Commercial scale deployment in mid/late 2020s in the UK with the right support incentives in place.
BECCS Hydrogen & Other Fuels	**TRL 4-9:** Lower range TRL 4-5 for hydrogen: commercial scale deployment of modular hydrogen production units without CCS in the UK by 2023-2025. Greater uncertainty with timescales for CCS retrofits. Late 2020s/early 2030s could be possible with the combined incentives for carbon removals and low-carbon hydrogen. Other fuels (e.g. bioethanol, biomethane) as high as TRL 9.
DACCS	**TRL 4-6:** Small-scale pilot and demonstration projects (<10 ktCO_2/yr) have been undertaken with the first large-scale plant aiming for construction in the US by mid-2020s. Most early projects have utilised captured CO_2 and integration with permanent CO_2 storage yet to be demonstrated at significant scale.

Table 4: Comparison of co-products, revenue streams, and policy support across GGR solutions

GGR	Co-products *(and Revenues)*	Existing / Planned Policy Support
BECCS Power	Electricity *(power market)*	Power contract for difference (CfDe) for biomass generators without CCS
BECCS EfW	Waste disposal *(gate fees)* Electricity *(power market)*	CfDe for EfW plants without CCS
BECCS Industry	Manufactured goods *(commodity markets)*	Industrial carbon capture contract (similar to CfD) for any industrial carbon capture (e.g. cement)[7]
BECCS Hydrogen & Other Fuels	Hydrogen / other fuels *(new low-carbon fuel markets)* Waste disposal *(gate fees)*	Low-carbon hydrogen commercial models under development by BEIS[7] and legislation to be implemented to require fuel suppliers to introduce E10 petrol[8]
DACCS	None[9]	BEIS competition to support development of large-scale GGR projects (including DACCS)[10]

[4] Toshiba Starts Operation of Large-Scale Carbon Capture Facility (October 2020) [LINK]
[5] Technical Report – CCS on Waste to Energy (IEAGHG, 2020) [LINK]
[6] Northern Lights CCS Project [LINK]
[7] An update on business models for CCUS (BEIS, 2020) [LINK]. Previous work suggested contractual producer subsidies: Business Models for Low Carbon Hydrogen Production (Frontier Economics, 2020) [LINK]
[8] E10 petrol is a fuel blend containing up to 10% bioethanol. Introducing E10 petrol: outcome and summary of responses (Department for Transport, 2021) [LINK]
[9] While a DAC plant could generate additional revenue from the sale of CO_2 (e.g. for CO_2 utilisation), permanent storage of CO_2 is required for DACCS to generate negative emissions.
[10] Direct Air Capture and Greenhouse Gas Removal Programme (BEIS, 2020) [LINK]

2.2 Current market failures and risks of GGRs

There are currently a range of market failures which are impacting the deployment of GGRs. Policy will be instrumental in addressing these market failures, primarily in the short term but also extending into the long-term as a mature GGR sector develops. The most important enduring market failure is that GGRs currently do not have a revenue source for the negative emissions they produce. GGR policy support will need to address this market failure, given that negative emissions will deliver direct benefits to corporations seeking to offset residual emissions form hard-to-abate sectors and will enable the UK to achieve net zero emissions by 2050. Additional short-term market failures for GGRs include lack of knowledge sharing, asymmetry of information, policy risk and uncertainty and broader network coordination challenges (i.e. of downstream CO_2 transport and storage infrastructure).

In addition, understanding the project risks associated with engineered GGRs will play a crucial role in designing effective policy support mechanisms. Figure 5 below summarises the six key project risks that all GGR technologies face as they approach commercialisation and large-scale deployment.

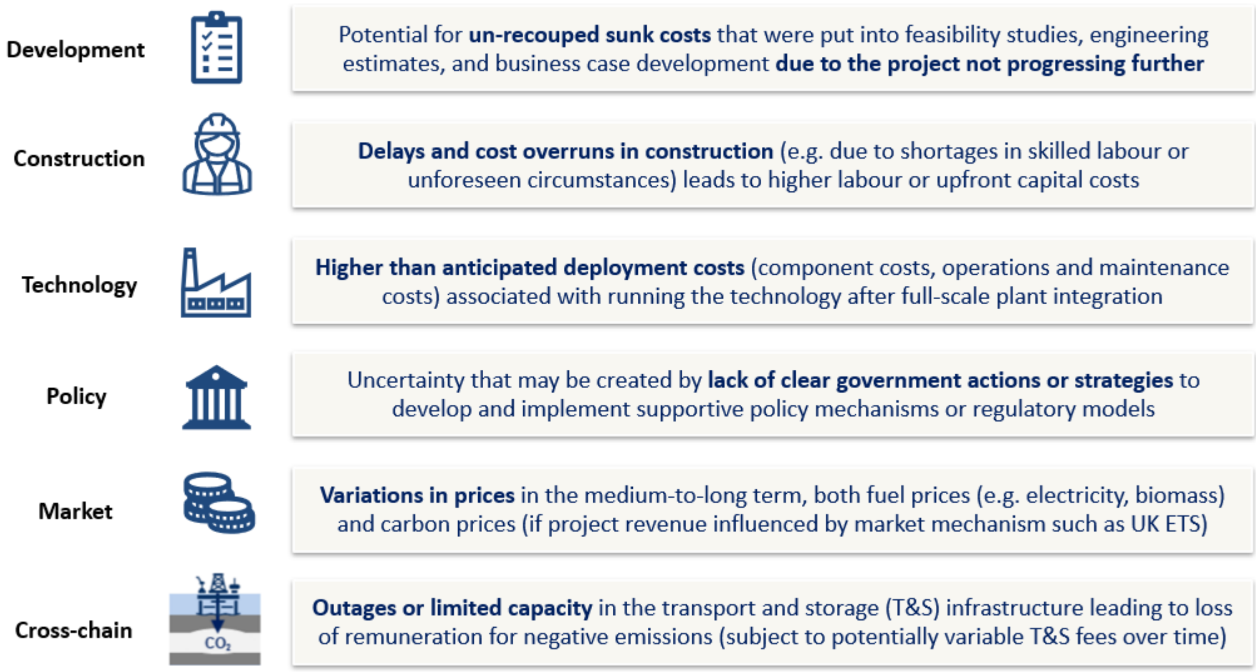

Figure 5: Project risks facing GGR technology developers

Specific GGR solutions will also face unique development and plant operational risks over the project lifetime. These unique risks and operational factors will influence the detailed design of GGR policies, which may need to be adapted for different GGR solutions to ensure that sufficient levels of support are used to incentivise technology development across all solutions and promote a sustainable GGR sector in the long-term. These key risks and influencing factors are outlined in Table 5. In addition, some factors will be cross-cutting across multiple GGR solutions. For example, large scale deployment of BECCS technologies would be limited by biomass/waste availability and competition with other more established sectors already utilising biomass.

Table 5: Primary risks and factors influencing detailed policy design for GGR solutions

GGR	Risks	Factors Influencing Detailed Policy Design
BECCS Power	• Biomass prices • Uncertain plant dispatch[11] • Electricity revenue	• Policy would likely need to closely consider mitigating against market risks associated with wholesale electricity price • There is currently only one mature BECCS power developer in the UK, giving limited opportunity to promote competition for a FOAK project in the near term • A BECCS power station would likely run baseload to maximise its negative emissions potential and associated revenue • Plant revenue from the electricity market would need to be accounted for in the design of a GGR policy mechanism
BECCS EfW	• Feedstock availability and variability • Electricity revenue and gate fees	• Plant revenue from both the electricity market and waste gate fees would need to be accounted for in the design of a policy mechanism to support BECCS conversion • Future availability of waste given currently policies aimed at reducing waste quantities (e.g. deposit return scheme) • Future variability on the biogenic portions of waste used as fuel input could impact the long-term potential of negative emissions and its associated revenue
BECCS Industry	• Carbon leakage[12] • Difficulty financing / short payback periods required • Counterparty risk	• Risks associated with carbon leakage would need to be considered in tandem with BECCS policy support to ensure industry remains cost-competitive in the UK • Likely to have higher counterparty risks than other GGR sectors due to greater proportions of revenue from co-product markets (as well as greater volatility in these markets) • Policies incentivising negative emissions in industry would need to carefully consider existing policy support for low-carbon fuel switching or CCUS (e.g. industrial carbon capture contract)
BECCS Hydrogen & Other Fuels	• Hydrogen / fuel market demand and sale price • Hydrogen T&S availability • Feedstock availability / price	• Competition likely to exist from other low-carbon hydrogen/fuel production methods with costs expected to decline over the coming decades (e.g. green hydrogen produced via electrolysis) • Policies incentivising negative emissions resulting from hydrogen/fuel production would need to carefully consider any future policy support for low-carbon hydrogen/fuel production (i.e. only renumerate additional costs of CCS)
DACCS	• Energy prices (heat and electricity) • Plant operation reliant on revenue or subsidies for negative emissions	• Policies may need to carefully consider the risks associated with energy costs (i.e. electricity and heat) over the long-term • Given the scalability and flexibility of locating DACCS, mechanisms should seek to support projects which offer the greatest benefits over time (e.g. concentrated in industrial clusters or potentially co-located with nuclear power stations for waste heat)

[11] Dispatch here refers to the electricity generation load profile (e.g. baseload / dispatchable power generation).
[12] Carbon leakage refers to the situation that may occur if, due to costs related to climate policies, businesses were to transfer production to other countries with lower emission constraints, thereby leading to an increase in their emissions.

2.3 Policy mechanisms review and long list

A long list of policy mechanisms was developed to cover a range of policy options for supporting GGRs. This 'long list' was derived from a comprehensive list of frameworks identified in literature and discussions with stakeholders. Table 6 below breaks down the long list by distinct categories, along with a core description of each policy mechanism. A summary of the structure and operating assumptions for each policy mechanism is expanded upon in this section, with further detail on the long listed policies' strengths, weaknesses and UK or global implementation examples contained in Appendix 6.1. Policy mechanisms ruled out from the long list assessment and the rationales for exclusion are set out in Appendix 6.2.[13]

Table 6: Long list of potential GGR policy mechanisms

Category	Policy Mechanism	Core Description
Market-based	**Negative Emissions (NE) Credits in UK ETS**	Integration of NE credits into UK ETS where emitters are able to purchase NE allowances sold by GGR developers
	Carbon Dioxide Removal (CDR) Market with Obligations	Mandate emitters to deploy or invest in a defined level of a GGR technology via obligation certificates (tradeable or not) or face penalties for non-fulfilment
Contracted	**NE Service Contract**	Government procurement of GGR projects through a bespoke contract providing direct subsidies for negative emissions (£/tCO_2)
	Co-product Contract for Difference	Payment to generator/emitter for the difference between a contractual price and a market or reference price for a low-carbon product (e.g. electricity in £/MWh or manufactured goods in £/tonne)
	Dual Contract Subsidy	Subsidy for low-carbon product derived from GGR (e.g. power market contract for difference or low-carbon hydrogen - £/MWh) combined with service contract for negative emissions (£/tCO_2)
	Carbon Contract for Difference (CfDc)	Carbon contract for difference (£/tCO_2) with reference price linked to a carbon price or negative emissions market (e.g. NE credits in the UK ETS or new compliance market for GGRs)
Government interventions	**Tax Incentives**	Reduce the tax liability of businesses investing in GGR technologies, based on negative emissions (£/tCO_2) or upfront capital (£)
	Costs Plus Subsidy	Direct operational payments from government to cover all properly incurred costs annually, on an open book basis, with an addition of an agreed return on investment
	Public Ownership	Direct government ownership and operation of a GGR plant through a public company or similar
	Competitions	Grant funding that generally follows R&D and innovation funding to 'pull through' low TRL technologies (TRL 4 to 6) in development phase across the commercialisation cycle towards TRL 7 and above

2.3.1 Market-based policy mechanisms

Negative Emissions Credits in the UK ETS

Under this policy option, the UK ETS would be adapted to allow for GGRs to generate NE credits which could be sold on the new UK ETS trading scheme. Any such adjustment would likely need to be supported by robust verification systems for the quantities of NEs achieved. While NE credits from both engineered and nature-based GGRs have the potential to be monitored, reported, and verified (MRV), the ease in which NE credits

[13] Policy mechanisms excluded from the long list included carbon tax, regulated asset base, and cap and floor.

from BECCS or DACCS technologies can be verified could support their earlier market integration.[14] However, there still exists significant administrative and political challenges to include NE credits in the UK ETS, making it very challenging for it to support FOAK GGR deployment in the UK.

Carbon Dioxide Removal Market with Obligations

This policy option involves enforcing obligations on certain emitters to purchase carbon dioxide removal (CDR) credits within a new compliance market. Obligations would require certain "emitters" to offset their emissions (or face penalties), for example:

- Obligations on upstream fossil fuel producers to offset a fixed percentage of the CO_2 contained within their fuel sales (e.g. Carbon Takeback Obligation[15])
- Obligations on large emitters from other hard-to-abate sectors (e.g. aviation, maritime)

Implementation would require a new market-based emissions price (£/tCO_2 abated) which would be driven by supply and demand from GGR sellers and emitters, respectively. Separate from the UK ETS, the quantity of credits in a CDR market could target specific allocations of negative emissions which could be aligned with UK carbon budgets. Initial entrants selling credits are likely to be engineered removals (e.g. BECCS, DACCS) or nature-based solutions (e.g. afforestation) which have reliable measuring, reporting, and verification (MRV) methods for the amount of CO_2 removed. Over time, the market liquidity[16] could increase with the inclusion of other GGR solutions or through the expansion of engineered GGRs as they become more cost-competitive.

2.3.2 Contracted policy mechanisms

Negative emissions service contract

This policy mechanism involves delivering a bespoke service contract for negative emissions (in £/tCO_2). Administration of the contracts could be under two variations:

1. **Direct subsidies:** As a standalone policy mechanism, service contracts for FOAK GGR projects in this context are likely to be bilaterally negotiated between Government and developers. While contracts could theoretically be auctioned for FOAK projects, there are anticipated difficulties due to limited competition for FOAK deployment from GGR developers in the near term (e.g. due to limited number of industrial / EfW sites in clusters with CCS infrastructure access). Contract lengths could cover similar timeframes as CfD contracts (e.g. up to 15 years) and could have different incentive levels for different GGR technologies.
2. **Procurement (via reverse auctions[17]):** In a mature GGR market, procurement could be managed through reverse auctions with bids submitted for new projects seeking to offer the lowest-cost negative emissions. This approach has been previously used in the UK electricity market to drive down the costs of low-carbon electricity generation (e.g. offshore wind).

Service contracts would be subject to revision over time with the incentive level (£/tCO_2) assumed to decrease for renewed contracts at the end of the contract length (e.g. 15 years). This will be important to avoid rent extraction while maintaining investor confidence as other revenue streams emerge (e.g. UK ETS credits) or for a mature GGR sector with lower project costs.

[14] While some nature-based GGRs currently have relatively robust verification frameworks for NEs (e.g. afforestation), engineered GGRs are generally assumed to have greater potential to have earlier MRV standards in place.
[15] Carbon Takeback Obligation has been proposed by Net Zero Oxford and Climateworks Foundation. [LINK]
[16] Market liquidity here refers to the extent to which a new market would allow for stable and transparent NE credits to be bought/sold.
[17] A reverse auction is one in which there is one buyer and many potential sellers. In this context, the buyer of NEs would be government with GGR developers as the sellers.

Co-product contract for difference

Another familiar policy option to UK developers and policymakers is a contract for difference (CfD). The aim of a CfD is to provide an operational subsidy for the difference between the cost of producing a product (the strike price) and the product's market price. For GGRs, co-product CfDs could be administered as:

- **Traditional CfDs** for low-carbon electricity (CfDe), where a generator is paid the difference between a contractually agreed strike price and market price for electricity (or generator refunds revenue if market price exceeds strike price)
- **Other co-product CfDs** for manufactured goods (e.g. low-carbon cement) or low-carbon fuels (e.g. hydrogen) which would provide a subsidy paid above a prevailing reference price for the co-product (e.g. £/tonne cement or £/MWh hydrogen)

Power CfDs could be adapted to GGRs which generate electricity by increasing the strike price to cover the additional costs of the CCS plant and wider integration costs (e.g. CO_2 transport and storage) relative to a counterfactual biomass generator or EfW plant. Other CfDs could be adapted across all GGRs with co-products along with amendments to contracts to ensure the strike price is set sufficiently high to cover all additional operating and capital costs of a project.

Dual contract subsidy

This policy option combines the previous two contracted policies outlined above: a low-carbon product subsidy, either new or existing, could be combined with a service contract for NEs to form a single policy mechanism (which is referred to as a 'dual contract subsidy' in this study).[18]

A combined contract would likely be awarded through bilateral negotiations for FOAK GGRs, with the potential to be awarded through reverse auctions in the longer term to drive further competition. The financial incentive from the low-carbon product subsidy could be capped and aligned with an approved level of costs for the product (e.g. value of low-carbon electricity to electricity consumers), with the NE service contract (£/tCO_2) covering remaining costs. Volumes of contracts (i.e. Mt/annum of negative emissions) could be aligned with government-based targets for GGRs in an early/developing sector.

Carbon contract for difference

The last contracted policy mechanism considered is the carbon CfD (CfDc). A CfDc for GGRs would provide a subsidy paid above the prevailing carbon market price for negative emissions (or another reference carbon price) up to a contractually agreed strike price on CO_2 captured (£/tCO_2).[19] The CfDc could cover the additional costs of the CCS plant and wider integration costs (e.g. for CO_2 transport and storage). Government would therefore bear the risk on carbon market price, both its volatility and implementation timeline. Volumes of contracts (i.e. Mt/annum of negative emissions) could be aligned with volumes of NE credits in a market-based mechanism based on offsetting emissions from hard-to-abate sectors over time.

As shown in Figure 6, the UK's proposed industrial carbon capture contract (following a CfDc mechanism for CCUS) are set to provide a subsidy paid above a prevailing carbon price (referenced to the UK ETS), with contractually agreed strike prices assumed to cover operational capture costs (including fuel), capex investment and CO_2 transport and storage costs. In the UK's industrial CfDc, the reference price is set to follow a fixed trajectory. However, the proposed reference price for GGRs in this policy mechanism could follow a market-linked price (e.g. integrated in the UK ETS or new compliance market for removals).

[18] For an illustrative diagram showing stacked revenue streams for a GGR project receiving the dual contract subsidy, refer to Figure 8 in section 4.2.
[19] For an illustrative diagram of the CfDc policy mechanism, refer to Figure 9 in section 4.3.

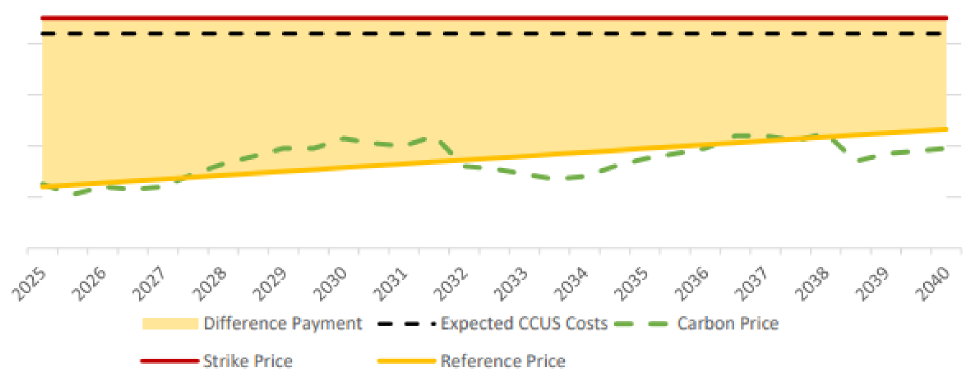

Figure 6: Illustrative diagram of BEIS' industrial carbon capture business model[20]

2.3.3 Government intervention policy mechanisms

Tax incentives

This policy mechanism involves developing tax incentives specifically for GGR developers. A prominent form of tax incentives could be provided to GGR projects to receive credits against their corporation tax liability for negative emissions (in £ per tonne of CO_2 stored). The value of tax credits could be set for specified time periods, subject to revision and re-evaluation in successive periods. For example, the US's 45Q tax credit provides a set amount of monetary credit over time, the value of which differs depending on whether CO_2 is permanently stored tertiary oil injection or in geologic formations.[21] Moreover, credits could be traded to allow for firms with smaller tax liabilities to take advantage of the mechanism. For example, the tax credit could be purchased by any other large tax paying entity. As an alternative to credits, tax incentives could also be provided for the initial capital investment in the whole GGR plant or CCS plant retrofit, reducing cost of capital for projects.

Costs plus subsidy

A costs plus subsidy mechanism would involve an open-book contract which includes direct payments covering all incurred operational costs of the GGR project (fuel costs, CO_2 transport and storage, etc.), plus an agreed margin for return on investment. It is likely that margins on the subsidy would need to be contractually negotiated for bespoke FOAK GGR projects, whereas a competitive allocation mechanism could be used to determine profit margins for a mature GGR sector. It is assumed in this study that GGR developers would need to construct project proposals outlining the delivery timeframes for their volumes of CO_2 captured over the operational lifetime of the facility. Government would be expected to bear the majority of risks associated with operational costs and any overall increases in project costs. Risk management could include build-in of pain-gain sharing mechanisms to incentivise improvements - enabling the contractor to share in the benefits of cost savings, but also to bear some of the cost when there are cost overruns.

Public ownership

This policy involves Government taking complete ownership and control of a GGR project, from plant construction through to long-term operation of the facility, likely through a state-owned enterprise. Government could subsidise the deployment of GGR projects across different technology solutions, particularly with engineered GGRs, to achieve the scale of negative emissions needed for net zero. Taxpayer funds would be directed towards a newly inaugurated state-owned enterprise to cover the full range of costs (which may include costs of producing other low-carbon fuels or electricity in addition to negative emissions). Under this policy option, Government bears all project risks, including the risks associated with operational costs,

[20] An update on business models for CCUS (BEIS, 2020) [LINK]
[21] The US Section 45Q Tax Credit for Carbon Oxide Sequestration (Global CCS Institute, 2020) [LINK]

increases in project construction costs (e.g. due to plant-wide integration), and any risks associated with revenue from electricity or low-carbon fuel markets.

Competitions

Competitions can be introduced to follow on from research and development (R&D) and innovation funding to 'pull through' low TRL technologies (TRL 4 to 6) in development phase across the commercialisation cycle towards TRL 7 and above by providing grant funding. Funding pools can be allocated budgets for specific GGR solutions (e.g. DACCS, BECCS industry, etc.) to incentivise competition between developers for pilot or demonstration projects. Projects could be awarded funding based on a range of criteria – some examples are[22]:

- Technology feasibility and applicability
- Social metrics (e.g. job growth)
- Cost reduction potential
- Value for money (to Government or consumers)
- Scalability potential
- Synergies with decarbonisation of other sectors (e.g. cement and EfW plants)

Competitions are typically government funded although some may only be partially funded due to state aid rules. However, they could be designed with contingencies for projects to acquire additional private sector investment to drive technology commercialisation.

[22] The full set of criteria BEIS are using for their GGR competition can be found in the Competition Guidance Notes (2020).

3 Assessment of Policy Mechanisms

3.1 Evaluation criteria

Key criteria were developed to assess each of the policy mechanisms in the long list on their relative strengths and weaknesses in supporting GGR deployment. They represent the important requirements and factors that will increase the attractiveness of the policy mechanism for stakeholders in both the public and private sector. The criteria in Table 7 were developed from literature review and further refined in discussion with the NIC project team.

Table 7: Criteria used for the assessment of the long list of GGR policy mechanisms

Category	Criteria	Description
Bankability	**Reduces revenue uncertainty**	Mechanism improves revenue certainty and predictability (e.g. generates sufficient demand for negative emissions or has successful track record)
	Provides investor confidence	Mechanism enables a balanced allocation of the key GGR project risks between the public and private sectors to ensure projects are investable for financiers and developers
Effectiveness	**Cost reduction promotion**	Mechanism promotes operational cost reductions and technology performance improvements over time
	Optimal project selection	Mechanism promotes innovation and competition, facilitates the selection of the lowest cost projects, and ensures future cost reduction and long term value for money
	Polluter pays principle	Mechanism enables costs to be distributed to emitters, particularly hard-to-abate sectors requiring offsets
Suitability	**Adaptative capacity**	Mechanism is flexible enough to operate effectively across a range of GGR technologies, able to transition between FOAK to mature projects, and able to meet varying levels of GGR demand
	FOAK applicability	Mechanism structure incentivises FOAK GGR projects and is implementable within the early timescales for FOAK GGR deployment (i.e. late 2020s/early 2030s)
	Mature sector applicability	Mechanism is capable of supporting a mature GGR sector with competing technologies and projects and most likely to be widely implemented from the 2030s/40s

Assessment criteria focused on bankability assessed a policy mechanism's ability to reduce revenue uncertainty and provide investor confidence. Mechanisms which provide greater revenue certainty over the lifetime of a GGR project were deemed particularly important for developers to ensure the project receives a successful financial investment decision. For example, a co-product or carbon CfD could provide sufficient revenue certainty both due to their track record in the UK and contracted strike price of 10 years or more. In addition, mitigating against risks faced by GGR developers is key to ensuring investors are willing to take on the significant financing requirements. This is particularly important for FOAK GGR projects where policies that protect against market risks (e.g. unstable fuel or carbon prices) are likely to be needed given the uncertain investment environment. Government is therefore more likely, at least for FOAK projects, to be positioned to bear risks due to cost uncertainty, with the allocation of risks changing as the GGR sector matures.

The next set of criteria deemed important **assessed the effectiveness of the policy mechanisms**. Firstly, this considers a policy's ability to promote cost reduction and plant efficiency over the project lifetime. Policies which provide a payment structure based on £/tCO_2 for negative emissions would be effective in this area, as developers are incentivised to reduce their costs to guarantee greater profit margins for each negative emission produced. Secondly, policy mechanisms which optimise project selection were deemed more effective, given the importance of promoting innovation, competition, and low-cost project development in both a nascent and maturing GGR sector. Lastly, given the importance of internalising costs of carbon emissions, mechanisms which follow the polluter pays principle (e.g. market-based mechanisms with emitters purchasing NEs)[23] were assessed to be more effective in the long-term to avoid private sector rent extraction.[24]

The final set of criteria assessed policy mechanisms for their **suitability in a variety of different settings**. This stressed the importance of mechanisms which could be adaptive, both being able to be applicable across GGR solutions and to be able to transition between FOAK and mature projects. The two final suitability criteria were the applicability of the policies to either FOAK projects or a mature GGR sector. Policy mechanisms were deemed particularly attractive if they could be applicable to both FOAK projects and a mature sector with limited adjustments needed or with existing frameworks in place (e.g. CfD transitioning from bilaterally negotiated contracts to auctioned contracts).

3.2 Assessment results

The results of the multi-criteria assessment of the long list of policy mechanisms are shown in Figure 7. Each of the criteria were scored on a red, amber, or green (RAG) methodology:

- Red: policy mechanism struggles to meet criteria
- Amber: policy mechanism partially meets criteria
- Green: policy mechanism successfully meets criteria

In some instances, blended scoring (e.g. red/amber) were used to provide greater granularity in the assessment between similar policy mechanisms. The full set of rationales for each policy-criteria score are provided in Appendix 6.3.

[23] The 'polluter pays' principle suggests placing the burden of societal costs for emissions reductions on fossil fuel producers / consumers and emitters.
[24] Private sector rent herein refers to a GGR project receiving subsidies exceeding that which is financially (or socially) necessary.

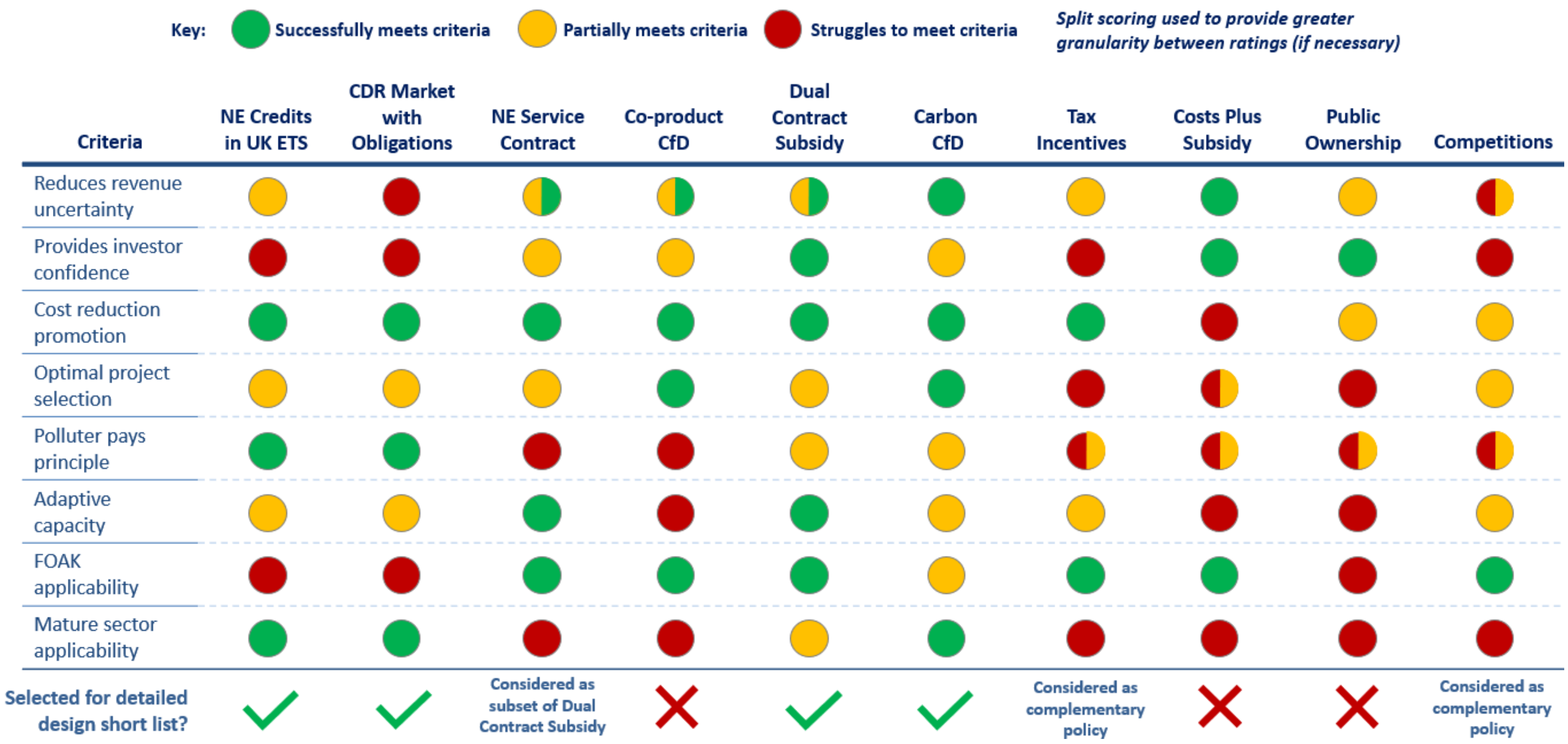

Figure 7: Results of multi-criteria assessment on the long list of GGR policy mechanisms[25]

[25] NE = Negative Emissions, CfD = Contract for Difference, CDR = Carbon Dioxide Removal

3.3 Rationales for short listed policies

From the assessment and further discussion with the NIC project team, four policy mechanisms were shortlisted to be explored in detailed analysis and design. This included the market-based policy mechanisms ('NE credits in the UK ETS' and 'CDR market with obligations') and two contracted policy mechanisms (dual contract subsidy and CfDc). The criteria ratings shown in Figure 7 provided guidance in this selection process. However, these four policy mechanisms were not selected solely on the basis of their average or above average scoring. Further justification for the selection of shortlisted mechanisms, particularly around their key strengths relative to others, is provided below:

- **Market-based policy mechanisms** ("NE Credits in the UK ETS" and "CDR Market with Obligations")[26]
    - Both policies have the potential to be applied across all engineered GGR solutions with the long-term ability to place costs on emitters via a market for NEs, thereby strictly following the polluter pays principle
    - Additional strengths and limitations of both market-based options are explored in detailed design and analysis (section 4), for example, the difficulty in integrating hard-to-abate sectors in the UK ETS or concerns around market volatility/liquidity in a new compliance market
- **Dual contract subsidy**
    - This policy mechanism effectively shields against market / co-product revenue risks to ensure investor confidence along with the ability to be applied to all GGR solutions[27] which are anticipated to receive low-carbon subsidies for their co-products (in some cases, these subsidies may already be in place, e.g. power sector CfDs for low-carbon electricity)
    - Both payment mechanisms (for the low-carbon product subsidy and the NE service contract) are readily adaptable between FOAK and mature GGR projects with the ability to be administered via competitive auction-based allocations
- **Carbon CfD**
    - This policy mechanism builds off BEIS' proposed industrial carbon capture contract (CfD payment structure for CCUS), providing a simplified contract structure that could be readily implemented and adapted between GGR solutions (e.g. modifications to strike price to account for different costs of GGR technologies)
    - By linking the payment mechanism to a market reference price for negative emissions (i.e. UK ETS or new compliance market), this mechanism has the ability to reduce costs borne by Government over time as the price for NEs increases as the UK approaches net zero and only residual emissions remain in the ETS

Moreover, both contracted policies have the ability to provide sufficient revenue certainty to developers and investors, given both a) the track record of CfDs in the UK and b) their long-term contract lengths (10+ years). Detailed analysis also considers the standalone NE service contract as a policy option, reflecting its nature as an 'edge-case' of the dual contract subsidy (i.e. for GGR solutions without co-products such as DACCS). Lastly, two of the policy mechanisms (competitions and tax incentives) in the long list were also deemed of value to be considered as complementary policies to the primary shortlisted policies. These are included in the wider discussion on potential complementary policies in section 4.7.

[26] Given their shared similarities (e.g. design features, risk mitigation, broader context, and limitations), detailed design considerations of both market-based options were less extensive than the two other contracted policy options.
[27] For DACCS, this policy option would collapse to a single payment structure via a NE service contract.

4 Detailed Analysis of GGR Policies and Support Mechanisms

This section outlines the detailed analysis and design that was undertaken on the shortlisted GGR policy mechanisms. It examines their design features and enabling policies with further discussion provided on the risk allocation of each policy mechanism and broader context which influences each policy's implementation. In addition, this section outlines the potential evolution of each shortlisted policy from FOAK projects to a mature GGR sector. Thereafter, analysis is provided on the market revenue potential of the shortlisted policies, and the additional enabling or complementary policies which might be needed for the policy mechanisms and the GGR sector.

In analysing the shortlisted policy mechanisms, this section first examines the market-based policy mechanisms which could be the preferred long-term solution to incentivise GGRs and ensure hard-to-abate sectors are able to offset their emissions. However, in the near term, due to a range of market failures and project risks, additional policy mechanisms are needed to support the further development and deployment of GGRs. Furthermore, recognising the challenges associated with the market-based policy mechanisms in the short-term, this section then focuses on the contract based policy mechanisms as options to support FOAK projects and a developing GGR sector.

4.1 Market-based policy mechanisms

Design features

In the long-term, standalone regulated NE markets could be the preferred option as they enable NE credits to be traded, driving efficiencies and cost reductions in a mature GGR sector. In addition, standalone markets void of any contracting arrangements enable administrative efficiency by reducing the number of auctioning and procurement processes involved. Furthermore, with the long-term preferred policy approach being to place costs on emitters via a market for NEs, both market-based policy mechanisms achieve this aim. The two market mechanisms considered in this study were:

1. **NE credits in the UK ETS**: Involves adaptation of the UK ETS to integrate NEs. GGR developers would be able to generate NE credits which could be sold in the ETS market.
2. **CDR market with obligations**: Emitters would be required to offset their emissions with obligations to purchase CDR credits within a new compliance market supplied by GGRs.

These market options share some similarities and differences in their key design features:

- **Purchasers of NE credits**: Both market-based mechanisms would need careful design consideration around the purchasers or obligated parties for NE credits:
    1. *NE credits in the UK ETS*: New market regulations would likely need to ensure the volumes of NE credits from GGRs are aligned with the necessary emissions abatement volumes from hard-to-abate sectors. This would help ensure that mitigation deterrence[28] (from existing counterparties in the UK ETS) is not possible.[29]
    2. *CDR market with obligations*: A new market will need to consider which hard-to-abate sectors are obligated to purchase carbon removals. This would likely require adjustments to ensure all sectors with remaining emissions (either unable to abate or cost-prohibitive) are fully integrated and obligated as the UK approaches net zero.
- **Sellers of NE credits**: Both markets require careful consideration of which GGR technologies are able to compete and sell NE credits over time. While this study has focused on engineered GGRs,

[28] Mitigation deterrence is defined here as the unfavourable outcome where sectors which have cost-effective abatement options available are able to purchase low-cost allowances from the UK ETS due to overcrowding from GGRs. Further information about mitigation deterrence can be found in Lancaster University's project on "Assessing the Mitigation Deterrence Effects of GGRs" [LINK].
[29] Guidance on the currently evolving rules and regulated sectors in the UK ETS are being updated by BEIS. [LINK]

there are also a range of potential nature-based carbon removal solutions (e.g. afforestation, soil carbon sequestration) that could potentially produce NE credits. However, there are key differences in the robustness of CO_2 accounting methods and long-term CO_2 storage durability and permanence for engineered versus nature-based GGRs. Moreover, even different BECCS options will require careful accounting methods for their credits (e.g. to accurately account for the biogenic portions of waste fuels or meet biomass sustainability criteria). As a complementary policy, establishing a CO_2 accounting method for GGRs is discussed further in section 4.7.

Broader context and limitations

Inherently, both market-based mechanisms would seek to provide a means for which emissions from hard-to-abate sectors can be mitigated by negative emissions. In doing so, a revenue stream for developers to support GGR projects could be developed. That being said, each market-based policy has some potential advantages and limitations compared to the other (as shown in Table 8). These advantages and limitations have been informed by early stage research and investigations and further detailed analysis and design of the market based mechanisms is recommended.

Table 8: Advantages and limitations of the two market-based policy mechanisms for GGRs

Policy	Advantages	Limitations
NE credits in the UK ETS	• Potential to reduce initial setup complexity as existing market mechanisms are in place and would require adaptation or integration of NE credits • Key learnings could be gathered from other markets which already have carbon offsetting mechanisms in place (e.g. New Zealand[30])	• Careful design of regulatory measures is likely needed to ensure the market does not treat NEs and emissions reductions as substitutable (except for hard-to-abate sectors), leading to mitigation deterrence[28] • Risk of leading to significant carbon price volatility or crash in prices of the current carbon market for emissions abatement[31]
CDR market with obligations	• Obligated "emitters" could include upstream fossil fuel producers to offset a fixed percentage of CO_2 contained within their fuel sales[32] • Government can mandate annual obligations with reduced complexity to align GGR targets with net zero	• New regulatory framework would need to be set up, which would be unfamiliar to GGR developers and investors • May require greater time and resourcing spent on developing a new market, along with informing market participants about its structure and regulations

Risk considerations

With standalone market-based mechanisms to support GGRs, the private sector would be taking on a significant portion of the revenue risk, particularly for FOAK projects. This is largely due to the uncertainty over the stability of the price of credits over the lifetime of a GGR project, reducing certainty to developers and investors around their anticipated revenues and rates of return. Moreover, the markets could be subject to issues around market liquidity and volatility, particularly around earlier years where there are fewer market participants and volumes of credits being traded. In addition, there are risks associated with regulating greater supply than demand in the market. This could lead to dampening of the NE market price if greater volumes of GGRs are introduced compared to obligated hard-to-abate sectors. However, to mitigate against these risks,

[30] New Zealand's ETS allows for the purchase of international offsets via importing Kyoto Protocol emissions units.
[31] A similar outcome occurred in New Zealand's ETS in 2011. The government allowed organisations to meet emissions reduction obligations through less expensive international carbon removal credits, leading to a carbon price crash in the ETS.
[32] For example, this could be through a carbon takeback obligation (CTBO). The CTBO has been proposed by Net Zero Oxford and Climateworks Foundation as a means to incentivise GGR development. [LINK]

the mechanism need not be set up as a spot market. Instead, GGR providers and buyers could enter into long-term contracts or hedge offset prices to reduce the risks associated with volatility in future NE market pricing.

A new compliance market may be seen as riskier for developers and investors for FOAK GGR projects. This is partly due to the fact that a new market would require a new set of market regulations and rules governing its operation, impacting market participants and credit pricing. Conversely, the UK ETS may be deemed less risky and able to provide greater revenue certainty given the previous track record of the EU ETS in successfully incentivising emissions abatement through an increasing carbon price. Nonetheless, the UK ETS still faces significant uncertainty of its carbon price into the future as we approach net zero.

There is also a wider risk with introducing market mechanisms too early. By exposing high-cost GGR technologies to market mechanisms for FOAK deployment, this could lead to insufficient demand-pull to drive engineered GGR commercialisations at scale. In addition, given the existing price differential between UK ETS allowances and GGRs, there is the risk that only lower-cost technologies are adopted. The challenge is that there is a need to 1) drive FOAK deployment of high cost, lower TRL GGRs given the paucity of low cost, higher TRL GGRs and 2) reduce the cost of lower TRL GGRs through technology learning. It is unlikely that a market-based mechanism can achieve these two aims.

4.2 Dual contract subsidy

Design features

The dual contract subsidy combines a low-carbon product subsidy, either new or existing, with a negative emissions (NE) service contract to form a single policy mechanism. This is represented in Figure 8 which shows the combined revenue streams for a GGR project receiving a dual contract subsidy.

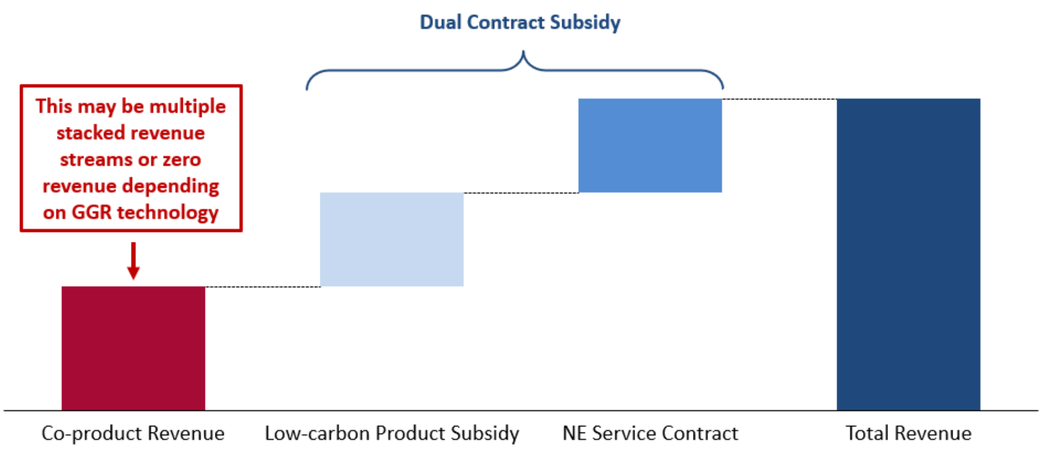

Figure 8: Illustrative stacked revenue streams for a GGR project receiving the dual contract subsidy

The key design features which this policy mechanism would need to account for include:

- **Contract length**: Ideally, lengths for both contracts (low-carbon product subsidy and NE service contract) would be aligned to reduce complexity for project developers and investors. For new build GGR projects, there is greater likelihood of both contracts to start at the same time the new plant is commissioned or is operational. Conversely, for GGR projects which involve CCS retrofitting it is reasonable to assume different contract lengths for the NEs if an existing plant is already receiving a low-carbon subsidy. For example, an existing plant receiving a low-carbon subsidy may choose to retrofit CCS in the middle of a 10 or 15 year contract. In this case, the NE service contract length could be designed to cover an agreed return on investment for the CCS plant up to the expiry of the subsidy or extending beyond the subsidy's expiration, the latter likely resulting in reduced £/tCO_2 payments over a greater time period.

- **Incentive level of low-carbon product subsidy**: While falling outside the scope of this study, Government would need to ensure that any value given to a low-carbon product is appropriately aligned with approved level of costs to reach net zero in specific sectors. For example, the incentive provided to hydrogen production via BECCS might subsidise up to the lowest cost route to produce low-carbon hydrogen relative to production via a counterfactual route (i.e. steam reforming without CCS). This incentive may also need to be capped and follow a reference or market price (e.g. strike price for CfDe relative to wholesale electricity price) to ensure value for money over time to Government. Regarding delivery of the low-carbon subsidy, an auction-based or market-linked allocation could be used to promote competition in an effort to award lower subsidy values.
- **Incentive level of NE service contract**: The incentive provided by the NE service contract (in payments of £/tCO_2 captured and stored) is likely to require differentiation between GGR solutions, at least initially. This is because of the varied range of costs to retrofit CCS or construct new build GGR plants (see section 2.1) and the different incentive levels that the low-carbon product subsidy would be providing. In the medium to long term, the value of the NE service contract should reflect the value to society for producing negative emissions (i.e. aligned with cost of abatement in hardest-to-abate sectors). However, for FOAK GGR projects, variations of NE service contracts are likely needed to incentivise commercialisation across a range of nascent technologies.

Enabling policies

Inherently, the dual contract structure requires an existing or implementable low-carbon product subsidy (e.g. co-product CfD or other subsidy mechanism). Examples include:

- Power contract for difference (CfDe) for low-carbon electricity generation, which could be applicable to power or EfW BECCS plants.
- Subsidies for low-carbon hydrogen or other biogenic fuels produced with CCS (i.e. biomass or waste gasification technologies) and subsequent processing of syngas. Commercial models to support low-carbon hydrogen are currently under development by Government.
- Subsidies for low-carbon manufactured goods in industry (e.g. cement, paper products). As the UK is currently proposing an industrial carbon capture contract (similar to a CfD) for these sectors, this may be one of the potential low-carbon subsidies industry takes advantage of.

This is not an exhaustive list as it is likely that bespoke dual contract subsidies would need to be created on the basis of any other subsidy that the GGR technology solution is receiving. This would ensure the NE service contract is appropriately designed to account for the costs and revenues already being received by low-carbon or carbon neutral processes.

Broader context and limitations

The dual contract subsidy is limited to engineered GGR solutions which produce co-products eligible for a low-carbon subsidy (in addition to producing negative emissions). This means that under this policy mechanism, DACCS would not offer the option for a dual subsidy contract and instead would revert to a sole NE service contract. Conversely, GGRs which have more than one co-product and associated revenues may fall under an ‘X’ contract subsidy, where ‘X’ refers to the number of subsidies or revenues (e.g. an EfW plant receiving a subsidy for low-carbon electricity and revenue from gate fees for disposing of waste).

While theoretically implementable, an ‘X’ contract subsidy would provide greater administrative requirements compared to a standalone policy with a single contract. From stakeholder engagement conducted for this study, it was expressed that the financial/investment community would favour a policy option with greater simplicity. Conversely, the dual contract subsidy would likely result in increased complexity for developers and investors given the multiple funding/revenue streams involved.

Risk considerations

The low-carbon product subsidy provides a key strength for the dual contract policy mechanism. GGR developers and financiers are shielded from the market risks associated with co-product revenue streams with the low-carbon product subsidy providing an additional incentive (e.g. for electricity, hydrogen/fuels, or manufactured products). For example, a co-product CfD would provide assurance to investors that the co-product maintains its value over the contract length for every unit sold to the market (e.g. in £/MWh or £/tonne), despite the uncertainty of market pricing into the future.

On the other hand, the NE service contract (with costs likely placed on Government, at least initially), results in Government taking on additional risks. Some NE service contracts may end up overcompensating GGR projects if they run through the same time period in which a market-based mechanism for NE credits has been developed or is under development. Thus, Government may be contracted to pay a full amount for the value of the NEs instead of being able to pass costs onto the market.[33] Conversely, auctioning contracts for both the low-carbon product subsidy and NE service contract could avoid this inability to drive down costs. However, auctioning dissimilar contracts would have greater administrative complexity, particularly due to the different co-products generated by GGRs.

4.3 Carbon contract for difference

Design features

A carbon contract for difference (CfDc) would be used to provide a subsidy above a prevailing market price for negative emissions up to a contractually arranged strike price in £/tCO_2. This is represented in Figure 9 which shows how the CfDc mechanism would operate in circumstances where the market price is both below and above the strike price (i.e. low and high price scenarios). The exact circumstances that would drive the NE market price above the GGR costs are still uncertain, however, some potential drivers could be expected. These include an insufficient supply of GGRs participating in the market, GGR plants with unplanned outages, sudden demand for offsets (e.g. introduction of agriculture in market), or time lags for increasing GGR capacity.

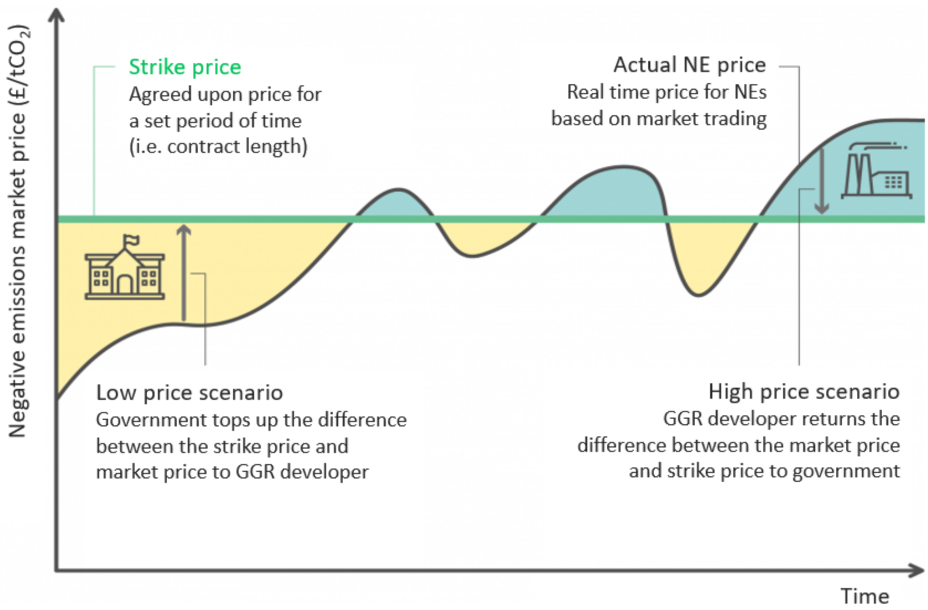

Figure 9: Illustrative diagram from the CfDc policy mechanism[34]

[33] There is potential to mitigate against this risk by adjusting the NE service contract to a CfDc in a more mature GGR sector (see section 4.5 for further discussion on the potential policy evolution of the dual contract subsidy).
[34] Image adapted from the CFM Traction project. [LINK]

In contrast to the dual contract subsidy, the CfDc policy mechanism would not have a direct subsidy for any GGR co-products. However, the GGR solutions themselves may be operating in sectors in which subsidies are indirectly providing a revenue benefit (e.g. low-carbon hydrogen markets supported by government subsidies for consumers). The key design features of the CfDc policy mechanism are summarised below:

- **Contract length:** The length of the contract payments could be similar to existing CfDs (e.g. 15 years for low-carbon power CfDs) to provide sufficient revenue certainty over the majority of a GGR project's operational lifetime. However, the contract period could be adjusted for different GGR technologies, on the basis of technology lifetime but also due to unique circumstances for each GGR technology solution. For example, revenue generation from some GGR solutions may be anticipated to scale-up earlier than others (e.g. demand for low-carbon hydrogen or other fuels in 10 years). While the investment community engaged with in this study supports long-term contracts, Government could seek to find an optimal contract length that provides value for money whilst ensuring investor confidence.
- **Carbon strike price**: The value of the strike price may need to align with the additional costs of producing negative emissions relative to the counterfactual technology without CCS (excluding DACCS which does not have a counterfactual in this circumstance). In most circumstances, this includes the added costs of adopting CCS retrofits, but can also be the total cost for new build plants or DACCS plants. A single strike price could cover all the additional incentive that a plant may be receiving. Regarding delivery of the mechanism, an auction-based allocation could be used to promote competition between GGR projects to achieve lower strike prices being awarded.
- **Price-indexing (optional feature)**: Since the CfDc does not shield against other market risks (e.g. electricity price), price-indexing could be used in the contract design to adjust the strike price over time. While adding more complexity to the policy design, this would assure developers and investors that variations in revenue received from co-product markets do influence the level of subsidy that GGRs receive. In addition to the sale of co-products, strike price indexing could also apply to the costs of the input requirements of a GGR plant (e.g. DACCS plants purchasing electricity from the wholesale electricity market). It is important to note this is deemed an optional design feature as GGR plants may have other contracts in place which shield them from these market risks (e.g. vertically integrated biomass supply chains).

Enabling policies

The CfDc contract would require an additional policy mechanism which has set up an appropriate NE market to provide a reference price. This could be either of the other shortlisted market-based policy mechanisms (see section 4.1):

1. Integration of NE credits in the UK ETS
2. New compliance market for CDR with obligations

Structurally, the CfDc would not change whether the first or second market-based option is used in the future, as both could be linked to the contract similarly to how an existing power CfDe is linked to the wholesale electricity market. However, there may be unintended consequences in the value of NEs in either market option which would influence the value of NE credits over time (e.g. market liquidity and volatility). This would inherently have direct impacts on the CfDc policy, which would seek to improve value for money over time as a market reference price for NEs increases.

Broader context and limitations

The CfDc succeeds in its simplicity as a single contract mechanism that could be applied to all of the engineered GGR technologies explored in this study. While this is valuable, this also means that the CfDc does not have the ability to directly fund the co-products of GGRs through a dedicated funding source (e.g.

consumers funding low-carbon electricity or fuels through co-product CfDs). The exact distribution of funding could still be integrated into the CfDc's subsidy level, for example via consumers levies plus government (taxpayer) funding. Further considerations on funding GGR investment are being explored by the NIC in a complementary study to this work.

Most importantly, the CfDc is limited by the availability of a prevailing market price for NEs. This is a key issue for Government to consider in the design of any potential FOAK CfDc contracts. If a market-based policy mechanism was not in place by the time CfDc contracts were being considered for GGR projects under development, then this could result in delayed implementation (i.e. until the NE market is setup) or higher payments in earlier years (i.e. through paying the full strike price or using an agreed non-market based reference price). Another option could be for Government to own and accumulate the NE credits before a market is set up, later selling the NE credits into the market once it is fully operational.

Risk considerations

A CfDc would place the risks associated with the NE market price on Government. These are risks associated with the volatility and trajectory of the NE market price over time, which could arise from failed regulatory measures (e.g. insufficient participation by purchasers of NEs) or due to demand decreases (e.g. mitigation of hard-to-abate sectors). In the event of such market risks materialising, Government may potentially overpay above initial forecasts for some GGR projects should the market price fail to increase over time to equal or become greater than the agreed strike price.

In comparison to the dual contract subsidy, market risks associated with GGR co-product revenue streams (e.g. sale of manufactured products or electricity) sit with GGR developers under a CfDc policy mechanism. This risk could lead to higher rate of return requirements by investors which deem the co-product revenue streams to risky and not effectively shielded by the CfDc strike price. One optional policy lever previously discussed to mitigate against this could be price indexing; however there are other mechanisms that private industry could potentially use to shield against some of these market risks (e.g. long-term fixed price contracts for sales of manufactured products/fuels or power purchase agreements).

4.4 Policy modelling and sensitivities

In order to illustrate the likely impact of GGR policies on project costs, a high-level techno-economic model[35] is used to calculate the levelised costs of capturing and storing one tonne of CO_2 from the atmosphere by DACCS under various assumptions. The full set of modelling assumptions can be found in Appendix 6.4. The CfDc policy was chosen for modelling as it enables an illustrative case study that effectively captures potential NE market revenue along with the revenue changes between a FOAK and NOAK GGR project.

Figure 10 below shows representative costs for a FOAK DACCS plant commissioning in 2030 receiving a CfDc subsidy. The base case assumes that the project cost of capital is 10% for FOAK and 5% for NOAK plants. Project lifetime is 15 years, which is assumed to be the same as the financial lifetime (a typical CfD contract period).

The exact costs of operating a DACCS facility are complex and depend on many parameters. Costs shown here are not intended to accurately represent global or UK DACCS costs. Rather, this section aims to illustrate the change in costs which may be realised under certain policy settings.

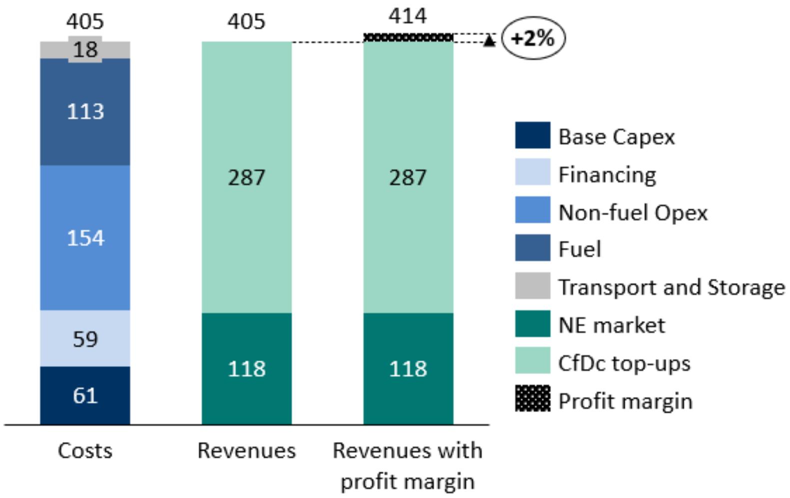

Figure 10: Costs and revenues required for removal of one tonne of CO_2 through FOAK DACCS (£/tCO_2)

Under the CfDc policy mechanism, there are two revenue streams for the project:

1. **NE market** represents an economy-wide price for negative emissions the project would receive if it were freely trading in the market. Prices for negative emissions are estimated from the carbon price projections in The Treasury's Green Book Supplementary Guidance[36] (base case based on the central carbon price estimates).
2. **CfDc top-ups** are the additional financial incentive needed for the project to break even. It represents the policy cost to Government. Although this study shows break-even revenues, in reality GGR projects would be awarded a slightly higher CfDc strike price to make profits. The effect of a 2% profit margin is illustrated in the last stack in Figure 10. This margin would be determined either by bilateral negotiations or through a competitive auction-based mechanism. In the rest of this section, it is assumed that the CfDc policy only covers the basic modelled costs.

Figure 11 shows how the change in the NE market (economy's base carbon price) impacts the CfDc top-up payments needed for a FOAK DACCS project over a 15-year contractual period. The project is assumed to be commissioned in 2030 with the CfDc contract running until 2045.

As the carbon price in the NE market increases with time, additional payments needed reduce directly, assuming that the strike price (the breakeven price) stays constant. This illustrates that although the net cost

[35] Model based on the study Global Assessment of Direct Air Capture. By Element Energy for IEAGHG, 2021 [to be published].
[36] The Treasury's Green Book supplementary guidance table 3 - Link

of a FOAK CfDc to the Government may be significant, the financial burden is expected to reduce significantly with time. In this illustrative example, top-ups may reduce from 80% of total project costs to 52% in 15 years.

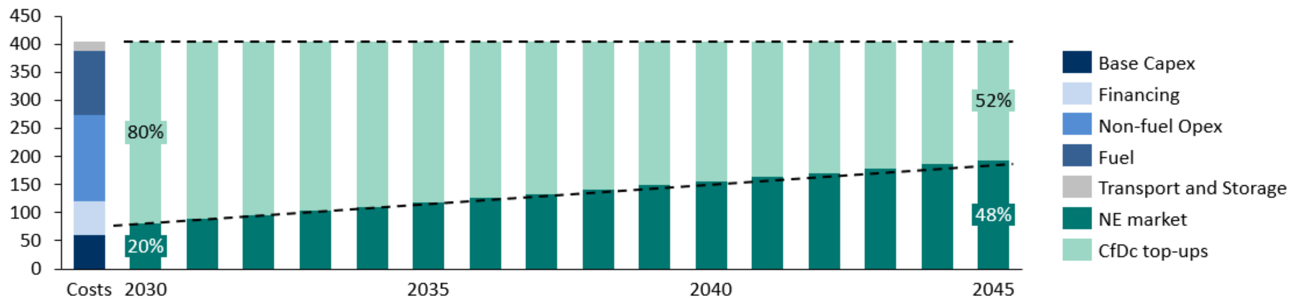

Figure 11: Change in the CfDc top-up payments needed over the 15-year lifetime of a FOAK DACCS project as the base NE market price increases (£/tCO_2)

FOAK project costs

Figure 12 and Figure 13 illustrate the impact of contract period, cost of capital and NE market prices on the costs and thereby required CfDc incentives for financing FOAK DACCS projects.

It is estimated that increasing contract periods from 15 to 20 years can reduce overall levelised costs by 4% and CfDc top-ups by 6%. FOAK plants are not likely to afford to operate only through a NE market price at the end of their CfDc contract period without new incentives or revenue sources. Therefore increasing contract periods may be able to extend asset lifetimes for plants which would otherwise have been decommissioned.

The NE market price of the economy directly impacts required incentives. A 50% change in the NE market price[37] can move top-ups needed by ~21% in either way.

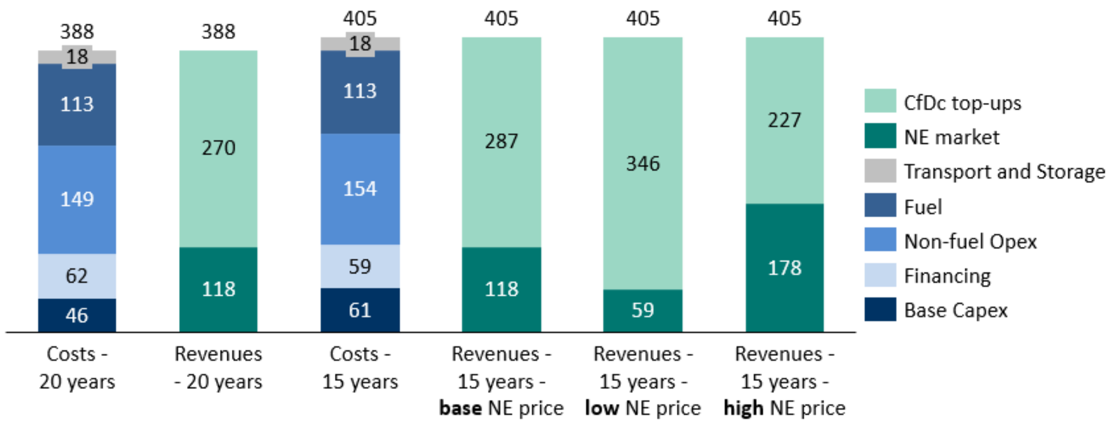

Figure 12: Costs and revenues required for removal of one tonne of CO_2 through FOAK DACCS under different incentive periods and NE market prices (£/tCO_2)

Cost of capital tends to be higher for FOAK plants, where risks are expected to be higher. Guaranteed returns through government policies can reduce these risks, thereby lowering overall costs. For example, additional complementary policies such as capital loan guarantees could be used to achieve lower financing costs (see section 4.7 for further discussion on loan guarantees). A shift from a high cost of capital of 15% towards a lower 7.5% can reduce overall DACCS costs by 6% and required CfDc top-ups by 16%.

[37] Low, central, high NE market prices are based on 2035 carbon prices in The Treasury's Green Book supplementary guidance table 3.

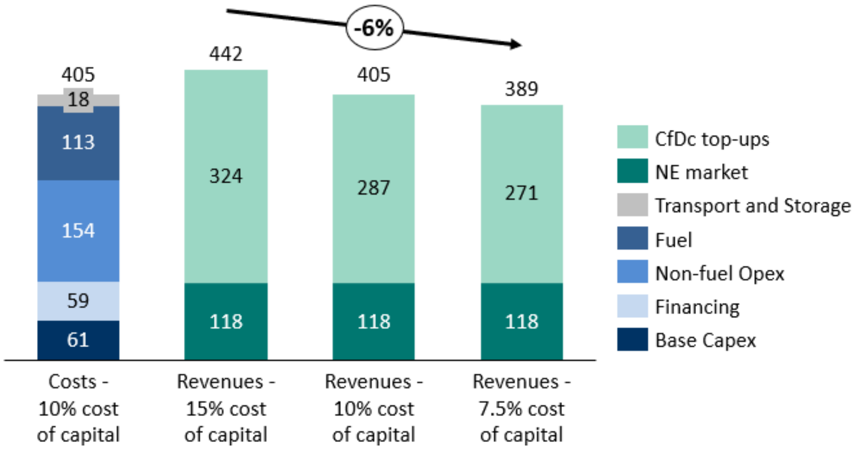

Figure 13: Policy top-ups needed to incentivise 15-year FOAK DACCS projects under different costs of capital (£/tCO_2)

NOAK project costs

NOAK DACCS projects are expected to experience significant cost reduction. In the techno-economic modelling assumptions used in this study[35], the base case cost falls from £405/tCO_2 to £189/tCO_2.

Policy top-ups needed are also significantly lower due to increasing NE market prices[38]. Figure 14 below illustrates the CfDc payments needed in year 2040, however, a NOAK plant is likely to require no additional subsidies shortly after 2040 if base NE market prices increase in line with projections of economy-wide carbon prices.

Increasing the contractual period from 15 to 20 years may reduce CfDc top-ups by a third. On the other hand, NE market prices are found to have a much more significant impact on policy costs. Under a low NE market price, top-ups may triple, whereas a high NE market price may require the plant to pay some of its extra revenues back to the Government.

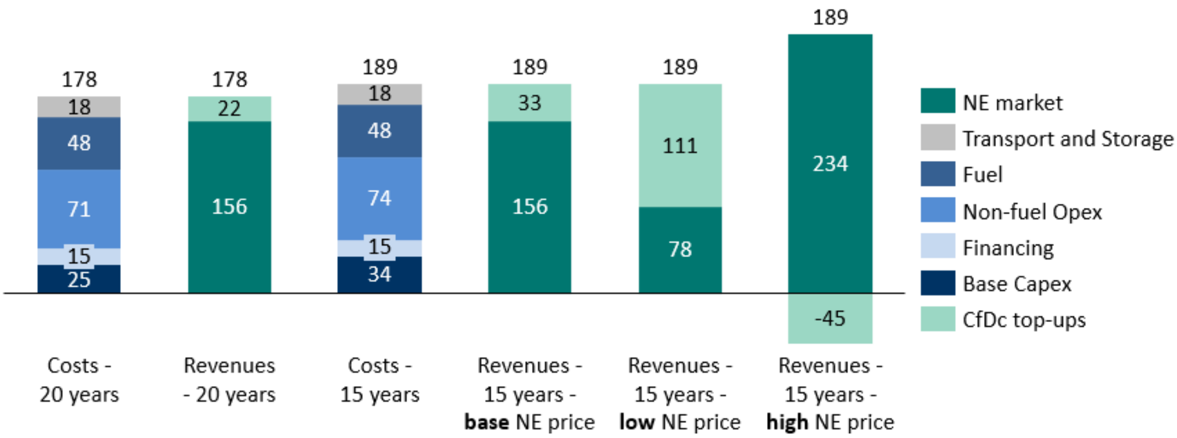

Figure 14: Costs and revenues required for removal of one tonne of CO_2 through NOAK DACCS under different incentive periods and NE market prices (£/tCO_2)

In the mid-to-late 2040s, projected revenues from a NE market may be high enough to cover the full costs of a GGR plant. As shown in Figure 15, the NE market revenues in the 2030s for a FOAK DACCS plant do not make up a significant portion of the total revenue. Conversely, a NOAK DACCS plant commissioned in 2040 may still be receiving a CfDc top-up to cover its costs, although the majority of costs would be covered by the NE market revenue. By 2045, the illustrative NE market price used in this analysis exceeds the costs of NOAK DACCS. Between 2045 and 2050, CfDc top-ups would not be needed based on these market price projections.

[38] Low, central, high NE market prices are based on 2040 carbon prices in The Treasury's Green Book supplementary guidance table 3.

Under these assumptions, any NOAK plants commissioned earlier than 2045 would likely be returning market revenue to government in this later time period since the projected market price would be exceeding the CfDc strike price. In contrast, as previously shown in Figure 11, a FOAK plant which continues to operate into the 2040s would likely still need CfDc top-up support. Additionally, any NOAK plants commissioning after 2045 would likely not take up a CfDc contract and could instead operate purely on market revenue.

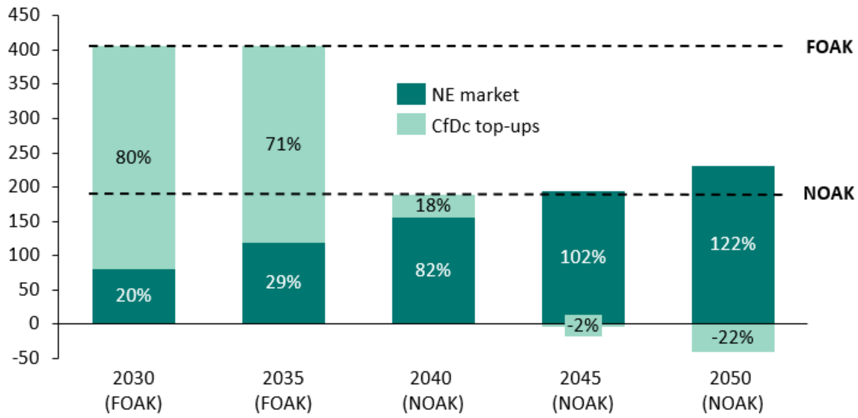

Figure 15: Change in NE market revenue (£/tCO_2) between FOAK and NOAK DACCS projects to 2050 (timeline for FOAK and NOAK costs are illustrative)

Overall costs of capital for NOAK projects are expected to be lower than FOAK since the technology and the business model would be better understood at this point. As shown in Figure 16, if policy certainty can reduce cost of capital from 7.5% to 2.5%, carbon removal costs may reduce by 4%, which would have a rather significant impact on CfDc top-ups (40% reduction).

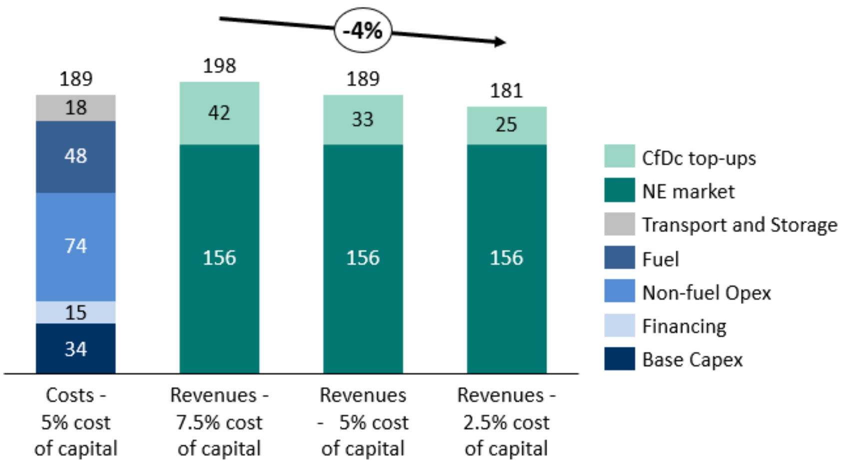

Figure 16: CfDc top-ups needed to incentivise 15-year NOAK DACCS projects under different costs of capital (£/tCO_2)

Sensitivities

Figure 17 and Figure 18 present tornado graphs summarising the sensitivity of required CfDc top-ups to the different parameters evaluated in this section. For FOAK projects all 3 parameters (NE market price, contract length and cost of capital) are relatively influential on CfDc top-ups, therefore efforts to improve all 3 would be beneficial to reduce costs to the Government. CfDc top-ups for NOAK plants are highly sensitive to NE market carbon prices, as they are expected to equal a large portion of DACCS costs in the late 2030s and 2040s. Therefore, even small differences percentage-wise would have large impacts on public spending needed. Contract length and cost of capital are still valuable tools to help NE markets meet most of DACCS costs.

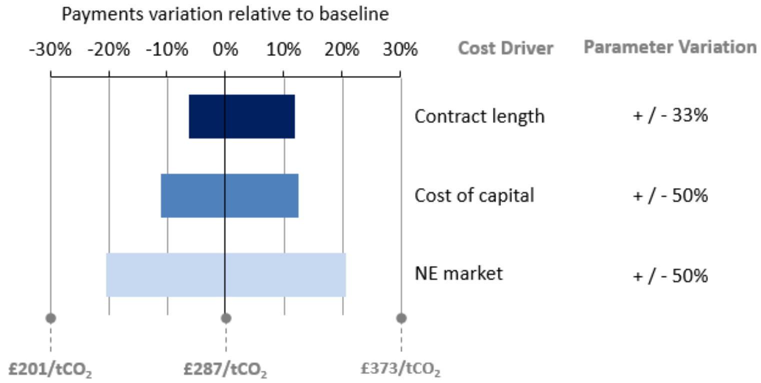

Figure 17: Sensitivity of CfDc top-ups needed for FOAK DACCS projects to various parameters

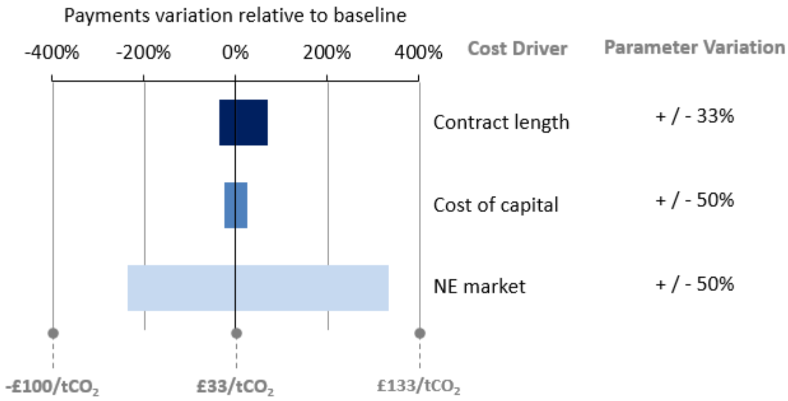

Figure 18: Sensitivity of CfDc top-ups needed for NOAK DACCS projects to various parameters

4.5 Evolution of the policy mechanisms

This section outlines potential evolutions of each policy mechanism in the transition from FOAK projects to a more mature GGR sector. Additional information is provided on the applicability of policy mechanisms to FOAK projects or a mature sector more generally, along with discussion on potential future linkages between the shortlisted policy mechanisms.

Market-based policy mechanisms

The two market-based mechanisms would share many of the same design features, making their applicability to FOAK and mature GGR projects similar.

- **FOAK projects**: As standalone mechanisms, the market-based policies would unlikely be able to support FOAK GGR projects. As previously discussed, this would be due to the initially low and volatile price of negative emissions in each market, leading to significant revenue uncertainty for GGR developers and investors. It is assumed that any future GGR policy approach would require additional contract-based subsidies or government incentives to support a new sector.
- **Mature GGR sector**: Both market-based mechanisms could be well integrated by the time a mature GGR sector is under development. It is reasonable to assume that for a mature GGR sector, sufficient market liquidity could be provided as demand for carbon removals grows as the UK approaches net zero emissions in 2050. This could further drive market competition between GGR developers, incentivising cost and technology improvements even further in a mature sector.

Compared to the two contracted based policy mechanisms, the trajectory of either market-based option between FOAK projects and a mature sector need not involve fundamental design changes to the market. More than likely, over time the adjustments will need to focus on which hard-to-abate sectors (e.g. aviation, agriculture, etc.) are introduced into the market and to what extent (e.g. by reducing free allowances as the UK approaches net zero emissions in 2050).

Dual contract subsidy

This policy is well-suited for FOAK GGR deployment as many low-carbon product subsidies are already in existence or are under development. This would then require additional effort by Government to setup an integrated NE service contract for the different GGR solutions. Additionally, this policy could be adapted for a mature GGR market, provided both contracts can move towards competitive allocation mechanisms (e.g. auctioning). However, there are added complexities with auctioning a dual contract (i.e. auctioning both a low-carbon subsidy and NE service contract together versus separately) and the additional uncertainty of mature GGR solutions receiving low-carbon subsidies. The schematic below provides a possible evolution trajectory for the dual contract subsidy policy mechanism.

- A bilaterally negotiated dual contract is likely for FOAK projects where existing plants are already receiving a low-carbon product subsidy with the potential to adopt CCS or there is limited competition for FOAK deployment (e.g. due to limited number of industrial / EfW sites in clusters with CCS infrastructure access)
- The NE service contract could be negotiated between Government and developers to cover the additional costs for the plant transitioning to a GGR (i.e. costs of CCS retrofit and wider plant-wide system integration)

- Both contracts could move to a combined auction-based mechanism (e.g. co-product CfD plus NE service contract) or independently auctioned, although the latter is likely to increase complexity for project developers and financiers
- Competitive allocation could be used to kickstart a mature GGR sector or promote lowest-cost deployment for specific GGR solutions (e.g. multiple EfW plants competing for NE service contract)

- In a mature GGR sector with a developed market for NEs (e.g. credits in UK ETS), the NE service contract under this policy option could be replaced by a CfDc
- Instead of a flat-rate payment for NEs, only the top up to the CfDc strike price would be required, reducing the costs borne by Government over time
- The CfDc could also be allocated via an auction-based mechanism, similar to a NE service contract

Note this is not the required or only possible evolution of this policy option. For instance, step 2 could be skipped and the dual contract subsidy could transition to a CfDc in place of the NE service contract if a market for NEs is developed in advance of the GGR sector maturing. Similarly, while bilateral negotiations are likely for step 1, a competitive allocation mechanism could be used if the currently limited number of GGR developers/plants increases ahead of FOAK deployment.

Carbon contract for difference (CfDc)

The CfDc mechanism could support FOAK projects, although there is the possibility that a reference price based on a functioning market price for NEs would be unavailable in the 2020s. If used without an available market price, this would require paying the full strike price prior to market linkage or assuming a non-market reference price in earlier years. As a single contract-based subsidy, the CfDc is readily capable of supporting a mature market by transitioning to an auction-based mechanism (i.e. similar to CfDe's supporting low-carbon electricity generation). The schematic below provides a possible evolution trajectory for the CfDc policy mechanism.

- It is likely, but not necessary, for FOAK GGR projects to be awarded CfDc contracts via bilateral negotiations – particularly for GGR solutions where there are a limited number of developers able to meet FOAK deployment timeframes in the UK (e.g. power BECCS in late 2020s) or limited number of industrial / EfW sites in clusters with access to CCS infrastructure
- The contracted strike price may require agreements to be in place that guarantee the full value of the subsidy in the event that a reference or market price for NEs is unavailable for FOAK projects

- A CfDc contract could move to a competitive auction-based mechanism, which is familiar for developers and investors in the UK (e.g. biomass generators competing for power CfDs for low-carbon electricity generation)
- Competitive allocation could be used initially to promote competition and innovation in specific GGR solutions, e.g. energy from waste plants competing for lowest cost retrofits or DACCS plants competing for lowest cost new builds

- In a mature GGR sector with successful commercialisation across multiple GGR solutions, the CfDc's auction-based mechanism could pool multiple (or all) engineered GGRs together to promote the most cost-effective negative emissions solutions
- While likely that a mature sector will also involve nature-based GGRs, careful design considerations would need to be in place if competing with engineered GGRs for CfDc contracts due to differences in CO_2 storage durability, permanence, and accounting

Note this is not the required or only possible evolution of this policy option. For instance, step 1 could be skipped if there are enough developers competing for CfDc contracts in specific GGR solutions and Government is able to implement an auction-based mechanism for FOAK projects.

4.6 Market revenue generating potential

Beyond thinking about policy support for GGRs, it is important to recognise and analyse the potential for other avenues to generate market revenue for GGR technologies. This market revenue would be in addition to any revenue received from future regulated markets for NEs, which has been explicitly covered as one of the shortlisted policy mechanisms in section 4.1.

GGR co-product revenue

As previously shown in Table 4, most GGR technologies have the potential to recoup costs from a range of co-products, with the likely exception of DACCS which has no (or limited) co-products. This section sets out some additional considerations around the potential revenue from these co-products, particularly as the UK progresses towards being a net zero economy.

Electricity	Power and EfW BECCS plants both produce electricity, typically at baseload or near baseload operation. It would be anticipated for power and EfW BECCS plants to continue running at high utilisation factors to ensure they are able to generate necessary and predictable volumes of negative emissions. As such, the revenue from electricity generation will face similar wholesale power market risks as other low-carbon generation methods (e.g. baseload nuclear plants) if the plants were to continue operating in the decades to come.
Waste	EfW plants (as well as potentially waste gasification plants which produce hydrogen or other fuels) with CCS implemented can be considered as BECCS due to the biogenic emissions contained within the organic portions of waste they process. Such plants are paid a gate fee for processing this waste (i.e. in £ per tonne of waste) often paid by local authorities as a means to avoid sending waste to landfill. While projections of future amounts of waste processing are uncertain, it is highly likely that gate fees will still be used to incentivise waste collection in a net zero economy.
Hydrogen / other fuels	Markets for low-carbon hydrogen or other fuels (e.g. biogas, bioethanol) are nascent and growing. It is likely that in the near-term, these fuels will require subsidies to ensure they remain cost-competitive with counterfactual fossil fuels in industrial fuel switching or automotive applications. However, as carbon prices increase and the costs of fossil fuels are internalised, it is likely that revenue from sales of low-carbon fuels will be increasingly sourced from fuel consumers through low-carbon fuel supply contracts.
Manufactured goods	Similar to fuels, markets for low-carbon manufactured products (e.g. cement) are in early stages of growth. While some governments are considering or have already put in place green public procurement programs (e.g. to limit emissions associated with public building or infrastructure projects[39]), these market drivers have yet to reach the scales necessary to drive deep decarbonisation of manufacturing sectors. As carbon prices continue to rise and regions consider placing border tariff adjustments on globally competitive sectors[40], this will further incentivise the sale of low-carbon products, allowing industrial GGRs such as cement BECCS plants to secure greater revenue certainty.

[39] For example, California's Buy Clean California Act requires state-funded building projects to meet global warming potential limits (CO_2-eq) for construction materials such as steel, glass, and insulation. [LINK]
[40] As part of the EU Green Deal, the EU is considering a carbon border adjustment mechanism. [LINK]

In summary, the same level of co-product revenue is generated under each of the short-listed policy options. However, given the **dual contract subsidy's** direct linkage with a low-carbon product, it is likely for co-product revenue to be more easily integrated into the policy mechanism. Conversely, a **CfDc contract** would likely require additional integration steps to ensure the strike price is aligned above revenue generated from GGR co-product markets.

Voluntary offset markets

This study has identified voluntary offset markets for their potential to increase the revenue generating potential for UK-based GGRs. In comparison to a compliance or regulated market for negative emissions, voluntary offset markets enable businesses or individuals to offset carbon emissions. Typically these purchases have been historically used to showcase sustainability strategies and public relations efforts by businesses which seek to show their ambitious response to the climate change challenge. However, the emissions abated in voluntary offset markets are not exclusively emissions associated with hard-to-abate sectors. This has resulted in a wide range of programs, entities, and standards for the operation of voluntary offset markets. Similarly, the pricing of voluntary carbon offsets is influenced by many factors (e.g. project type, location, co-benefits), with differences in price not always truly reflective of precise quantities of negative emissions.

However, initiatives such as the Taskforce on Scaling Voluntary Carbon Markets[41] are aiming to generate increasing demand and transparency around carbon offsets to ensure business models around voluntary trading are aligned with goals of the Paris Agreement. Given their momentum, greater corporate activity is expected to develop in voluntary offset markets as they continue to develop higher quality standards and protocols to improve the credibility of individual credits' negative emissions potential. In relation to this study, engineered GGRs have the potential to achieve significant scale as they begin to compete as suppliers in voluntary offset markets. While it is unlikely for voluntary offset markets to provide sufficient revenue certainty by themselves, there exists long-term circumstances where a UK-based GGR project could receive a portion of their revenue from businesses seeking to purchase large scale and permanent carbon offsets.

This study has identified the potential for one of the shortlisted policies to interact with a voluntary offset market. Under the dual contract subsidy, which does not interact with a potential future compliance market for carbon removals, there are two potential routes for which revenues from voluntary offset markets could be incorporated into the overall policy mechanism (as shown in Figure 19)[42]:

1. **GGR developer owns and sells the NE credit on a voluntary offset market**. In this scenario, GGR developers would be actively encouraged to sell their NE credits to private companies. Since the GGR developer is already receiving a service contract for the NEs, Government could incentivise developers to sell credits by allowing developers to keep a percentage of the revenue from the voluntary offset market. The remainder of the revenue could be returned to Government. This option would require specific design features in the dual contract subsidy to allow for such an incentive scheme to operate effectively.

2. **UK Government owns and sells the NE credit on a voluntary offset market.** Conversely, Government could mandate that any GGR developer receiving a NE service contract would need to transfer ownership of their NE credits to Government. This would allow Government to engage with the voluntary offset market directly. In doing so, Government could sell NE credits directly to corporates to recoup costs spent in procuring GGRs through the NE service contract. This option may be attractive to Government as they would be able to receive the full value of any voluntary offsets sold. However, this comes with the added administrative and resourcing requirements to own and sell credits on a private market.

[41] For further information on the Taskforce on Scaling Voluntary Carbon Markets: [LINK]

[42] In both options, any NE credits sold on a voluntary offset market are assumed to be sold to UK businesses. This is avoid double counting NEs in both the UK and another jurisdiction/country.

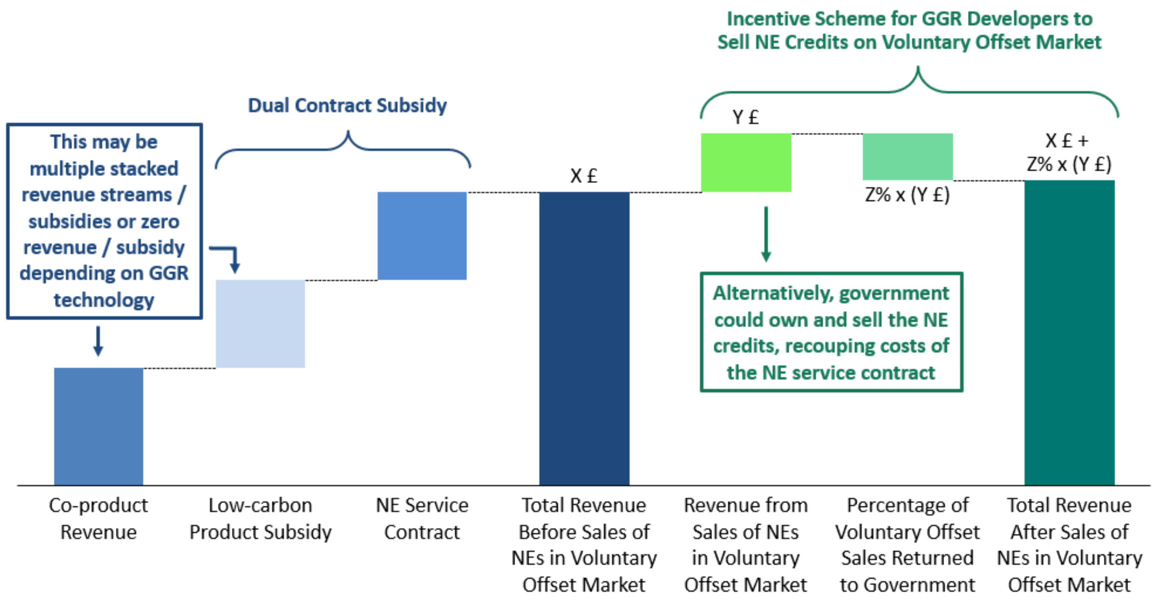

Figure 19: Potential incentive scheme for voluntary offset market integration with a GGR developer receiving the dual contract subsidy

If the CfDc policy mechanism is used in the future for incentivising GGR deployment, projects with a CfDc contract are unlikely to be able to interact with a voluntary offset market. This is because the GGR project would already be trading their credits on a regulated market for NEs. In effect, double counting NE credits on both a regulated market and voluntary offset market in the UK would not be possible. This implies that voluntary offset markets would not be compatible with any GGR trading on a regulated market based mechanism for NEs, such as those proposed as shortlisted policies in this study. However, GGR developers could still seek avenues to begin integrating with a private market post-CfDc contract should this be deemed a more lucrative revenue stream for investors.

In summary, the ability to integrate revenue from the voluntary offset market is only deemed possible in the dual contract subsidy (under the design assumptions used in this study). However, it may be possible in the future for regulations to allow GGRs incentivised by a CfDc linked with a regulated market to opt-out of the contract to participate in a voluntary offset market or switch to using a private voluntary offset market as the reference price.

4.7 Complementary policies

This section covers complementary policies which could be used to support the main policy mechanism. It is worth noting that these are additional policies that could be considered for implementation and are not deemed essential. Some of these policies could also be considered as additional design features for the shortlisted policies. This is highlighted in the respective descriptions where this may be the case.

Co-investment

Government could seek to co-invest on GGR projects, particularly for FOAK plants, with the private sector. This complementary policy would help with three important aspects for the deployment of GGRs: (1) to reduce the cost of capital for developers, (2) achieve greater success rates for final investment decisions, and (3) crowd in private sector financing into the GGR sector. A concrete strategy for co-investing in GGRs would reduce investors' hesitancy and further drive confidence for investing in new GGR technologies at-scale.

The recent establishment of the UK Infrastructure Bank (UKIB) is anticipated to drive a significant portion of co-investment in climate related infrastructure projects.[43] By aligning with the strategies of the UK Government's Ten Point Plan for a Green Industrial Revolution[44], the UKIB can capitalise on key growth markets towards net zero, including the nascent GGR sector. Co-investments in GGRs could be further aligned with social co-benefits (e.g. growth in local economies and supporting jobs in transition from legacy industries such as the oil and gas industry). Underpinning all co-investment decisions, it will be important for the UKIB (or other potential government institutions) to support projects with specific metrics that measure success towards a net zero economy (e.g. cost-effective negative emissions per year).

Competitions

Competitions for grant funding can be integrated as complementary policies in a broader definition than that considered for the long list of standalone policy mechanisms. In section 2.3.3, competitions were defined as government interventions to provide upfront grants to pull through low TRL technologies in development phase across the commercialisation cycle towards demonstration and at-scale plants. In this context, the UK Government is already running a competition for DACCS and GGR technologies, for which 24 projects recently received between £75K-£250K in funding for developers to complete detailed designs of their GGR solution.[45]

As we have seen in the past, funding competitions can be a valuable tool for developing larger scale projects. For individual GGR plants however, these may not be able to provide value for money if there is large government expenditure involved. A familiar example is the UK's previously proposed £1bn CCS competition, which was cancelled in 2015, six months before the funding was due to be awarded. Any future competitions would need to be well-designed and learnings from the past considered. For example, competitions are currently being used for the targeted deployment of CCUS infrastructure in the UK's industrial clusters.[46]

Loan and credit guarantees

The high upfront capital investment requirements and relatively unproven technologies and business models of large-scale GGR technologies make FOAK project financing particularly difficult. One mechanism to help alleviate this problem is a government backed loan or credit guarantee scheme, where the Government agrees to pay back the project loans regardless of its successful operation. Such a guarantee considerably reduces the risk premium of projects, unlocking lower cost finance. This would be particularly valuable for FOAK projects with unproven at-scale technologies or projects exposed to higher commodity market risks.

The UK has an active Guarantees Scheme (UKGS) for 'nationally significant' infrastructure projects, with a particular focus on energy and the environment. The scheme was operated by the Infrastructure and Projects Authority until recently, but now the function is being transferred to the UK Infrastructure Bank (UKIB)[43]. UKIB is tasked to co-invest and use the UKGS tool to unlock significant private investment into climate and sustainability related infrastructure projects. Inclusion of all aspects of BECCS and DACCS supply chains in these schemes would be valuable complementary policies to those shortlisted in this study, by increasing the bankability of early GGR projects.

Price indexing

Given the market risks faced by GGRs, price indexing could be considered as an additional design feature to the various payment structures of the shortlisted policy mechanisms. In this study, price indexing refers to adjustments to contract payments (e.g. £/tCO_2) relative to the costs (typically fuel costs) faced by a GGR developer. For example, two specific cases where price indexing could be considered might be:

1. *BECCS projects purchasing biomass from the global biomass market*. Biomass prices are subject to volatility as the world approaches net zero and further regulations continue to constrain the use of

[43] Policy Design of the UK Infrastructure Bank (HM Treasury, 2021) [LINK]
[44] Ten Point Plan for a Green Industrial Revolution (UK Government, 2020) [LINK]
[45] As part of Phase 1 of BEIS' DACCS and GGR competition (May 2021). In Phase 2, a selected number of projects from Phase 1 will be awarded up to £5m in funding for demonstrating and piloting their GGR solution. [LINK]
[46] Cluster sequencing for carbon capture, usage and storage (CCUS) deployment: Phase-1 (BEIS, 2021) [LINK]

sustainable biomass. BECCS developers are therefore subject to the risk of long-term price changes in the growing biomass market.

2. *DACCS projects purchasing electricity from the wholesale electricity market*. The UK's wholesale electricity market is undergoing rapid decarbonisation with uncertainty in future power prices. DACCS plants which require significant volumes of electricity are therefore subject to the risks of volatility in the energy cost over the plant's lifetime.

It is important to recognise that it may be possible for GGR developers to mitigate against these market risks by other means (i.e. by supply chain integration with biomass sources or long-term power purchase agreements from renewables). Careful consideration would need to be given to certain GGR solutions and developers to determine in which cases price indexing would be a valuable policy design feature.

Availability payments

Availability payments made to GGR operators in case of an outage of CO_2 T&S infrastructure may be a powerful tool to mitigate the cross-chain risk observed in most CCS based projects. Cross chain risk refers to the risk of all the companies associated with a carbon capture and storage chain to potentially halt operations if one component cannot work properly for some reason. This may occur if one of the companies fails to commission the project in time or experiences a technical difficulty during the project lifetime. CCS clusters partially mitigate the cross-chain risk by increasing the number of CO_2 capture companies sharing CO_2 T&S infrastructure, however, defaulting by the T&S company can still compromise the whole cluster.

BECCS and DACCS companies would not be able to deliver negative emissions in case of an associated T&S infrastructure outage and would financially suffer under the main policy mechanisms proposed in this study. A separate 'availability payments' mechanism may be added to the GGR policy mechanisms which would pay a portion of the payments GGR companies would normally receive if their plants were ready to operate, but unable to do so due to third party issues. BECCS facilities producing co-products (e.g. electricity, fuels) may continue running without carbon capture, but DACCS may have to shut down completely without CO_2 storage.[47] Since the facilities would either have secondary income or have reduced costs due to shutdowns, payments are likely to be less than full contracted incentives (e.g. below the strike price for a CfD).

Tax incentives

Tax incentives in the form of enhanced capital allowances or accelerated depreciation would aid GGR developers by alleviating some of the burden associated with high upfront capital investments. Industrial machinery and most of the costs of large GGR plants are depreciating assets, which means that they can be deducted from taxable profits as capital allowances. Currently, annual writing-down allowances for most large-scale investments range from 3% for structures and buildings and 6% to 18% for other long life assets[48]. However, recently the Government has introduced a new super-deduction mechanism[49], which awards businesses 130% capital allowances in year one for qualifying plant and machinery investments from 1st of April 2021 to March 2023. It is estimated that at the current business tax rate, this is equivalent to savings of 25p per £1 of investment.

Such enhanced capital allowances would increase the rate at which the tax can be deducted, therefore project finance in early years would be more manageable for GGR companies. Considering the novel nature and the wider public benefits of carbon removal, GGR projects would be well justified for qualifying for such super-deduction mechanisms, even at higher rates. Capital allowances are relatively easy to implement and can complement other operational financial incentives, which are less successful at addressing the high upfront investment requirements. Moreover, in this study's stakeholder engagement with the financial community, the importance of maintaining capital allowances in place over the medium-to-long term to avoid complexity for developers and investors due to changing incentives was highlighted.

[47] A DAC plant may still capture CO_2 regardless of whether it can be permanently stored. For example, a DAC plant may be able to sell additional CO_2 to CCU companies, provided they have some form of onsite storage facility and/or ability to conduct CCU onsite.
[48] Current UK capital allowance rates [LINK]
[49] Super-deduction Guidance (HM Treasury, 2021) [LINK]

4.8 Enabling policies

In addition to the complementary policies explored, a suite of enabling policies are presented in this section. The enabling policies in this section cover mechanisms that will likely sit alongside the primary shortlisted policy mechanisms to enable successful GGR deployment. As shown in Table 9, this study has identified five key enabling policies which would be valuable for developing a mature GGR sector. Along with a brief description of the policy mechanism, Table 9 provides the current status of each policy in the UK. Further development and refining of these enabling policies in the next 5 to 10 years will be crucial to support a growing GGR sector and any primary support mechanisms that are in place (e.g. CfDs, NE service contracts).

Table 9: Key enabling policies for GGR deployment

Enabling Policy	Description	Status in the UK
Negative emissions accounting	Regulatory framework for effective monitoring, reporting, and verification (MRV) standards for each GGR technology, partnering with industry to develop MRV models and metrics	The UK's ongoing GGR competition includes some reporting and verification requirements for key performance metrics[50], but no MRV accounting methods currently exist for full-scale GGR projects
CO_2 T&S regulatory models	Regulatory business model to ensure availability and expansion of the CO_2 T&S infrastructure with risks and liabilities placed on the T&S company to reduce GGR cross-chain risk	CO_2 T&S Regulatory Investment business model under development by BEIS, with expected updates in Q3/Q4 2021[51]
Biomass sustainability	Regulatory frameworks or payment structures[52] which address life-cycle emissions of biomass or other sustainability criteria (e.g. biodiversity, carbon stocks)	Biomass generators receiving CfDs are subject to thresholds on meeting supply chain emissions intensity (i.e. limit on $kgCO_2e$ / MWh_{elec})[53]
CCUS industrial clusters	Support mechanisms for industrial clusters to deploy GGRs in conjunction with CCS and CCU measures[54], using the same CO_2 infrastructure, to reach net zero or net negative emissions	CCUS Infrastructure Fund (£1bn) aims to deliver CCUS in at least two industrial clusters, with the aim to have one in the mid-2020s and a second by 2030[55]
Workforce and supply chains support	Support programs for local workforces and supply chains needed for GGR project development, such as training via repurposing skills from declining industries (e.g. oil and gas sector) and identifying skills shortages and gaps	UK Government launched a taskforce in 2020 to drive the transition towards a net zero workforce (aiming for 2 million green jobs by 2030)[56]

There are also a range of enabling policies which can help to support specific GGR solutions. These include support mechanisms for low-carbon hydrogen (for hydrogen BECCS), renewable energy support to enable DACCS and power BECCS, and waste management policies which impact BECCS technologies utilising biogenic waste as inputs. For example, regulatory requirements could be introduced for any new plants which process waste (e.g. EfW, hydrogen gasification) to be built ready for CCS retrofits.

[50] Direct Air Capture and Greenhouse Gas Removal Programme – Competition Guidance Notes (BEIS, 2020) [LINK]
[51] CCUS – An update on the business model for Transport and Storage (BEIS, 2021) [LINK]
[52] An example of a revised payment structure for BECCS would be a 'net negative payment', where BECCS developers are paid a £/CO_2 incentive which adjusts depending on the plant's biomass supply chain emissions. For example, power BECCS developers would account for their net negative emissions (tCO_2/MWh) by subtracting their supply chain emissions from their site's captured emissions.
[53] Contracts for Difference – Generator Guide (Low Carbon Contracts Company, 2019) [LINK]
[54] Support for wider economy CCS and CCU projects would aid with bringing the cost of DACCS and BECCS down as costs decrease for infrastructure and plants due to economies of scale.
[55] Design of the CCS Infrastructure Fund (BEIS, 2021) [LINK]
[56] Press release: "UK government launches taskforce to support drive for 2 million green jobs by 2030" (BEIS, 2020) [LINK]

5 Discussion and Conclusions

5.1 Policy discussion

Detailed design and analysis has shown that each shortlisted policy mechanism may be more appropriate depending on future decisions surrounding the deployment of GGRs.

1. **Timelines for GGR deployment**. To support FOAK GGR plants in the 2020s, the favoured policy mechanism should have reduced complexity and minimal need for wider enabling policies. For example, the NE service contract is likely the easiest to implement for FOAK plants during the next decade given its simple contract and price incentive. As explored under the dual contract subsidy policy mechanism, combining the NE service contract with existing low-carbon subsidies would be one option to accelerate the roll-out of GGRs. Conversely, given the CfDc would need to be set up with a market price for NEs, this may delay FOAK deployment given the complexities with integrating GGRs and hard-to-abate sectors into a regulated market (e.g. integrating NE credits in the UK ETS may not be possible until early 2030s).

2. **Regulatory approach for hard-to-abate sectors**. This study examined two market-based policy mechanisms to support GGR deployment. The first was integrating NE credits in the UK ETS, allowing GGR developers to sell NE credits to hard-to-abate sectors to offset their emissions. The second was creating a new compliance market, obligating hard-to-abate sectors or fossil fuel suppliers to purchase carbon offsets. The pros and cons of both options were outlined in Table 8. Follow-on studies will be critical to further evaluate which regulatory market-based option will best enable the UK to meet the scale of GGR deployment required by 2050. Above all, if a regulated NE market is operational, this could favour a FOAK policy mechanism for GGRs which more easily integrates with this market (i.e. CfDc) to provide long-term value for money.

3. **Funding sources for GGRs**. While analysing the direct source of funding for GGRs was outside the scope of this study, each policy's design has inherent assumptions around their potential funding sources. Acknowledging the complexity, uncertainty, and nuances in funding policy mechanisms, a few initial findings can be inferred from this study's analysis. Distributing costs associated with GGR's co-products to their consumers would likely favour adoption of the dual contract subsidy. In the dual contract subsidy, the portion of funding for the low-carbon product subsidy could be levied on consumers under existing frameworks (e.g. electricity consumers funding power CfDs). Conversely, funding for GGRs could strictly follows the polluter pays principle, which is likely desirable for a mature GGR sector. This would favour the accelerated roll-out of a regulated market for NEs to ensure a large proportion of costs are passed on to emitters (e.g. hard-to-abate sectors or fossil fuel suppliers).

While these are expected to be the prominent deciding factors influencing GGR policy support, this is by no means an exhaustive list as there are additional cross-sectoral factors that would influence GGR deployment. Examples include strategies on sustainable biomass which influence the availability of biomass for BECCS GGRs or circular economy plans which influence the future of waste-to-energy GGRs (i.e. EfW or waste gasification plants).

5.2 Conclusions

From an initial assessment of a long list of policy mechanisms, this study has closely examined four policy mechanisms that could be utilised to support deployment of engineered GGRs in the UK. Each policy mechanism has a distinct framework, payment structure, and implementation and operating assumptions. It is important for any future policy approach to GGRs to closely examine the design features of each policy mechanism, including any enabling or complementary policies that may result in favouring one policy or another. From this study's analysis, concluding remarks can be made for each of the proposed policy mechanisms.

Regulated markets for GGRs are likely the preferred long-term policy option to incentivise a maturing GGR sector and ensure hard-to-abate sectors are able to offset emissions. Of the two market-based policy mechanisms explored in this study, both achieve this outcome. The first option explored was to integrate NE credits (sold by GGRs) into the existing UK ETS market, while at the same time including and reducing free allowances for hard-to-abate sectors to purchase NE credits. Conversely, a new compliance market could be developed, with obligations on specific hard-to-abate sectors (or other parties such as fossil fuel suppliers) requiring the purchase of carbon offsets from GGRs. In the long-term, standalone regulated NE markets could be preferred as they enable NE credits to be traded, driving efficiencies and cost reductions in a mature GGR sector. While both markets inherently follow the polluter pays principle and are able to pass on costs to emitters, standalone markets may be unable to provide sufficient revenue certainty and risk mitigation for investors, particularly for FOAK GGR projects. Furthermore, careful consideration to how both engineered and nature-based GGRs interact with the market will be key to managing any adverse side effects (e.g. crowding out of engineered GGRs by low-cost NE credits from nature-based GGRs).

Combining a low-carbon product subsidy and NE service contract into a dual contract policy mechanism could kickstart a nascent GGR sector. Beyond its relative ease of implementation for FOAK projects, the dual contract subsidy is an attractive option for providing revenue certainty to investors given the long-term contract lengths. In addition, the dual contract subsidy policy option could adapt over time as the GGR sector matures, either by utilising competitive auction-based allocations or even replacing the NE service contract with a CfDc. However, there is greater complexity involved with this policy mechanism if used in a mature GGR sector, as competing GGRs would be receiving different low-carbon product subsidies. Nonetheless, the low-carbon product subsidy would effectively shield against market risks faced by GGR developers for every unit sold to the market (e.g. in £/MWh or £/tonne). This would likely lead to increased investor confidence and reduced costs of capital. Finally, if the NE service contract is maintained as a direct subsidy (i.e. not linked to any regulated market), developers could be given the ability to interact with the voluntary offset market. This would further support the dual contract subsidy's potential to generate market revenue from the private sector.

Integrated with a NE market price, a CfDc policy mechanism would be a familiar and viable incentive to drive FOAK deployment and a maturing GGR sector. Similar to the dual contract subsidy, a CfDc would provide sufficient revenue certainty to investors over the lifetime of a GGR project. Moreover, its track record in the UK both for low-carbon power and for BEIS' proposed industrial carbon capture contract enable it to be a relatively easy to implement policy mechanism. In the long-term, an increasing NE market price would ensure value for money, since the subsidy is only paid on the difference between the strike price and market price. There are risks however of integrating the CfDc with a NE market price, particularly given the uncertainty of regulated markets for NEs being available for FOAK GGR projects. In addition, this may result in overpayments for some GGR projects should the market price fail to increase over time or become equal to or greater than the agreed strike price. As the GGR sector matures, careful consideration will need to be given to how CfDc contracts are awarded, as competitive auctions between GGR solutions (e.g. EfW BECCS, power BECCS, DACCS, etc) could increase value for money but may lead to unintentional underdevelopment of certain GGR technologies.

In summary, while each policy mechanism offers advantages relative to the others, a clearer set of priorities for GGR deployment would be valuable to narrow down the preferred policy mechanism(s) for implementation. To develop the evidence base on a preferred GGR policy mechanism(s), further work could focus on investigating the feasibility and timescales for implementing either regulated market for NEs and hard-to-abate sectors. Furthermore, complementary analyses on the funding routes for GGRs would be valuable to ensure any policy approach ensures an appropriate distribution of costs and risk allocation across the public and private sectors. Lastly, policymakers and investors would benefit from refined analyses on the potential for revenue to be generated from voluntary offset markets. Given their potential integration with a regulated approach to GGRs, further investigations would inform and enable GGR developers to consider selling their offsets privately should this be deemed desirable, scalable, and profitable alongside any public support mechanisms.

6 Appendices

6.1 Strengths, weaknesses, and examples of the long list of policies

Policy Mechanism	Strengths	Weaknesses	Examples
NE credits in UK ETS	- Market-based mechanism which incentivises GGR cost efficiencies by inducing competition between GGR developers - Promotes 'polluter pays principle' cost distribution by placing the burden of costs on emitters purchasing NE credits	- Uncertainty on the impact of NE credits in the UK ETS, potentially leading to price volatility and market disruptions which lead to lack of confidence from project developers and investors - Unlikely to be able to support FOAK GGR projects or at least be unable to provide the level of revenue certainty required - Potential to lead to mitigation deterrence or difficulty including all sectors (e.g. agriculture) which may need offsetting in the UK	No current examples of NE credit trading in existing carbon pricing schemes; however, the EU is similarly considering the role of NE trading in the EU ETS
CDR Market with Obligations	- Supports 'polluter pays principle' cost distribution since costs are borne by emitters and the mechanism would be revenue-neutral for Government - Incentivises competition between GGR projects, increasing long term value for money	- Private sector would bear significant risk due to the uncertainty over the stability of the price of obligations credits over time - High administrative barrier to setup a new compliance market - Unfamiliarity of a new market may reduce confidence from investors and developers leading to delays in GGR deployment	No governments have developed compliance markets to offset emissions via negative emissions; however, shares similarities with Renewables Obligation previously used in the UK electricity market for deploying low-carbon generation
NE Service Contract	- Procurement mechanism allows for a tighter control on the exact volumes of CO_2 removed from the atmosphere, allowing Government to deploy GGRs at more exact quantities for controlling the pathway to net zero and ensure no mitigation deterrence - Long-term service contracts for negative emissions provide revenue certainty to project developers and financiers	- Does not follow 'polluter pays principle' cost distribution as subsidy costs to incentivise GGR projects will likely be high and borne entirely by Government (i.e. taxpayers) - No competition post contract award raises likelihood of rent extraction and impacts long-term value for money[57] - Payment variations (£/tCO_2) which are not a flat rate over time would provide uncertainty to project developers and financiers	Currently, no governments are directly subsiding GGR projects via contract payments for negative emissions

[57] Pain-gain sharing mechanisms could be used to address this weakness to ensure developers are incentivised to reduce costs and increase efficiencies

Policy Mechanism	Strengths	Weaknesses	Examples
Co-product contract for difference	- Existing track record in the UK, reducing administrative complexity of policy implementation and familiarity helps with investor confidence - Fixed strike price and long-term contract (e.g. 15 years) provides revenue certainty to project developers and financiers - Linkage with co-product reference / market price likely to result in reduced costs borne by Government over the project's lifetime	- Standalone CfD may pass higher distribution of costs for GGRs onto the consumer (e.g. electricity consumers purchasing BECCS power) - Government risk in overpaying due to uncertainty in determining the appropriate level of the strike price for FOAK GGR projects - Unable to be applied to DACCS which has no additional co-products	UK CfDe for low-carbon electricity; Netherlands' sustainable energy transition (SDE++) subsidy shares similar structure
Dual contract subsidy	- Combining the two payments spreads the costs across the two services which a GGR plant provides (e.g. electricity consumers fund low carbon power, Government (initially) funds the NEs) - Long-term payment contracts provide revenue certainty to project developers and financiers	- Difficult to drive competition between GGRs initially as NE service contracts would likely be negotiated for separate GGR solutions and technologies to account for nuances between other subsidies/co-products and ensure a wide portfolio of technology development - Greater administrative requirements compared to standalone policies (potentially mitigated if administered through single entity)	While subsidies already occur for low-carbon products in some GGR solutions (e.g. power CfDe in the UK), directly subsiding GGR projects via contract payments for NEs does not exist
Carbon contract for difference	- CfD contract provides familiarity for investors and is likely to reduce administrative complexity of mechanism implementation - Fixed strike price and long-term contract provides revenue certainty to project developers and financiers - Linkage with carbon price likely to result in reduced costs borne by Government for deploying GGRs	- Uncertainty on whether a prevailing market price for negative emissions would be available for FOAK projects, resulting in delayed implementation or high payments for the full strike price - Does not fund co-benefits of GGRs (e.g. low-carbon electricity or fuel), instead driving incentive for the lowest cost options for NEs	UK's proposed industrial CfDc for CCUS; however, currently no governments are directly subsiding GGR projects via subsidies linked to market prices for negative emissions

Policy Mechanism	Strengths	Weaknesses	Examples
Tax incentives	- Tax incentives covering both operational and capital costs may provide a strong incentive for project developers and financiers - Minimal administrative burden compared to other policies, as tax credits do not require a direct funding stream from Government	- Uncertainty with long-term support of tax credits which could change under different governing political parties and reduce investor confidence (particularly for FOAK GGR projects) - As a long-term option for a mature GGR sector, there is no inherent mechanism to adjust tax credits to pass costs on to consumers - Lack of incentivising competition between GGR projects, so risk of overcompensating projects which do not require full credit value	Successful track record in developed markets (e.g. 45Q tax credit in USA)
Costs plus subsidy	- Guaranteed payments and long-term contracts provide revenue certainty to project developers and financiers, shielding FOAK GGR projects from market uncertainties and reducing financing costs - Targeted control of project development could allow for Government to select strategically important projects (e.g. baseload power BECCS) or those with maximum co-benefits	- Politically unfavourable cost distribution as all costs and risks are borne by Government, with significant annual subsidies required - Administratively complex, making the policy unfavourable to apply to a wide range of GGR solutions or for a maturing GGR sector	Policy has not been widely used to support investments in the energy industry, however, has been used for infrastructure and defense projects in the UK (e.g. Heathrow Terminal 5)
Public ownership	- Targeted control of project development could allow Government to select strategically important projects with maximum co-benefits - Relatively quick to implement as the project would not be subject to investment consortia delays or require developing new markets - Lower financing costs may reduce overall project cost	- Not easily scalable to a mature GGR sector or all GGR technologies without requiring significant government resourcing and spending - Politically unfavourable cost distribution as all costs and risks are borne by Government (taxpayers); no recent successful track record in the UK - Requires relevant expertise to operate a state-owned enterprise	Although uncommon today in the UK, some developed markets still have public oversight of energy assets (e.g. Norway's state-owned enterprise, Gassnova, coordinating the Longship CCS project)
Competitions	- Incentivises cost-competitiveness between FOAK GGR projects, increasing value for money in the short term - Able to be adapted to drive commercialisation across a range of GGR technology solutions or to be focused on specific technologies which deliver additional co-benefits	- Unlikely to have long-term potential to support a mature GGR sector, as funding for multiple large-scale projects likely to require significant government expenditure and resourcing - Unable to be adapted to a market-based mechanism for emitters to cover cost externalities or consumers to fund GGR co-products	UK Government recently announced funding awarded under their Direct Air Capture and other Greenhouse Gas Removal technologies competition (May 2021)

6.2 Policy mechanisms excluded from the long list

Policy Mechanism	Core Description	Rationale for Exclusion
Carbon tax	Tax payment based on the quantity of carbon discharged by emitters	• Non-GGR specific, given the broad economy-wide coverage of a carbon tax on large emitters • While indirectly able to incentivise firms to potentially adopt GGRs, other abatement options will be likely more cost-effective and deployed as a result of higher carbon pricing • Given its role in the economy, the carbon tax would effectively be combined already with the other policy mechanisms explored
Regulated asset base model	GGR developer receives a licence from an economic regulator, giving pricing certainty to the developer and customers	• Potentially only relevant for power or EfW BECCS (which could integrate regulated returns from electricity consumers), with very limited scope for other GGRs (e.g. setting regulated tariffs for DACCS would devolve to a NE service contract with Government) • In the power market, could lead to high tariffs and a disproportionately high cost distribution on electricity consumers • Unlikely to be used for mature GGR projects, as no competitive market would exist • Fairly atypical financing mechanism for electricity generation and more geared towards large-scale infrastructure
Cap and floor	Top up payments to floor if revenues are below this amount and revenues returned above a set cap	• Very limited track record, primarily used as a regulated approach by Ofgem to support interconnectors in the UK electricity market with a minimum level of availability required • For GGRs requiring a subsidy, the floor would be used to provide revenue directly, like a CfD. This is captured in the CfD models explored, with the introduction of a cap having no distinct benefits.

6.3 Rationales for the criteria assessment scoring

NE Credits in the UK ETS

Criteria	Score	Rationale
Reduces revenue uncertainty		Market integration of the UK ETS with NE credits would likely ensure sufficient demand for NEs; however, the unpredictable trajectory of the market price would reduce this uncertainty
Provides investor confidence		As a standalone policy mechanism, private sector bears all risks in project costs (i.e. biomass fuel price, CO_2 T&S fee, capex and opex, electricity price). Market risk is likely to cause hesitancy as investors may not see the policy as capable of providing stable long-term payments over a GGR project's lifetime
Cost reduction promotion		Private sector is incentivised to reduce operational costs over time to increase profits or offer lower cost NE credits
Optimal project selection		Naturally incentivises competition as a market-based mechanism, however, uncertainty exists as to whether GGRs would compete equally if regulations mandate purchases to specific technologies to support their development (which may mean some higher cost GGR solutions, at least initially, are able to sell credits)
Polluter pays principle		Emitters pay for the costs of GGRs directly, no further burden requiring government (taxpayer) or consumer payments
Adaptative capacity		Uncertain as to whether all GGRs would be able to compete against one another and limited ability to meet varying levels of GGR demand without stark adjustments to the ETS rules and regulations (e.g. including agriculture emissions in ETS may not be possible, at least in the near term)
FOAK applicability		Not implementable within required timeframe due to inherent administrative challenges with integrating hard-to-abate sectors and negative emissions allowances into the UK ETS by 2030
Mature sector applicability		Sufficient time to integrate a market-based mechanism linked to carbon pricing in the UK ETS for a mature GGR sector

CDR Market with Obligations

Criteria	Score	Rationale
Reduces revenue uncertainty		Early market unlikely to have sufficient liquidity, thus may be unable to provide sufficient revenue and long-term revenue certainty as a standalone mechanism for GGRs (particularly FOAK plants). Investors likely to be less assured of revenue certainty given this is a new market. However, the incentive strength is dependent on the market value of credits, which is influenced by Government through their choice of parties to obligate and at what level.
Provides investor confidence		As a standalone policy mechanism, private sector bears all risks in project costs (i.e. biomass fuel price, CO_2 T&S fee, capex and opex, electricity price). In addition, GGR developers bear significant revenue risks due to the uncertainty over the stability of the price of obligations credits over time and market liquidity in earlier years.
Cost reduction promotion		Private sector is incentivised to reduce operational costs over time to increase profits or offer lower cost NE credits
Optimal project selection		Naturally incentivises competition as a market-based mechanism, however, uncertainty exists as to whether GGRs would compete equally if regulations mandate purchases to specific technologies to support their development (which may mean some higher cost GGR solutions, at least initially, are able to sell credits)
Polluter pays principle		Emitters pay for the costs of GGRs directly, no further burden requiring government (taxpayers) or consumer payments
Adaptative capacity		Uncertain as to whether all GGRs would be able to compete against one another and limited ability to meet varying levels of GGR demand without stark adjustments to the market rules and regulations
FOAK applicability		While such a market could be setup for FOAK deployment in the late 2020s, the regulatory structure and accounting mechanisms may not be robust enough to incentivise FOAK GGRs
Mature sector applicability		Sufficient time to be implemented for a mature GGR sector and able to operate as a stand-alone market-based mechanism similar to the UK ETS for achieving scale of NEs required for net zero

NE Service Contract

Criteria	Score	Rationale
Reduces revenue uncertainty		At a high enough negative emissions payment, the contract would be able to incentivise deployment and provide revenue certainty with procured volumes specified by contracts; however, there is also uncertainty of delivering flat-rate payments over long-term contracts (15+ years)
Provides investor confidence		Payments may not be able to provide confidence for investors seeking to mitigate financial risks faced by the developer over the project lifetime (i.e. biomass price, electricity price, CO_2 price, CO_2 T&S fee, capex and opex costs)
Cost reduction promotion		Private sector is incentivised to reduce operational costs over time to increase profits or secure lower-value service contracts from Government
Optimal project selection		Policy could provide long-term value for money if GGR projects are awarded service contracts through reverse auctions (i.e. developers bid on lowest-cost); however, medium rating as this is unlikely to be available for FOAK projects or may need to be split between GGR solutions (which may not select optimally for the lowest cost negative emissions)
Polluter pays principle		Disproportionate amount of costs would not be borne by emitters (since this contract would not be linked to a market for NEs), costs for co-products (e.g. low-carbon electricity, low-carbon fuels) borne by consumers, and the costs of the NE service contract (likely) borne by Government/taxpayers
Adaptative capacity		Policy can apply to all GGR technology solutions as focus of payments are on NEs and can transition to auction-based mechanism for a mature GGR sector
FOAK applicability		Relatively straightforward, implementable contracts within the timeframes of FOAK projects
Mature sector applicability		While NE service contracts could move to competitive auctions for a mature sector, this is unlikely to be used as a standalone mechanism for GGRs given the long-term high costs and associated private sector rents

Co-product CfD

Criteria	Score	Rationale
Reduces revenue uncertainty		At a high enough strike price, the CfD would be able to incentivise deployment and has a strong track record which reduces its uncertainty over the contract lifetime; however, there is also uncertainty of being able to support co-product CfDs with sufficiently high strike prices that account for costs of NEs
Provides investor confidence		CfD strike price would sufficiently shield against market risk; however some risks may not be mitigated against across all CfD categories (e.g. co-product CfDs do not shield against ETS carbon prices)
Cost reduction promotion		Private sector is incentivised to reduce operational costs over time to increase profits
Optimal project selection		Policy could provide long-term value for money if GGR projects are awarded CfD through an auction-based allocation method (i.e. developers bid on lowest-cost) and market reference provides long term value for money to Government/taxpayers
Polluter pays principle		Disproportionate amount of costs would not be borne by emitters with costs primarily being passed on to consumers in some cases (e.g. CfDe for low-carbon electricity)
Adaptative capacity		Unable to implemented across all GGR solutions (i.e. DACCS has no co-products) and uncertainty with implementing a stand-alone co-product CfD that provides a sufficiently high incentive, which would need to be considerably higher in value than current CfDs (e.g. for biomass generators)
FOAK applicability		Readily able to adapt existing CfD structures for FOAK GGRs (where applicable in specific GGR solutions such as power BECCS)
Mature sector applicability		While a CfD could be allocated via competitive auctions in a mature sector (e.g. CfDs for offshore wind), this is unlikely to be used as a standalone mechanism for GGRs given the long-term high costs

Dual contract subsidy

Criteria	Score	Rationale
Reduces revenue uncertainty		Long term contracts that will provide sufficient revenue certainty and predictability for investors; however some uncertainty exists due to combined mechanism having no track record.
Provides investor confidence		GGR developers likely shielded against market and policy risks with the combined payment structure able to provide sufficient financial incentive to ensure financiers meet their required rates of return, in comparison to a stand-alone low-carbon product subsidy or service contract for negative emissions which may not provide high enough incentives.
Cost reduction promotion		With both financial incentives, a GGR operator has an incentive to reduce operational costs over time (e.g. through innovation) to increase profits.
Optimal project selection		Policy mechanism could incorporate a competitive auction process to select lowest-cost projects, however, FOAK projects likely to be bilaterally negotiated.
Polluter pays principle		Government likely paying the majority of costs, however opportunity exists for consumers to fund low-carbon subsidies (e.g. power CfDe)
Adaptative capacity		Values of low-carbon product subsidies could be readily adapted or transferred to competitive allocations processes for a mature GGR sector.
FOAK applicability		Dual contract mechanism implementable within timeframes for FOAK GGR projects
Mature sector applicability		While able to adapt to a mature GGR sector, medium rating reflects uncertainty to whether the policy can be moved to a market-based mechanism which passes costs on to emitters.

Carbon CfD

Criteria	Score	Rationale
Reduces revenue uncertainty		Long term contracts should provide sufficient revenue certainty and predictability for investors, along with CfDs having a strong track record which reduces its uncertainty over the contract lifetime
Provides investor confidence		CfDc strike price under a long term contract shields from risks associated with uncertainty in market CO_2 prices in future negative emissions markets, providing overall revenue confidence to developers/financiers. However, mechanism does not protect against market risks associated with revenues from GGR co-products (e.g. electricity, fuels)
Cost reduction promotion		Private sector is incentivised to reduce operational costs over time to increase profits
Optimal project selection		Policy mechanism could incorporate a competitive auction process to select lowest-cost projects (although likely bilaterally negotiated for FOAK) and market reference price provides long term value for money to Government/taxpayers
Polluter pays principle		Cost distribution assumed to be entirely borne by Government (i.e. benefit of negative emissions to society). However, mechanism could pass on costs to emitters or consumers if levied or costs to Government (and therefore taxpayers) could reduce over time.
Adaptative capacity		CfD mechanism can be readily adapted or transferred to competitive allocations processes for a mature GGR sector. However, may face difficulty promoting competition across all GGR technology solutions given the unique differences in costs and revenues for low-carbon products (e.g. electricity, fuels).
FOAK applicability		This policy could support FOAK projects, although it's unlikely for the reference price to be based on a functioning carbon market price for negative emissions in the 2020s
Mature sector applicability		Sufficient time to be implemented for a mature GGR sector and able to be integrated with a market-based reference price

Tax incentives

Criteria	Score	Rationale
Reduces revenue uncertainty		Tax credits covering both operational and capital costs could provide strong revenue certainty for project developers. Medium rating reflects the uncertainty as to whether the tax credits can be guaranteed for long-term contracts (i.e. 15+ years).
Provides investor confidence		Tax credits could face higher policy risk due to the uncertainty of long-term support which could change depending on the priorities of the government of the day and this could undermine confidence for investors financing GGR projects. GGR developers are not mitigated against key market risks such as biomass price, CO_2 T&S fee, capex and opex costs, electricity price.
Cost reduction promotion		Private sector is incentivised to reduce operational costs over time to increase profits
Optimal project selection		Lack of incentivisation for competition between new projects, so risk of overcompensating some projects and unlikely to provide long term value for money
Polluter pays principle		Cost distribution assumed to be entirely borne by Government (i.e. benefit of negative emissions to society). However, mechanism could pass on costs to emitters or consumers through levies (deemed less likely than other policy options).
Adaptative capacity		Likely to be able to apply across all GGRs, however, there is very limited adaptive capacity to transition to a mature sector and pass on costs to emitters or consumers.
FOAK applicability		Relatively straightforward incentive structure implementable within the timeframes for FOAK projects
Mature sector applicability		While tax incentives could be used for a mature GGR sector, this is unlikely to be favourable given the long-term high costs to Government, reducing value for money for taxpayer funds

Costs Plus Subsidy

Criteria	Score	Rationale
Reduces revenue uncertainty		Guaranteed payments and long-term contracts provide revenue certainty to project developers and financiers, also likely to lead to reduced financing costs
Provides investor confidence		High revenue confidence for investors since Government bears most of the operational risks of costs attributed to the GGR plant and any overall increases in project costs (e.g. due to plant-wide integration). Developers are protected from cost/market uncertainties over the project lifetime (e.g. biomass fuel price, CO_2 T&S fee).
Cost reduction promotion		Subsidy does not incentivise the plant to reduce operational costs, since these are all covered by the contract.
Optimal project selection		Guaranteed government payments reduce capital financing costs and the framework could include pain-gain sharing mechanisms to reduce likelihood of cost overruns.
Polluter pays principle		Cost distribution requires greater payments from Government/taxpayers. Politically unfavourable cost distribution as all costs and risks are borne by Government, with significant annual subsidies required.
Adaptative capacity		Unlikely able to be used to meet increasing volumes of GGR demand and no adaptations inherently possible to pass on costs to emitters or consumers.
FOAK applicability		Implementable within the timeframes for FOAK projects and provides sufficient incentives for developers/financiers
Mature sector applicability		Exchequer is unlikely to provide the sufficient funding needed to utilise cost plus subsidy for a mature GGR sector

Public Ownership

Criteria	Score	Rationale
Reduces revenue uncertainty		Ownership by state-owned enterprise would allow for all additional costs to be covered by public investment, however, the limited successful track record of this option reduces revenue certainty (which could increase over time as public ownership take over an increasing number GGR solutions/plants).
Provides investor confidence		Government bears all of the risks of the project (i.e. biomass price, CO_2 T&S fee, capex, and opex, electricity price), including the operational risks of costs attributed to the entire GGR plant and any overall increases in project construction costs (e.g. due to plant-wide integration).
Cost reduction promotion		Unlikely to achieve cost reductions that would be possible in the private sector. However, lower financing costs may reduce overall project cost.
Optimal project selection		Limited opportunity to compete for selecting low cost projects and low value for money as entire plant would be subsidised by government/taxpayer funding.
Polluter pays principle		Cost distribution for entire GGR plants would be subsidised by government/taxpayer funding. Politically unfavourable cost distribution as Government bears all costs and risks.
Adaptative capacity		Low rating reflects unlikelihood for public bodies to own and operate plants across all GGR solutions and the inability for costs to be passed on to emitters.
FOAK applicability		While applicable for FOAK GGR projects, medium rating reflects uncertainty as to whether Government could mobilise a state-owned enterprise with the resourcing needed for FOAK implementation timelines (i.e. late 2020s).
Mature sector applicability		Very unlikely for a mature GGR sector to continue under public ownership, due to high costs to taxpayers and political unfavourability.

Competitions

Criteria	Score	Rationale
Reduces revenue uncertainty		Competitions do not provide long-term revenue certainty or predictability as the awarded grants are typically just an initial instalment, however, they do have a strong record of success in developed markets (e.g. UK GGR competition, EU Innovation Fund)
Provides investor confidence		Competitions could face higher policy risk due to the uncertainty of long-term support which could change depending on the priorities of the government of the day and this could undermine confidence for investors financing GGR projects (e.g. cancelled £1bn CCS competition in the UK). GGR developers are not mitigated against key market risks associated (e.g. biomass price, CO_2 T&S fee, capex and opex costs, electricity price).
Cost reduction promotion		GGR projects are incentivised to reduce operational costs over time to increase profits, however, this is unlikely to be a priority for competitions which incentivise early stage technology development
Optimal project selection		While the policy strongly promotes innovation and competition to select for low cost projects (amongst other criteria), there is limited long term value for money as cost burden remains on exchequer
Polluter pays principle		Cost distribution would require greater payments from Government/taxpayers to subsidise project grants
Adaptative capacity		Applicable across all GGR technologies, however, medium rating reflects unlikelihood of adapting competitions with grant funding to a mature GGR sector
FOAK applicability		Implementable within timeframes for FOAK projects, particularly for demonstration GGR plants which receive capital grants
Mature sector applicability		While policy could be used for a mature GGR sector, low rating reflects the low likelihood of Government using competitions to administer grants instead of market or auction-based mechanisms

6.4 Assumptions for DACCS costs modelling

The policy cost modelling presented and discussed in section 4.4 has been carried by using the global DACCS cost model Element Energy developed for the International Energy Agency's Greenhouse Gas R&D Programme (IEAGHG)[58]. The costs presented are not intended to represent the actual cost of DACCS in the UK or globally, since numerous project specific factors would be impactful. The analysis is intended to demonstrate the level of change that can be observed regarding the CfDc top-ups required for DACCS projects under different conditions. Some of the major modelling assumptions are:

- First-of-a-kind (FOAK) and Nth-of-a-kind (NOAK) DACCS costs are based on solid adsorbent DAC technology. It is assumed that the plant only consumes electricity and heat pumps are used where heat energy input is needed.
- The costs displayed are gross costs of capturing, transporting, and storing one tonne of CO_2 in an underground geologic formation. Lifecycle emissions of the process (such as scope two emissions associated with electricity use) are not considered in this analysis. The net carbon removal is likely to be lower once these emissions are considered.
- Modelling is based on a 1 $MtCO_2$/year capacity plant.
- Costs are provided in 2020 GBP (£).
- Plant capacity factor (availability) is taken as 90%.
- CO_2 transport and storage (T&S) cost is assumed to be £18/tonne.
- Carbon prices are based on Treasury's Green Book supplementary guidance table 3. For FOAK plants £118/tonne (2035 central price) and for NOAK plants £156/tonne (2040 central price) are used for the base case.
- The price of low-carbon electricity is assumed to be £62/MWh for FOAK and £48/MWh for NOAK plants. The model does not differentiate between the source of the low-carbon power.

[58] Global Assessment of Direct Air Capture. Element Energy for IEAGHG, 2021 [to be published]