ECONOMIC ANALYSIS OF UK CCUS

A report to Carbon Capture and Storage Association

JUNE 2021

cambridge econometrics
clarity from complexity

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1 Executive summary

The UK is in the early stages of developing a CCUS industry, with ambition to deploy four clusters and capture at least 10 million tonnes of CO_2 annually by 2030. We explore the economic impacts of this deployment, review some lessons from the success of the offshore wind industry to highlight policy gaps, and estimate the ongoing funding levels that will be required to roll-out CCUS in the UK.

CCUS is seen as essential to achieving Net Zero

The benefits of Carbon Capture, Utilisation and Storage (CCUS) to support decarbonisation in the United Kingdom have been recognised for many years, and the Climate Change Committee (CCC) states that CCUS is essential to achieving Net Zero at the lowest cost. With the government supporting the capture of 10 million tonnes of CO_2 per annum (Mtpa) by 2030, the first track of the cluster sequencing progress will select at least two clusters to progress near the end of 2021. It therefore looks likely that the UK will develop a CCUS industry through the 2020s and be amongst the early movers globally at developing large scale decarbonisation-driven CCUS.

We have explored the impacts of rolling out CCUS on the UK economy under two scenarios. The first, the Ten Point Plan scenario, delivers on the UK Government's ten point plan and Energy White Paper[1] commitment to deliver 10Mtpa of CCUS by 2030, before then scaling up in the 2030s. The second scenario, Net Zero Ambition, models deployment at the level recommended in the CCC's Sixth Carbon Budget, deploying 22Mtpa by 2030 and then more than tripling capacity through the 2030s.

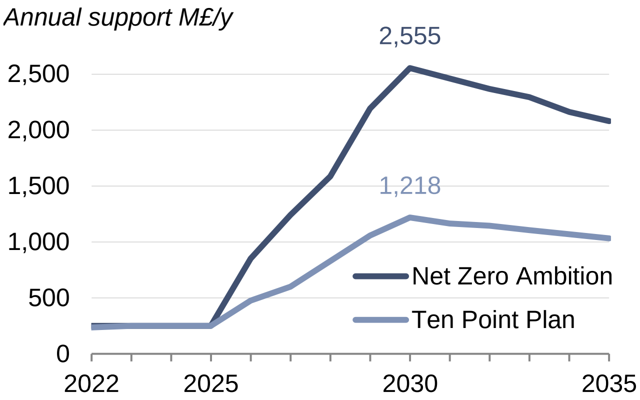
Annual CCUS support costs by 2030 are likely to be £1.2b–£2.6b depending on ambition

The support costs required to roll out CCUS in our two scenarios are shown in Exhibit 1.1. Deploying CCUS to 2030 across our two scenarios would require a peak in ongoing support of £1.2 and £2.6 billion per year, although significant uncertainty over required funding levels remains with the key risk

[1] Energy White Paper: Powering out Net Zero Future, Dec 2020.

factors including CCUS and commodity costs and policies around funding and revenue streams for hydrogen and carbon removals. These funding levels could therefore move up or down as these uncertainties are resolved. There is precedent for decarbonisation spending at this level to develop a new industry; the 2020/2021 UK budget for renewable support schemes is set at £8.6 billion[2], with around half of this for offshore wind.

Exhibit 1.1 – Estimated support level required for projects to 2030



Many of the cost uncertainties should narrow over 2021 through the cluster sequencing process. Continuing CCUS deployment beyond 2030 would require increased funding, although cost reductions should drive a significant reduction in support requirements as the industry develops towards a long-term goal of merchant-driven deployment.

Using Cambridge Econometrics' E3ME model, we have also explored the economic impacts of CCUS deployment across the UK. In both scenarios, significant economic impacts are seen, with growth in both jobs and GDP. Significantly, these are 'net jobs', including supply chain and multiplier effects as well as the loss of jobs from displaced activities and the costs of paying for CCUS support.

Exhibit 1.2 – Impact on UK jobs

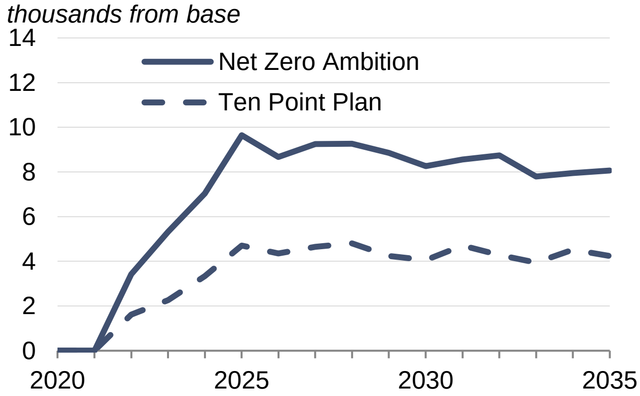


Exhibit 1.2 shows up to ten thousand new jobs created under the Net Zero Ambition scenario against a counterfactual where industry continues to emit CO_2. In practise, given the Government's commitment to net zero and enshrining the sixth carbon budget in law, not deploying CCUS risks forcing highly emitting industries offshore in the early 2030s to meet UK ETS emission limits, with around 50,000 existing jobs at risk through the 2030s from the iron and steel, cement, chemicals and refining industries, as visualised in Exhibit 1.3. The UK is likely to be early mover in the global CCUS space, driven by the UK's relatively ambitious decarbonisation targets, favourable conditions for CO_2 storage and a relevant skill-base. This creates an opportunity to build a CCUS export industry with the potential to create additional jobs.

CCUS could create 10k UK jobs by 2025 and help protect 50k more

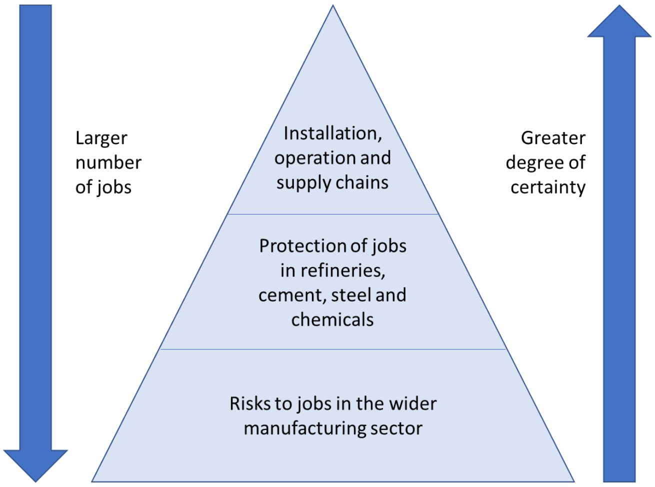
Lower levels of ambition, such as the current 10Mtpa target, will deliver similar types of benefits, but with a smaller overall impact. This will include

[2] Control for low carbon levies, House of Commons Library, 20 December 2017. Quoted in 2016/17 prices.

lower job creation and protection, and will potentially miss other stated government targets (e.g. on hydrogen production). CCUS development under both scenarios brings significant benefits and establishes infrastructure allowing further CCUS rollout.

Exhibit 1.3 – Interpreting the impacts on employment

CCUS investment delivers jobs directly, but also acts to protect jobs in carbon exposed industries.



We have also reviewed lessons from the success of the offshore wind industry, which ten years ago shared a number of similarities with the CCUS industry of today. We have drawn out five key components of offshore wind's success, and compared the steps taken to support offshore wind with the steps being taken to support CCUS today. This is summarised in Exhibit 1.4, and while many areas show good progress with CCUS broadly on target, it highlights needs in three policy areas. Two are long-term needs: establishing continual procurement of CCUS over time, and ongoing, consistent supportive messaging around the industry. The third is an immediate need: de-risking CCUS today requires visibility of a long-term funding framework, providing an equivalent to the Levy Framework which provided both funding visibility and consumer protection for renewables a decade ago. Funding within this framework should increase over time to signal continual, rather than stop-start, procurement. Parallels with renewables, and discussions with the industry, suggest this framework should extend to around 2030 to provide sufficient certainty to industrial developments needed now.

Exhibit 1.4 – GAP analysis for CCUS on 5 main components of offshore wind success

UK CCUS needs funding certainty and an ongoing supportive policy environment to flourish.

		Current status	GAP Analysis
1	**Certainty of funding**	Clear targets are in place Some CIF grant money available for early T&S	**Funding framework needed**
2	**Supportive policy & communications environment**	Currently supportive signalling from Gov. Public awareness low, but 93% supportive or ambivalent	Need ongoing supportive messaging from Gov. Public communication requirements may need further work, but consultations underway
3	**Building the industry**	Early stages: Track 1 in progress, Track 2 announced. Potential in UK, with industrial clusters + O&G experience	Continual procurement needed Optional: Design in local content if want UK to produce & export. Policy required.
4	**Financeable model**	BEIS in process of addressing: 3 business models released, 2 to be released shortly	(Dependent on BEIS release)
5	**Broad industry buy-in**	Industrial Decarbonisation Challenge Phase 2: £171m Gov./£342m Industry. CCUS Cost Challenge Task Force	(Contingent on 1-4)

Status legend On track | In progress | Not on track

2 For net zero, the UK needs CCUS

The Climate Change Committee's Sixth Carbon Budget recommended the establishment of CCUS clusters in the UK in the 2020s, and described CCUS as essential to achieving Net Zero at lowest cost. Internationally CCUS is also seen as crucial to meeting global goals to limit temperature rise from climate change. The UK government has responded to this, with plans to capture and store 10 million tonnes of CO_2 annually by 2030.

The most recent public studies of the role that CCUS should play in a net zero UK economy come from the Climate Change Committee (CCC), an independent non-departmental public body established to advise the UK and devolved governments on emissions targets. The CCC's Sixth Carbon Budget was released in December 2020 and presents a 'Balanced Net Zero Pathway' and four alternative scenarios, all of which included large scale deployment of CCUS. A CCC sensitivity on their 'easiest' decarbonisation scenario, Tailwinds, showed that decarbonising without CCUS would add eight years delay and significant extra cost to reaching net zero, with much greater risk that zero emissions would not be achieved[3].

The benefits of Carbon Capture, Utilisation and Storage (CCUS) to support decarbonisation in the United Kingdom have been recognised for many years. In 2014 the Energy Technologies Institute (ETI), a public-private partnership between global industries and UK Government, suggested decarbonisation costs could double without CCUS.

More broadly, CCUS is recognised as necessary internationally, for much the same reasons as in the UK: it is a cost-effective solution to delivering decarbonisation in hard-to-reach sectors, crucially for:

[3] The Sixth Carbon Budget – The UK's path to Net Zero (Box 2.4), 2020, Climate Change Committee.

- decarbonising industrial process emissions, which are not derived from combustion of fossil fuels and very difficult to reduce otherwise; and
- delivering removals ("negative emissions"), which can be used to offset emissions in industries where decarbonisation is prohibitively expensive, such as long-haul aviation and some parts of the agriculture and waste sectors.

While the above applications require CCUS as they do not have a reasonably scalable substitute, CCUS also has the potential to be a cost-effective decarbonisation tool across a range of other sectors:

- providing capacity and flexibility on decarbonised electricity grids;
- retrofitting global CO_2 emitting assets;
- producing low-carbon hydrogen for heating, transport and feedstocks;
- abating industrial heat; and
- addressing emissions in other sectors such as waste management.

Carbon capture and storage has in places been criticised as a decarbonisation solution for facilitating the continued use of fossil fuels. It should be emphasised that deployment of renewables coupled with energy efficiency are expected to be the main global drivers of decarbonisation by reducing the need for fossil fuels; the key role of CCUS is to act as a complementary tool where zero-emission energy either cannot reduce emissions (e.g. industrial processes), or where it would be very costly (e.g. long-haul aviation). Stabilising the global climate requires reaching net-zero emissions globally, and CCUS is critically important to reach that end-goal.

2.1 The global role for CCUS

Currently, global annual CO_2 capture and injection capacity stands at ~40MtCO_2/y from around 20 large-scale CCUS projects[4]. Studies looking at how to reach net-zero globally consistently rely on a dramatic expansion of CCUS in the decarbonisation mix, both for emissions abatement and as a tool for greenhouse gas removal, where CO_2 is captured from the atmosphere via bioenergy (BECCS) or directly (DACCS).

The Intergovernmental Panel on Climate Change (IPCC), an intergovernmental body of the United Nations, produces a range of scenarios for global decarbonisation the majority of which rely heavily on CCUS[5], with their special report on 1.5ºC encompassing a range of scenarios with up to 300,000Mt of CO_2 captured and stored by 2050. CCUS is used for deep emissions reductions across a range of sectors, as well as for CO_2 removals. By 2050, their median usage of CCUS in all 1.5ºC scenarios was around 12,000MtCO_2/y, and even in the less ambitious below 2ºC scenarios only falls to 7,000MtCO_2/y[6].

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[4] Global Status of CCS 2020, GCCSI, 2021.
[5] Scenarios without CCUS relied on significantly decreased energy demand and a halving of global emissions by 2030, a trajectory that the world is clearly not on track to meet.
[6] IPCC Special Report on Global Warming of 1.5C, Ch2, IPCC, 2018.

The International Energy Agency (IEA), a Paris-based autonomous intergovernmental organisation, also consistently relies on CCUS in their scenarios, with the Sustainable Development pathway using 4,000MtCO_2/y predominantly for emissions abatement. More recently, their 2021 Net Zero by 2050 report[7] relies on 5,000MtCO_2/y of CCUS in 2050, with CCUS abating most fossil fuel energy use as well as producing 1,700MtCO_2/y of removals.

While it is not yet clear that the world will move quickly enough to limit global warming to 1.5ºC, it is clear the world is mobilising for the challenge, with many governments, cities and businesses pledging net-zero targets, including the UK, EU, China, Japan and the USA, and several hundred cities and companies[8]. In total, more than 60% of global emissions come from countries with some form of commitment to net zero. Meeting these targets, as in the IPCC and IEA reports, will require CCUS globally at significant scale.

Current deployment of CCUS is therefore less than 1% of the 2050 levels suggested by the IEA and IPCC scenarios and there are only a limited number of projects under construction[9]. CCUS has consistently been flagged as 'not on track' by the IEA Tracking Clean Energy Progress reports. Most of the existing CCUS infrastructure has been developed based on revenue from Enhanced Oil Recovery, as historically there have been few economic incentives to deploy CCUS for climate reasons. This is changing: the 45Q tax credit and low-carbon fuel standards in the US, and SDE++ funding in the Netherlands, are three early examples of schemes that are expected to drive the development of CCUS projects for climate goals. Many countries are likely to follow Europe's trajectory of decarbonising electricity systems through renewables as a first step, but as focuses turn to emissions from other sectors, demand for CCUS for direct abatement, hydrogen production, preserving power assets and negative emissions is expected to follow.

While future global deployment of CCUS is highly unclear, the IEA and IPCC scenarios provide a reference point. One-hundred fold expansion by 2050 will be extremely challenging, but even if met only in part, they indicate that hundreds of millions of tonnes of capture capacity are likely to be deployed globally through the 2030s, with even greater uptake in the 2040s.

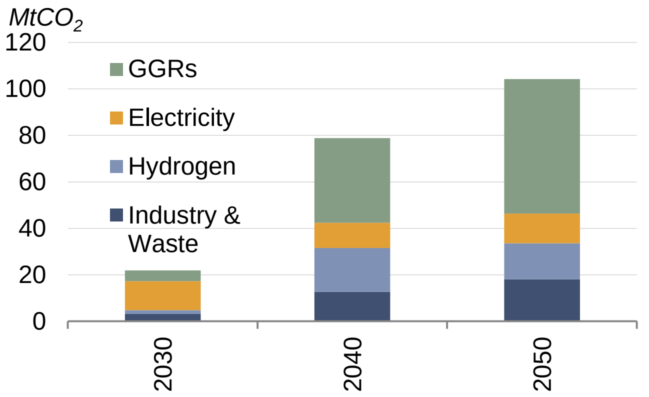
2.2 The UK role for CCUS

UK government plans to develop CCUS are based around the 'cluster' approach of developing regional transport and storage networks that can support carbon capture from multiple sites, with the ambition to capture at least 10 million tonnes of CO_2 annually by 2030. BEIS' current work on cluster sequencing lays out the process for choosing at least two clusters in 2021 to progress by the mid 2020s, with additional projects and clusters brought through later in the 2020s.

[7] Net Zero by 2050, IEA, 2021.
[8] Taking Stock: a global assessment of net zero targets, ECIU and University of Oxford, 2021.
[9] Global Status of CCS 2020, GCCSI, 2021.

These plans are driven by the UK's decarbonisation ambitions, with planned national emissions reductions (relative to 1990) of 68% in 2030, 78% in 2035, and reaching net zero by 2050. In laying out their Balanced Net Zero scenario with 104Mt of CO_2 stored in 2050 in their 6th carbon budget, the CCC was revisiting well-trodden ground in the UK, following recommendations to develop CCUS in previous carbon budgets, along with a long history of work from the Energy Technologies Institute, the Technology and Energy Innovation Needs Assessments (TINA, EINA), and many others. The Sixth Carbon Budget lays out the best estimates we have for what a future decarbonised UK will look like, with significant changes to energy generation and energy and land use.

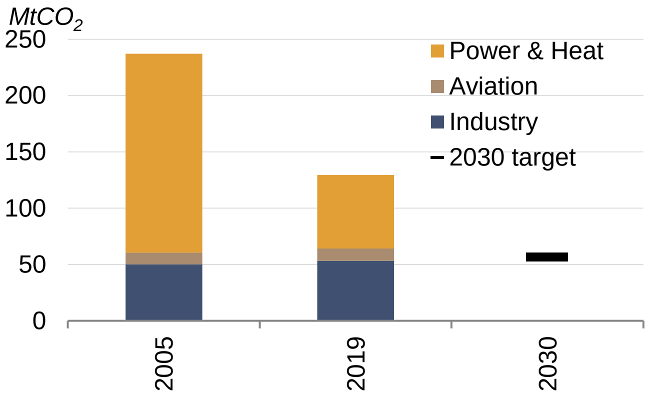
Exhibit 2.1 – CCUS in the CCC's Balanced Net Zero scenario



Source: The Sixth Carbon Budget dataset

Exhibit 2.2 – UK ETS sector emissions

Historical emissions from sectors within the UK ETS, compared to the CCC's proposed 2030 ETS emissions limit



Source: AFRY analysis of EUTL data (except aviation in 2005) and UK greenhouse gas emissions national statistics (aviation in 2005)

In the 2020s and 2030s, CCUS is needed to decarbonise the electricity and industrial sectors, generate hydrogen for broader decarbonisation, and providing a kick-start to the large-scale greenhouse gas removals (GGRs) required in the longer-term. From the 2030s, the CCC suggests that greenhouse gas removals will contribute the majority of CCS growth, but the requirement for CCS in other sectors will continue (Exhibit 2.1).

The electricity and industrial sectors fall within the UK Emission Trading Scheme (ETS), and Exhibit 2.2 gives a sense of the scale of the challenge, with ETS emissions needing to more than halve by 2030 under the CCC's recommended 57Mt cap. Industrial emissions are expected to fall even more sharply in the 2030s, reaching between 6% and 17% of 2019 levels across the five CCC scenarios.

While the UK has historically seen dramatic falls in power sector emissions, in future these will become harder to achieve and huge cuts in industrial sector emissions will be required from 2030. CCUS and hydrogen are prime candidates to drive this; without developing them the UK risks losing domestic heavy industry that does not have alternative decarbonisation methods, as their emissions will be incompatible with decarbonisation targets. This is unpalatable not only from an economic perspective, but also from a climate perspective, as losing high emission industries would shift the emissions geographically rather than reduce them.

2.3 Timing of deployment

Current UK plans to roll out CCUS during the 2020s align with the CCC's view that CCUS needs to be deployed at scale in the 2020s, driving cost reductions and allowing large scale rollout in the 2030s. The current national ambition of 10Mtpa in 2030, however, falls short of the ranges covered in the Sixth Carbon Budget; 13 to 26Mtpa across five scenarios, and 22Mtpa in their key Balanced Net Zero pathway. The CCC pathways are based around a 'least cost' principle, suggesting that 10Mtpa of deployment in the 2020s can be seen as a 'no regrets' option, and deploying higher levels may be preferred from a least cost decarbonisation perspective. Because of the range of sectors in which CCUS acts to decarbonise, delaying deployment past 2030 creates risks for the UK's climate targets, the UK's heavy industry, and/or substantial extra costs to deploy more expensive alternatives. Other public studies have shown £5b additional system costs[10] or 75,000 less jobs and £21b less GVA[11] from deployment delays.

UK deployment is likely to be at the forefront of global decarbonisation driven CCUS. While projects are planned in the mid-2020s in the Netherlands, Norway and the USA in particular, it is likely that the UK will be among the first movers to establish CCUS clusters at scale. This is driven in part by the UK's relatively ambitious decarbonisation targets (driving early introduction of CCUS), and in part because the UK has favourable conditions for CCUS with plentiful offshore storage and a relevant skill-base.

In general, early movers into new technologies have opportunities to become market leaders and establish export markets through domestic expertise, skills and supply chains. To realise these opportunities, the skills need to be built up domestically, and then maintained against new entrants who could come in and offer similar services. Success depends on how easy it is for new entrants to compete; given current skills the UK is well positioned with expertise in offshore operations, engineering and design. Early movers in CCUS may also be able to provide access to CO_2 stores as a product to later movers, although this would likely be restricted to nearby European nations.

Late movers gain access to lower costs once technology is refined, and for some technologies may be better able to adapt to user needs. Cost savings can be significant and compensate for the lack of domestic industry. However, where deployment is driven by annual climate targets, moving late is unlikely to realise cost savings as other measures would need to be deployed in the interim.

With ambitious climate targets driving the UK into moving early on CCUS, the UK has an opportunity to take a market leading position in this growing space. While this report does not delve into industrial strategy, CCUS policy should recognise the opportunities of being an early mover, consider the economic benefits of taking steps to support a future export industry, and decide whether those steps would be cost effective for the nation.

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[10] Value of Biomass with Carbon Capture and Storage (BECCS) in Power, Baringa, 2021.
[11] Clean Air – Clean Industry – Clean Growth, Summit Power, 2017.

3 Economic impact of investment into CCUS

An ambitious roll-out of CCUS would entail a substantial volume of investment. The amounts are large enough to have macroeconomic implications. In this chapter we explore the impacts on jobs, GDP and other sectors.

In this chapter, we assess the potential wider economic effects of investment in CCUS through a model-based approach, specifically using Cambridge Econometrics' E3ME macroeconomic model. Three scenarios are tested in the model: a baseline and two scenarios with CCUS implementation. The difference between the model results for the CCUS scenarios and the baseline indicates the potential impacts of the CCUS.

The next section describes in detail the scenarios that were modelled. Section 3.2 provides a brief description of the E3ME model that was used for the analysis. The results are presented in Section 3.3 and key messages pulled out in Section 3.4.

3.1 Scenarios

We have investigated two scenarios, Ten Point Plan and Net Zero Ambition. To draw out the CCUS related impacts, we have compared these to a counterfactual that does not include CCUS, and is otherwise the same (i.e., does not increase ambition elsewhere to account for not having CCUS). Both CCUS scenarios are based around the following principles:

- They show levels of CCUS across the UK without 'picking winners' from the clusters likely to enter the cluster sequencing process, and hence do not rely on information about cluster location.
- They reflect the types of CCUS projects in development, without attempting to 'pick winners' amongst the range of sectors covered.

— As far as the above allows, they attempt to reflect typical costs expected from the types of projects that will enter the sequencing process.

Following the above principles, we have split capture volumes to 2030 equally between four broad categories of projects:

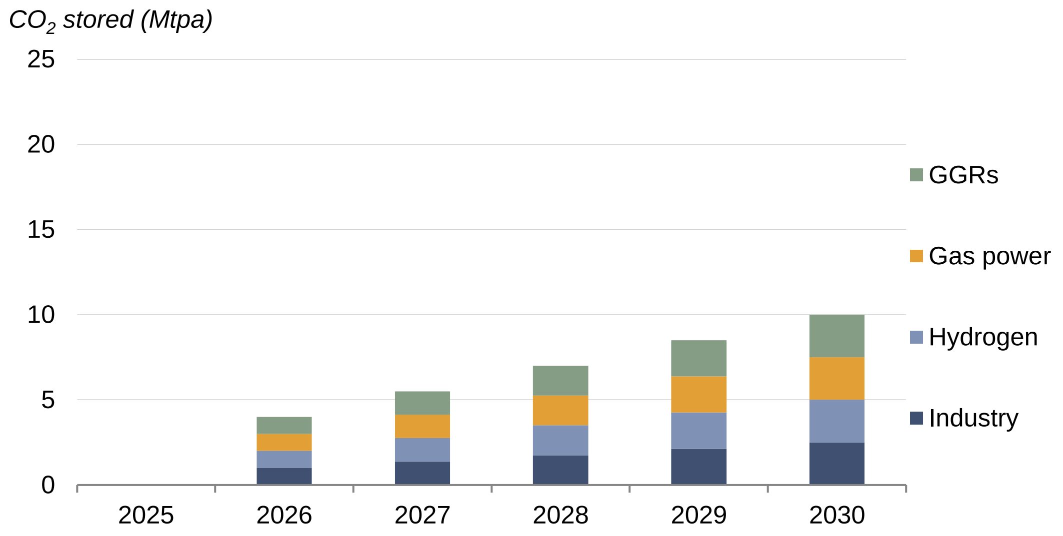
1. gas power with CO_2 capture;
2. Engineered Greenhouse Gas Removals (GGRs), represented in our modelling as bioenergy for power production, but potentially representing other bioenergy (BECCS) and direct air capture (DACCS) projects as well;
3. hydrogen production using Auto-Thermal Reformers (ATRs) with CO_2 capture; and
4. other industrial sites with CO_2 capture (including waste to energy)

While some CCUS projects do not fit neatly into these categories, we have used them as a simple representation of most carbon capture projects under development in the UK, spanning the various funding models expected.

3.1.1 Ten Point Plan scenario

The Ten Point Plan scenario reflects the ambition laid out in the White Paper in December 2020: to develop two clusters by the mid-2020s and capture 10 million tonnes of CO_2 annually (Mtpa) from four clusters by 2030. We have represented this as two clusters of 2Mtpa each operating in 2026 (i.e., commissioned in 2025), followed by a linear ramp-up of capture volumes to 2030, as shown in Exhibit 3.1. The increase in capture volumes could represent either new clusters, or additional projects at the initial clusters. For assigning the incidence of transport and storage costs, we have nominally assumed operation of the third and fourth clusters from 2028 and 2029.

Exhibit 3.1 – Sources of stored CO_2 in the Ten Point Plan scenario



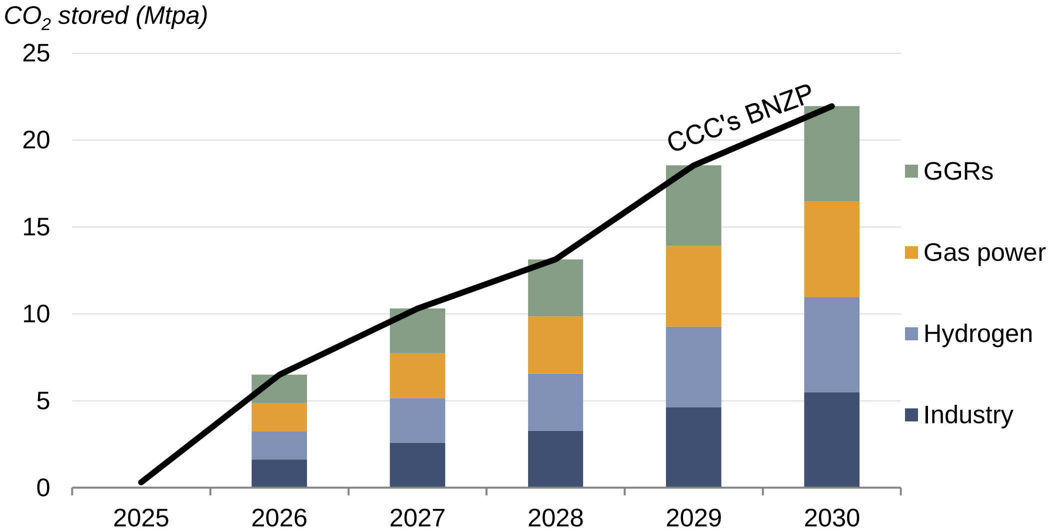
While the focus of this work is the period to 2030, post-2030, we assume a doubling of total installed capacity every 5 years to 2040, reaching 20Mtpa in 2035 and 40Mtpa in 2040. More details can be found in Annex A.2.

3.1.2 Net Zero Ambition scenario

The Net Zero Ambition scenario builds on the Climate Change Committee's Sixth Carbon Budget report[12], modelling deployment of CCUS at the level in their Balanced Net Zero scenario up to 2030. This scenario starts by capturing 6.5Mtpa of CO_2 in 2026, and capture volumes increase to 22Mtpa in 2030, as shown in Exhibit 3.2. Because of the greater volumes captured initially, we build transport and storage to support four clusters in 2026, with subsequent expansions as needed. While 22Mtpa by 2030 is significantly more than current government ambition, we note there are sufficient CCUS projects already under consideration to develop the 2030 volumes assumed.

Exhibit 3.2 – Sources of stored CO_2 in the Net Zero Ambition scenario

Sources of captured CO_2 (bars) compared to the volumes captured in the CCC's Balanced Net Zero scenario (black line).



Post-2030, we assume steady deployment in each sector to the sectoral volumes modelled for 2040 in the CCC's Balanced Net Zero scenario. Total capture volumes are 50Mt in 2035 and 79Mt in 2040; more details can be found in Annex A.2.

3.1.3 What happens without CCUS

The model results presented in this chapter describe the difference between the scenarios with CCUS and the baseline case without CCUS. Our assumptions about the baseline case are therefore important.

Our general approach is to isolate the effects of CCUS investment as much as possible. For example, we assume limited change in the energy system wherever feasible, so that the model results show the effects of the CCUS investment, rather than the effects of moving to a different energy system.

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[12] The Sixth Carbon Budget – The UK's path to Net Zero, 2020, Climate Change Committee.

However, there is a high degree of uncertainty about future trends of development in the energy and industrial sectors, and this should be acknowledged when interpreting the results.

The baseline assumptions for modelling in this chapter are as follows:

— If CCUS capabilities are not added to natural gas power plants, these gas plants continue to operate with unabated CO_2 emissions. Total UK emissions are therefore higher in the baseline and the net zero target becomes more difficult to meet.

— Even without CCUS, the use of bioenergy for electricity continues. It is noted that this outcome is unlikely given the current policy framework, but it is unclear what the alternative outcome would be.

— The industrial sector continues to operate in the UK regardless of whether it can capture its emissions or not. In the baseline case, industrial emissions are therefore higher than in the CCUS scenarios.

— In the CCUS scenarios, hydrogen is generated from natural gas with the emissions captured. It is assumed that the hydrogen displaces natural gas consumption either at specific installations or through blending in the gas network. The assumption in the baseline is that natural gas consumption continues without a contribution from hydrogen.

— If there is no CCUS then it is assumed that there is no investment in transport and distribution for CCUS either.

The baseline scenario is therefore more highly emitting than the CCUS scenarios. In reality not building CCUS could means higher emissions, or that the emissions reductions would come from other sources – likely a combination of alternative investments (the 6th carbon budget would suggest these are more costly) and loss of domestic high-emission industries.

Exhibit 3.3 summarises what these assumptions mean in terms of key model inputs. Although these are not the only model inputs, they are the ones that drive the main differences between the CCUS scenarios and the baseline. While there are some differences to gas consumption, the majority of the impacts result from the additional investment and operational costs for the CCUS.

Exhibit 3.3 – Key modelling inputs for econometric modelling

Sector	Key differences in model inputs
Electricity	Capex and Opex of CCUS. Additional natural gas consumption to cover efficiency loss.
Industry	Capex and Opex of CCUS.
GGRs	Capex and Opex of CCUS.
Hydrogen	Capex and Opex of ATRs with CCUS. Additional natural gas consumption to cover conversion losses.
Transport and Storage	Capex and Opex of T&S system.

3.1.4 CCUS cost assumptions

We have used investment costs and technical data based on data from the Carbon Capture and Storage Association, sourced from aggregated project data where available, public sources, and member feedback. The key assumptions are summarised in Exhibit 3.4; further details are available in Annex A.1. We consider these costs to be a fair representation of current knowledge, but recognise that actual project costs will be revealed in the project allocation process and are subject to a large degree of uncertainty at this stage. We examine the implications of this uncertainty for funding volumes as part of our sensitivity analysis in Section 5.3.

Exhibit 3.4 – Summary of key sector assumptions

Sector	Scope	Unit capex	Unit opex (excl. fuel, carbon)	Hurdle rate (pre-tax, real)
Industry	CCS unit	330 £/tpa	32 £/t	8.0%
Gas power	Whole plant	1730 £/kW	86 £/kW/y	8.0%
GGRs	CCS unit	1640 £/kW	82 £/kW/y	8.0%
Hydrogen	Whole plant	900 £/kW	88 £/kW/y	8.0%
Transport & storage	First 13.5Mtpa	217 £/tpa	7.6 £/t	4.5%
	First 30Mtpa	131 £/tpa	4.6 £/t	4.5%

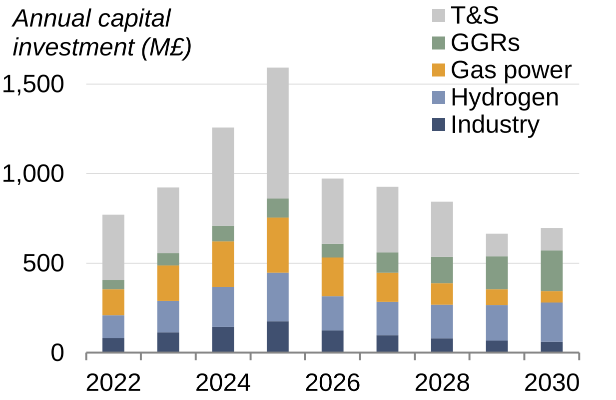
Notes: Costs are real 2020 pounds and do not include interest during construction. Hydrogen figures are HHV/GCV, based on the Hynet phase 1 report plus 25% to cover distribution costs. tpa means tonnes per annum (of CO_2). £/t figures are annual average costs per tonne of CO_2 captured (industry); transport and storage figures are in terms of available capacity. Hydrogen and industry opex figures include electricity and steam use.

We note:

- Industry has a very wide range in costs between different types of CO_2 sources; our figure represents a rough average but there will be a large spread in costs between different types of projects.
- We present gas power as whole plant costs for simplicity, although several projects propose to retrofit existing CCGTs. We use the whole plant costs in the funding models of Section 5, but isolate the CCUS spend for the econometric modelling in this chapter.
- Other than accounting for economies of scale in transport and storage, we do not differentiate costs between the scenarios to account for different levels of competition or technical learning. While our cost estimates are largely based on transport via pipes, this category could equally represent shipping.
- Costs represent those expected for the initial facilities deploying before 2030. We have not made any estimates of cost reductions that would be expected for follow-on facilities in designing the scenarios, but cost reductions may well be significant for the second and later generations of capture projects.

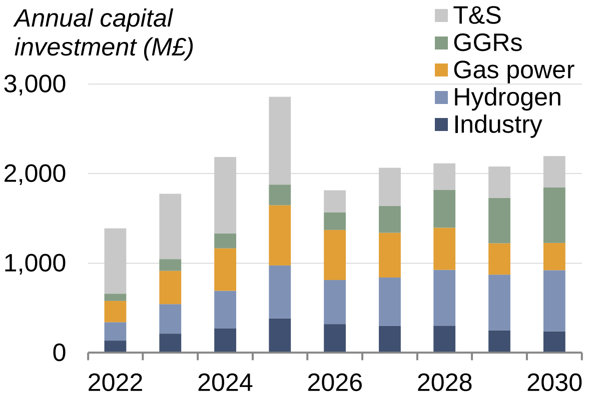
Exhibit 3.5 and Exhibit 3.6 show the annual capital investment required in the econometric modelling to 2030. For all sectors we have assumed that capex is uniformly distributed across a four-year build; we expect this to be at the upper end of project construction periods. Capital spend from 2027 includes spending on projects that would commission after 2030.

Exhibit 3.5 – Capital spend in Ten Point Plan scenario



Notes: Total spend to 2030 is £8.6b, including projects commissioning in 2031-33.

Exhibit 3.6 – Capital spend in Net Zero Ambition scenario

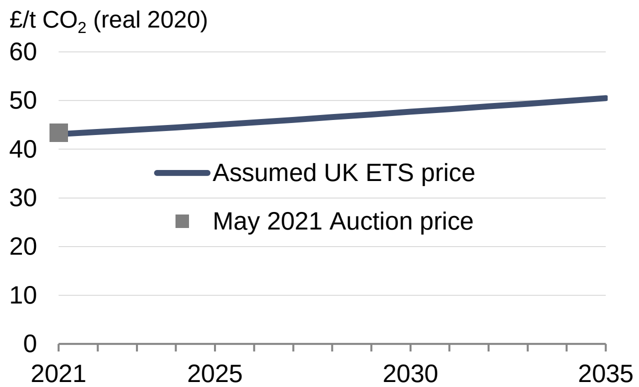


Notes: Total spend to 2030 is £18.5b, including projects commissioning in 2031-33.

3.1.5 Commodity prices

We have assumed that wholesale electricity and gas prices evolve as outlined in the Reference Scenario of BEIS' 2019 Updated Energy & Emissions Projections[13]. These scenarios are used to inform energy policy and associated analytical work across government. For consistency, we have also used the BEIS Reference scenario for carbon prices in the power sector and applied this to both the power and non-power sectors.

Exhibit 3.7 – Carbon price assumptions



Notes: Prices are from the BEIS 2019 Updated Energy & Emissions projections for power, as described in main text. After 2040, prices are held constant in real terms.

Carbon prices in the EU ETS have risen dramatically in recent years, from less than €25/t at the start of 2020 to over €50/t in early May 2021. The first UK ETS auction (May 2021) cleared at a similar price of £43.99/t. The BEIS' Reference scenario carbon prices outside the power sector are not in line with these developments (£25 in 2021 rising to £43 in 2030). We have therefore used the BEIS Reference price for the power sector as a broader UK ETS price (i.e., applied to non-power sectors). As shown in Exhibit 3.7, the 2021 price is broadly in line with the first UK ETS auction, and prices then rise by around 1.1% per year to 2040. We implicitly assume that the UK's Carbon Price Support level drops to £0/t by 2026.

[13] BEIS 2019 Updated Energy & Emissions Projections, Annex M, Oct 2020.

3.1.6 Paying for the investment

To determine the net effects at macroeconomic level, it is important to include the costs of the investment. Although it is not yet clear how all the investment will be funded, a basic set of assumptions was put in place to ensure that all investment is properly accounted for in the modelling. Exhibit 3.8 summarises the sources of financing assumed.

It is assumed that all private sector investment is financed through loans that are paid back over a ten-year period. Public investment is financed through a small increase in direct tax rates.

The investment costs for CO_2 transmission and distribution are shared between CCUS users in proportion to the levels of emissions captured, transported and stored.

Exhibit 3.8 – Funding sources

Sector	Support costs are:
Electricity	Added to electricity costs.
Industry	Government funded (recovered through taxation).
GGRs	Added to electricity costs.
Hydrogen	Added to gas prices.

Notes: In the absence of published business models, there remains significant uncertainty about the source of funding for greenhouse gas removals (GGRs) and hydrogen in particular. These assumptions were used to ensure costs were paid for in the modelling; we anticipate that alternative assumptions would have very minor impacts on the results.

3.2 The E3ME model

The analysis is carried out using the E3ME macroeconomic model. E3ME is a well-established tool that has previously been used in analyses for the UK government and the CCC. It is frequently used by the European Commission to contribute to Impact Assessments.

The model was originally developed in the 1990s and follows the Cambridge tradition of economic thought. The model is structured around a standard national accounting framework that breaks the UK’s economy into 70 sectors, which are linked together through input-output relationships that determine the structure of supply chains. Behavioural parameters are estimated using standard econometric techniques based on annual time series that go back to 1970.

E3ME is a simulation model that is designed for impact analysis through the development of scenarios. The input shocks, here mostly changes to investment, operating costs and energy consumption, are entered to the model and the outputs cover a range of standard macroeconomic indicators. The model covers the labour market in a relatively high level of detail, with econometric equations for labour demand, participation rates and average wage rates.

E3ME also includes a detailed treatment of the energy sector, which is used in the present analysis. However, the focus of the current scenarios is economic in nature, with only limited changes to the energy system.

Further information about the model, including the full manual, can be found at the model website www.e3me.com. A complete list of the model's equations is available in a recent academic publication.

3.3 Model results

The results in this section focus on the Net Zero Ambition scenario. The impacts in the Ten Point Plan scenario are similar but smaller in scale. We briefly present them at the end of this section.

3.3.1 Impacts on jobs

Exhibit 3.9 shows the net impact on jobs up to 2050. Most of the jobs relate to the additional investment and appear by 2025. At the peak there are around 10,000 additional jobs in the UK compared to the baseline, declining slowly over time as the cost of the CCUS equipment (reflected in higher debt levels) must be repaid. Once the debts have been repaid, however, higher levels of employment persist.

These results for jobs are 'net', as presented in standard impact analysis. This means that they include:

- the additional jobs from the investment and operational expenditures;
- supply chain and multiplier effects from these expenditures; and
- the loss of jobs from other activities that are displaced and any related supply-chain impacts.

The figures do not include:

- the scale of jobs potentially saved by allowing certain heavy industry sectors to remain in the UK in a net zero scenario; or
- any potential benefits from establishing an export industry for CCUS activities in the UK.

Both of these issues are discussed in Section 3.3.2.

Exhibit 3.9 – Employment impact in the Net Zero Ambition scenario

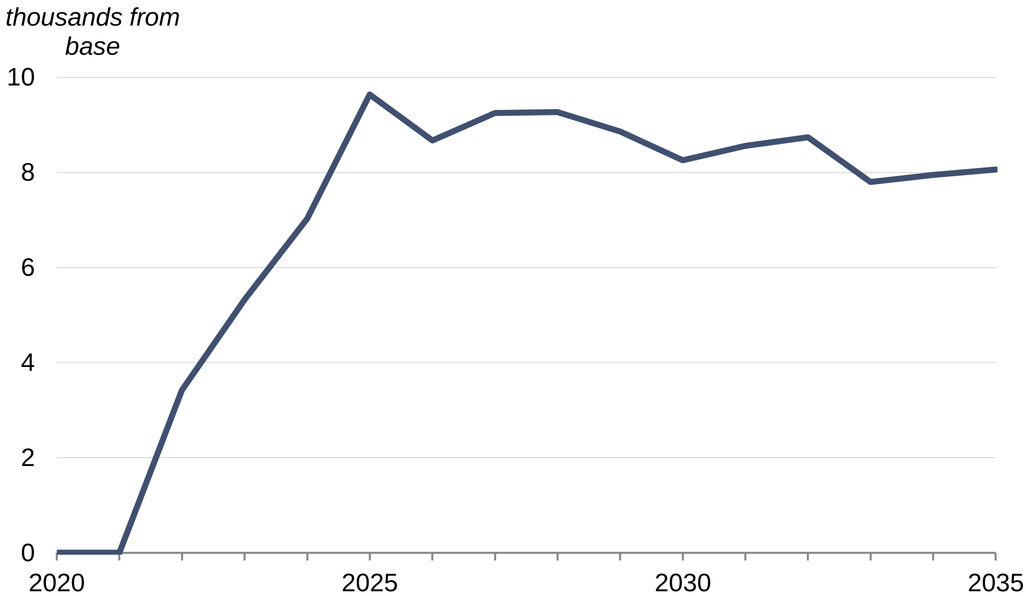


Exhibit 3.10 – Sectoral impact on employment (difference from base, thousands)

Sector	2030
Agriculture, etc	0.0
Mining & Refinery	0.1
Utilities	-0.1
Manufacturing & Construction	5.7
Distribution, Retail, Hotels & Catering	-1.7
Transport and Communications	0.9
Other services	3.4

Notes: Net Zero Ambition scenario shown

Many of the additional jobs are in manufacturing and construction, which are closely linked to the additional investment spending. These are often relatively high-skilled jobs. Service sector employment also increases both in 2030 and 2050, although there is a small reduction in employment in retail and consumer services in 2030 because of the investment costs that are ultimately borne by households (through taxation and higher energy prices).

There is a reduction in employment in the utilities sector, which results from lower demand because of the price increases for electricity and gas.

3.3.2 Wider employment effects

The scale of jobs in the previous section can be reported with some certainty; it is unlikely to be possible to create the required CCUS infrastructure without creating these jobs, even accounting for jobs that are offset elsewhere in the economy.

There will also be further employment impacts, although these are less certain. Broadly they fall into two groups.

The first group is the potential to build an export market for UK producers. We have not attempted to estimate the potential number of jobs created for exports but some of the sectors in which the jobs are created (notably professional services) are ones in which the UK has substantial expertise already. The *Energy Innovation Needs Assessment*[14] published by BEIS uses an approach based on existing global market shares to suggest that an additional 50,000 jobs could be created for exporting CCUS equipment and services. The report finds a similar number of domestic jobs to our analysis.

The second group of jobs relates to how feasible it is for heavy industry to continue operating in the UK without CCUS. If the UK is to achieve its goal of net zero emissions by 2050, all sectors of the economy must find ways to eliminate their emissions. For sectors that produce emissions from industrial processes (refineries, steel, cement and parts of the chemicals sector), CCUS is currently the only technologically feasible option.

Our assessment suggests that in 2030 there will be 53,000 people working in these specific sub-sectors in the UK, if they can continue production. These jobs are typically high-skilled jobs that are geographically concentrated, meaning that they are important for local communities. They are unlikely to remain viable without CCUS if the UK meets the decarbonisation targets described in Section 2.2, particularly given the steep industrial emission cuts required from 2030.

Furthermore, the elimination of UK sub-sectors such as steel could have further knock-on effects both up and down supply chains. It is impossible to predict how production patterns would change, but heavy industry (including the specific sub-sectors mentioned above) employs more than 250,000 people, whose jobs would be at risk if there was a hollowing out of basic manufacturing in the UK. It is likely that a small share of the estimated 2.5m jobs in broader manufacturing would be put at risk.

We can thus draw the following conclusions on employment effects:

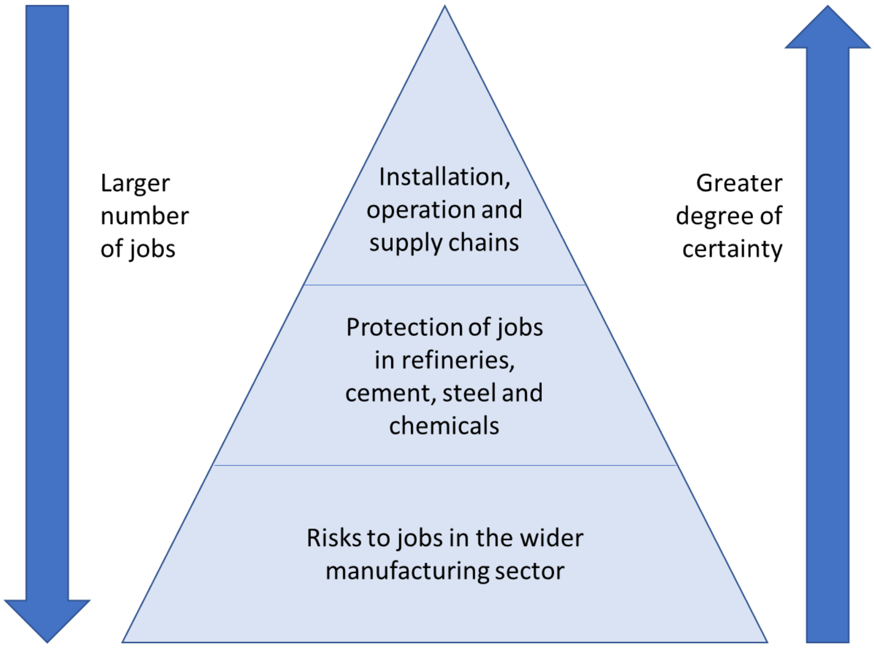
- We can say with a high degree of certainty that up to 10,000 new jobs will be created.
- We can say with a medium degree of certainty that CCUS will be required to save up to 53,000 jobs in a net-zero UK.
- Although uncertain, CCUS could protect a small share of 2.5m wider manufacturing jobs.
- CCUS could create additional jobs as an export industry (50,000 according to BEIS).

Exhibit 3.11 summarises these findings.

[14] Energy Innovation Needs Assessment, Vivid Economics for BEIS, 2019, p51-52 and 62.

Exhibit 3.11 – Interpreting the impacts on employment

CCUS investment delivers jobs directly, but also acts to protect jobs in carbon exposed industries.



Notes: Additional jobs supporting CCUS exports are not shown.

3.3.3 Economic impacts

Alongside the additional jobs created and protected, CCUS installation will provide a small increase to UK GDP. As shown in Exhibit 3.12, the GDP impacts are mostly driven by higher rates of investment because the spending on capex substantially outweighs spending on opex. As noted previously, the trajectory of impacts can be explained by the trends in investment, with increases seen to 2025 then pulled back due to accumulated debt, but higher GDP overall.

Similarly to the presentation of employment impacts, the results for GDP and the other macroeconomic indicators (Exhibit 3.13) are based on the reasonably certain outcomes and do not consider the effects of retaining UK industry or the potential for establishing a CCUS export industry in the UK.

The increases in consumer prices also reflect increasing debt levels, because some of the costs are eventually recouped through higher gas and electricity prices. Broadly, the costs of other products remain unchanged in the scenario over the projection period.

There is relatively little impact on the other main macroeconomic indicators. Imports may increase slightly for two reasons: first to provide some of the components for CCUS equipment that are not manufactured in the UK, and second because there are higher imports of natural gas (because conversion to hydrogen is less efficient than using natural gas directly). However, these effects are relatively minor.

Exhibit 3.12 – Impact on GDP (Net Zero Ambition)

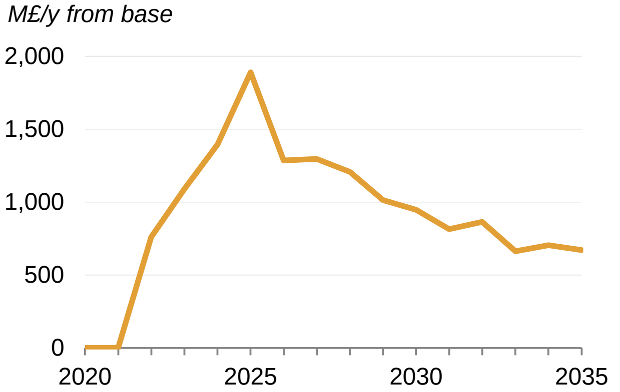
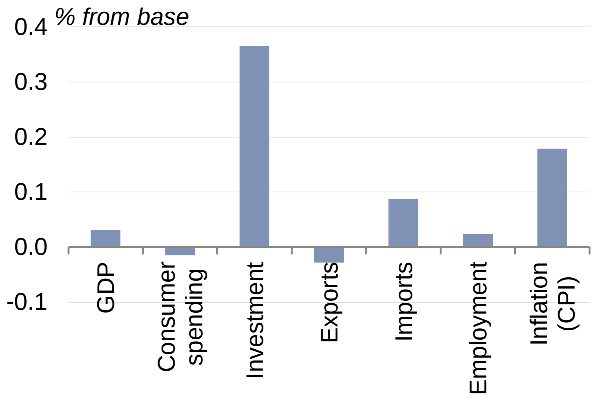


Exhibit 3.13 – Macroeconomic indicators – Net Zero Ambition 2030



At a sectoral level, the impacts on production levels follow a similar pattern to the results for employment (see Exhibit 3.14). The sectors that produce investment goods (mainly manufacturing and construction) increase rates of economic activity during the investment phase. Higher gas and electricity prices lead to lower consumption and output from utilities in 2050. The effects on services are dependent on activity in the wider economy.

Exhibit 3.14 – Sectoral impact on production (difference from base, £m (2020 prices), Net Zero Ambition)

Sector	2030
Agriculture, etc	0
Mining & Refinery	-85
Utilities	-12
Manufacturing & Construction	1445
Distribution, Retail, Hotels & Catering	145
Transport and Communications	60
Other services	532

3.3.4 The Ten Point Plan scenario

The results in the previous sections showed the impacts of the Net Zero Ambition scenario. Here we summarise the results from the Ten Point Plan scenario.

Exhibit 3.15 and Exhibit 3.16 summarise the main findings, with the dashed lines showing the impacts on employment and GDP for the Ten Point Plan scenario. The solid lines show the impacts in the Net Zero Ambition scenario for comparison.

With a lower level of ambition (10MtCO_2 rather than 22MtCO_2 captured annually), reflected in lower capex and opex levels, the impacts on employment and GDP are roughly halved in the period up to 2030. More generally, the results in the Ten Point Plan scenario show a halving in magnitude compared to those discussed in the previous sections.

Although we do not model job protection directly, the lower CO_2 abatement in the Ten Point Plan scenario is unlikely to offer the same level of protection to jobs at risk. By 2030, it has lower direct CCUS abatement within the ETS sector (5Mtpa of the 73Mtpa required under the CCC recommendation[15]), half the CO_2 removals recommend by the CCC, and only 1.4GW of hydrogen production from ATRs (of 5GW from low carbon sources targeted by the UK government). However, the Ten Point Plan scenario will have established CCUS infrastructure at scale allowing wider CCUS rollout in the 2030s.

Exhibit 3.15 – Employment impact in both scenarios

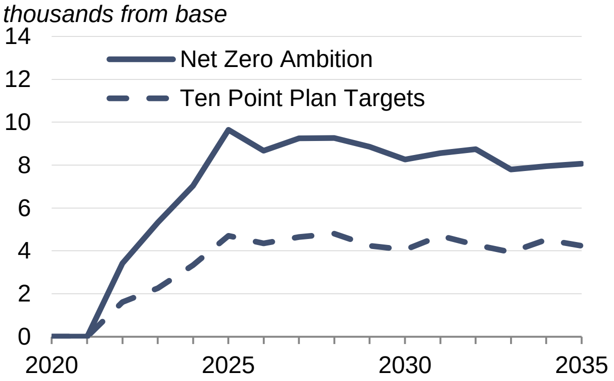
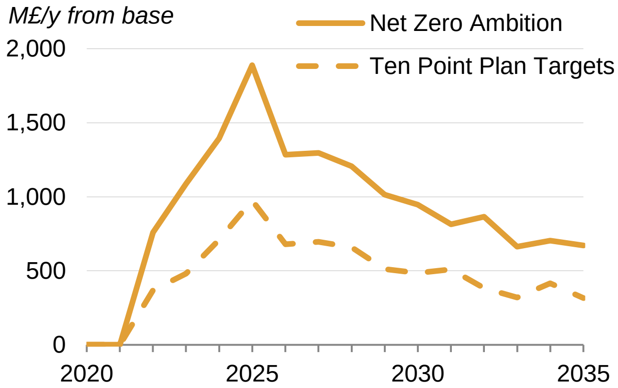


Exhibit 3.16 – GDP impact in both scenarios



3.4 Key messages

The results from the macroeconomic modelling provide a message of the potential economic benefits. We can say with reasonable certainty that prioritising investment in CCUS will lead to net job creation and an increase in economic production.

The scale of the increases remains unclear and depends in part on the level of ambition in CCUS roll-out and on other macroeconomic external factors. When interpreting these results, it is important to consider the role that CCUS could play in allowing the continued operation of heavy industry in the UK. As the BEIS *Energy Investment Needs Assessment* report noted, there is also the potential to establish CCUS expertise in the UK that could be exported.

Although regional factors go beyond what can be assessed in the current modelling exercise, it should be noted that the impacts could go beyond

[15] Based on 2019 emissions of 130Mtpa and 2030 target of 57Mtpa; most reductions will come from non-CCUS sources.

those reported by the model and have substantial impacts on communities that depend on localised heavy industry.

The key messages are thus:

- There will be socio-economic benefits to the UK from investing in CCUS, with higher levels of investment yielding greater benefits. At its peak under the Net Zero Ambition scenario, UK GDP could increase by £1.9b with nearly 10,000 additional jobs created.
- These benefits could be increased substantially if we include the protected value from the industrial sectors subject to the CCUS roll-out for which alternative decarbonisation options are unavailable, including 53,000 jobs within these sectors.
- There could be further benefits to the UK's economy if an export industry was established. Previous analysis has suggested that such an export industry could create 50,000 additional jobs.

To summarise, establishing CCUS capabilities is expected to provide direct economic benefits, while simultaneously increasing the resilience of UK industry.

4 Lessons from UK offshore wind

In the UK, offshore wind has marched forward over the past decade with a rapid roll-out of capacity, a strong pipeline of forthcoming projects and a thriving sector established. CCUS has had a more stop-start journey, but is aiming to scale up and replicate offshore wind's successes. Although recognised by the CCC, IEA and IPCC as a necessity to meet net-zero by 2050, CCUS is likely to require some form of assistance to reach widespread deployment. In this section we set out the lessons learned from UK offshore wind to investigate parallels - in situation and potential - that can be applied to CCUS. Attaining the current situation for offshore wind has been no small feat. A clear funding framework, consistent government targets, a supportive policy environment and industry-government collaboration have all contributed to facilitating the necessary supply-chains and investment.

4.1 Background

Back in 2011, the UK had 2GW of offshore wind operational[16]. While technical challenges were being overcome, offshore wind was still seen as a relatively expensive low-carbon technology albeit with the potential to create a significant UK based industry to drive cost savings and decarbonise significant volumes of electricity production.

Today the scale of deployment of UK offshore wind is seen as a clear success story; currently, in 2021, the UK has over 10GW of offshore wind capacity installed[17], and recent auctions have awarded strike prices under £50/MWh[18] reducing and potentially removing the need for consumer subsidies.

[16] The European offshore wind industry key trends and statistics 2011, EWEA, January 2012
[17] 'Wind Energy Statistics', Renewable UK, accessed 14 May 2021.
[18] Based on Doggerbank A, B, C and Seagreen sites awarded in 2019.

Affordable mass deployment is becoming a reality and looking to the horizon, the UK Government is now targeting 40GW of offshore wind by 2030[19] to further support climate goals. As an industry, it currently provides approximately 26,000 jobs in the UK, with announced potential for 40,700 direct jobs by 2026[20].

There are clear parallels between CCUS today with the situation for offshore wind from 10-years ago. CCUS is seen as a relatively expensive technology with the potential to create a significant, scalable industry that drives cost savings. It is also needed as a decarbonisation tool, as it is able to decarbonise significant parts of the economy.

A major stepping stone for offshore wind in reaching its current position was the work of the Offshore Wind Cost Reduction Task Force – a collaboration between the UK government[21], the renewables industry and The Crown Estate - and the recommendations made within their 2012 report[22]. Building on the Government's UK Renewable Energy Roadmap (July 2011), this industry-led task force's aim was to produce a path and action plan to get the cost of energy from offshore wind down to £100/MWh by 2020 – a target that has now been substantially overtaken.

The report states that the three following prerequisites are required to reduce costs and allow offshore wind to reach its full potential in the UK:

(i) a stronger and more consistent project pipeline with minimised fallow periods would allow confidence in the supply chain to improve, avoid downtime costs and allow the industry overall to learn, innovate and develop best practice more rapidly;

(ii) an increased supply chain capacity with a greater number of new entrants would improve price competition; and

(iii) a supportive policy climate with continued and demonstrable political support would improve investor confidence, in turn offering cheaper finance and a greater appetite to invest in projects and infrastructure more dynamically in anticipation of market need.

A significant part of offshore wind's success is because the required pre-prerequisites within the Offshore Wind Cost Reduction Task Force report were met and the commitment from governments was maintained over the last decade. Key among these was visibility that funding would continue

[19] 'The ten point plan for a green industrial revolution', BEIS, 18 November 2020.
[20] Offshore Wind Industry Council (OWIC) media release, 25 March 2021.
[21] DECC was the (UK Government) Department of Energy and Climate Change, now reformed as BEIS: The Department for Business, Energy and Industrial Strategy.
[22] Offshore Wind Cost Reduction Task Force Report, June 2012.

under the Renewable Obligation scheme and, later, Contracts for Difference (CfDs)[23] and the Levy Control Framework.

4.2 Key lessons from offshore wind

Drawing on AFRY's experience and a literature review, we have focussed on five main components of offshore wind success as comparable categories that may have transferable lessons for CCUS. Each is important in its own right, but works interdependently. This list is not designed to be exhaustive.

4.2.1 Consistent supportive messaging

The Ministerial foreword to the Offshore Wind Cost Reduction Task Force report states:

> *"As the industry takes action to bring down costs, Government will also act to ensure that the "enablers" such as transmission networks, the planning system and financial support mechanisms are in place. We are committed to getting these right to provide the industry with a strong base for the work that developers, suppliers and others are keen to take forward."*

Over successive governments, the UK has provided consistent, supportive messaging regarding offshore wind, for more than the past decade. It has been clear and conveyed that offshore wind is required for combatting climate change, now meeting net zero, and as an area of opportunity for the UK and job creation. This gives reassurance for investors, developers and the supply chain. The language used by Government is pivotal as this communication provides the backdrop for all other discussions and steps.

In the 2011 UK renewable energy roadmap, which set out how the UK planned to meet the 2020 goal of 15% energy use from renewables, UK offshore wind is described as world-leading and listed prominently as 1 of the 8 technologies required to meet the target[24].

Science communication with the public on offshore wind has been framed as necessary for climate change, and public support remains high with 76% in favour and only 4% opposed[25]. There has been some opposition to onshore wind (although support is still relatively high at 70%[25]), but this has not been as much of an obstacle for offshore wind.

The UK Government has set first overarching renewables (RES) targets, of which offshore wind was a key component, and, continues to set offshore wind targets. These targets provide direction for subsequent policy and Government funding. Initially, back in 2009, these fed through from EU-wide

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[23] CfD = Contract for Difference, a UK renewable energy support scheme.
[24] UK renewable energy roadmap, DECC, 2011 with updates released for 2012 and 2013.
[25] 'Public Attitudes Tracker: Wave 37', BEIS, 13 May 2021.

RES targets for 2020 under the RED (Renewable Energy Directive), but the UK has since gone on to define its own offshore wind targets as part of its trajectory to attempt to meet the CCC goals and net zero in 2050.

4.2.2 Financeable model

Currently, support for UK offshore wind, (as well as for other renewables), is awarded under the CfD (Contract for Difference) scheme, by the UK Government. CfD is a support model now used in various countries across Europe and a range of technologies and has been widely accepted by the financial community as a low-risk support structure. Prior to this, UK schemes relevant to offshore wind went through iterations of the 'Renewables Obligation' (RO, often referred to as 'ROCs', i.e. RO Certificates) and 'Final Investment Decisions Enabling for Renewables' (FiDeR) contracts, with the latter to ease the transition from RO to CfDs.

Having a reliable support scheme and grandfathering previous schemes as newer ones come in, provides continuity and reassurance to the finance community, which encourages buy-in. This in turn has brought - and continues to bring – interest and investment.

4.2.3 Certainty of funding

Having RES targets and a financeable model are parts of the jigsaw and function as a snapshot in time, however, to present a reliable investment model, offshore wind needed a funding framework from Government. This provides reassurance that not just one auction will take place, but that there will be future auctions as well. The industry can then work to develop a supply chain, and new sources of capital can be encouraged to develop the necessary know-how to enter the sector and bring down project financing costs.

For offshore wind, as well as other low carbon technologies, this funding framework has been the Levy Control Framework (LCF) since 2011, transitioning to become the Control for Low Carbon Levies[26] as of 2017. The LCF both supported and controlled projects, as well as the cost impact on the energy bills of consumers, through an annual set budget as part of a multi-year budget. For 2020/2021 the annual budget was set to be £7.6 billion (2011/12 prices)[27], however, as spending was likely to be higher this was revised up to £8.6 billion (2016/17 prices)[26]. Although there have been some changes over time, there has remained continuity of support and oversight from Government. The changes in 2017 effectively placed some limitations on further deployment; however, the LCF had already provided considerable support and certainty in those early growth years[28], in particular the presence of a multi-year budget provided confidence that the financial

[26] Control for low carbon levies, House of Commons Library, 20 December 2017. Quoted in 2016/17 prices.
[27] Levy Control Framework (LCF), BEIS, 25 November 2016.
[28] Though it should be noted its introduction was sudden, and as there had not previously been a public cap to funding, the immediate effect was to increase the perception of risk to funding allocation.

resources existed to build the sector. Allocated subsidy payments for existing ROC, FIDeR and CfD awards (awarded since 2003) for UK offshore wind are now in the region of £4-5 bn/year[29].

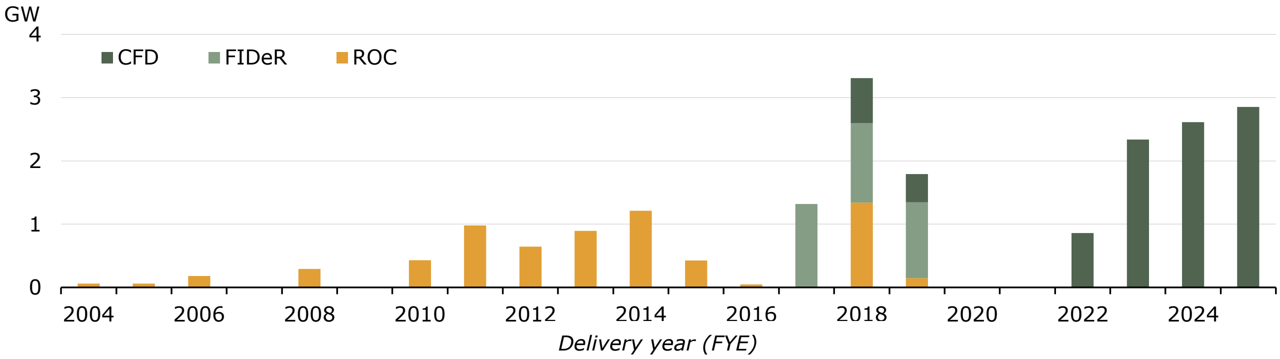
Additional to the funding framework, UK offshore wind saw some benefit from the Green Investment Bank (GIB), set up in 2012 by the UK Government via BEIS. Its existence, specifically for green, low carbon projects, signalled that there would be investment available, both then and in future; and showed that institutions were willing to invest in something relatively unproven. Loans tended to be relatively small scale and alongside other commercial lending decisions which in turn helped bring additional sources of capital to the market. Following its privatisation announced in 2015[30], it is now independent and known as Green Investment Group.

4.2.4 Building the industry

Offshore wind has continual procurement rounds (see Exhibit 4.1 showing capacity by commissioning date), which have provided a consistent pipeline for supply chain planning as well as investment. This also facilitates cost reductions as economies of scale can be achieved and advanced orders can be made.

Exhibit 4.1 – Supported offshore wind capacity by commissioning date

There has been a relatively consistent pipeline over ~20 years for UK offshore wind, with ROCs accredited when projects commissioned and repeated competitive auctions for CfD awards.



Notes: Years shown are the financial year end of the delivery year, i.e. if build occurs in December 2016, which is financial year 2016/2017, it is shown here as 2017. For projects which are to be commissioned in phases, delivery year is shown for the first phase of the project. Round 4 areas not included as CfD not yet awarded.
Source: BEIS, Ofgem.

Initiatives such as the Offshore Wind Accelerator (OWA)[31] and Offshore Renewable Energy (ORE) Catapult[32] have provided both funding for research, and a forum / collaborative space, encouraging industry and academia to work together in order to reduce costs and promote innovation.

[29] This amount varies, depending on the captured wholesale price for offshore wind among other factors, and could even be zero or a payment to Government.
[30] Green Investment Bank: Proposed Sale, House of Commons Library, 24 January 2017.
[31] OWA hosted by the Carbon Trust and present since 2008. Mainly focussed on reducing cost, promoting collaborative research and developing industry best practice.
[32] ORE Catapult covers 5 main areas (Research, Innovation, Testing & Validation, Supply Chain Growth) and works with SMEs, industry and academia.

Developments in UK offshore wind were not happening in isolation as concurrent advancements were made across Europe, with for example, the Danish building on their expertise in onshore wind. UK offshore wind industry building has been successful on many fronts and excelled in some particular areas of expertise. Looking forward, as outlined in the 2020 Offshore Wind Sector Deal[33] and reiterated in the 10 Point Plan[19], the UK has committed to increase local content in offshore wind from an estimated 48% in 2017[34] to a minimum of 60% by 2030.

4.2.5 Broad industry buy-in

There has been and continues to be high level of engagement and buy-in from the offshore wind industry. This is demonstrated, for example, through its collaboration of industry and Government on the Offshore Wind Cost Reduction Task Force (2012), and subsequently, including the Offshore Wind Sector Deal (2020). Industry have also shown a willingness to collaborate with academia through the OWA and ORE Catapult. In order to achieve the targeting cost reductions, industry participation has been paramount.

4.3 Transferable learnings for CCUS

Going forward, there is an opportunity for CCUS to mirror and, in selected areas, perhaps exceed the successes of the offshore wind industry over the past decade, with the aim of deploying CCUS at scale in the UK in a manner which maximises the benefit to decarbonisation goals and the UK economy.

As with offshore wind, there is an expectation of significant cost savings as CCUS is rolled out. On the capture side, this is evidenced by both the continued reduction in capture costs at relatively low deployment levels, and ambitious cost targets set by suppliers[35]. On the transport and storage side, cost reductions will largely come through economies of scale. Likewise, the CCC's work makes clear that future volumes of CCUS will drive an industry ultimately worth several billion pounds per year in the UK alone.

Of the criteria set out in this chapter, offshore wind broadly benefitted from all of these elements over the past decade, but the picture for CCUS is more mixed. We present our summary GAP analysis for CCUS in Exhibit 4.2, showing how much has been delivered (current status) and our judgement of whether overall progress is on track relative to required timescales (GAP analysis box colours). The commentary below covers the five key areas of:

- certainty of funding;
- supportive policy and communications environment;
- building the industry;
- financeable model; and
- broad industry buy-in.

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[33] Offshore wind Sector Deal, BEIS, 4 March 2020.
[34] Offshore Wind Industry Investment in the UK, 2017, RenewableUK.
[35] Such as $30/t: www.carbonclean.com/modular-systems accessed 27 May 2021.

Exhibit 4.2 – GAP analysis for CCUS on 5 main components of offshore wind success

UK CCUS needs funding certainty and an ongoing supportive policy environment to flourish

		Current status	GAP Analysis
1	**Certainty of funding**	Clear targets are in place Some CIF grant money available for early T&S	**Funding framework needed**
2	**Supportive policy & communications environment**	Currently supportive signalling from Gov. Public awareness low, but 93% supportive or ambivalent	Need ongoing supportive messaging from Gov. Public communication requirements may need further work, but consultations underway
3	**Building the industry**	Early stages: Track 1 in progress, Track 2 announced. Potential in UK, with industrial clusters + O&G experience	Continual procurement needed Optional: Design in local content if want UK to produce & export. Policy required.
4	**Financeable model**	BEIS in process of addressing: 3 business models released, 2 to be released shortly	(Dependent on BEIS release)
5	**Broad industry buy-in**	Industrial Decarbonisation Challenge Phase 2: £171m Gov./£342m Industry. CCUS Cost Challenge Task Force	(Contingent on 1-4)

Status legend On track | In progress | Not on track

Notes: Current status indicates how much of each area has been delivered. GAP analysis box colours relate to traffic light red, amber, green in terms of whether progress is on track relative to what would be expected at this stage, including tasks in progress but not yet delivered. Red indicates not on track so greater attention required. O&G = Oil & Gas. T&S = CO_2 Transport & Storage.

Source: AFRY analysis; CCSA; Public Attitudes Tracker: Wave 37, BEIS, 13 May 2021; Public dialogue commences on Carbon Capture Usage and Storage, Sciencewise, 2020.

Certainty of funding

The CCUS Infrastructure Fund (CIF) is a preliminary funding framework in place, to provide support to 2025. This adds visibility that short-term funding is available, but is not designed to drive projects by itself, as industry investment would need to be matched with long-term revenue support. CIF is provided as a grant, rather than being based on output, and must be matched by industry.

The presence of clear targets already in place for 2030 is significant, providing an indication of future volumes to be procured, but there is no indication of what funding levels would be associated with this, and hence uncertainty about whether required funding would be made available. This means there is a need for a more extensive and longer duration funding framework, similar to the LCF used for offshore wind, to go hand in hand with these deployment targets and provide visibility on support levels. Such a framework should be sufficiently long-term to provide certainty to investors in order to support the development of a CCUS industry and supply chain.

This requirement category is rated 1 out of 4. While significant funding has been announced for particular uses, there remains a need for long-term funding framework certainty.

Supportive policy and communications environment

The policy environment surrounding CCUS is currently positive and supportive, with a strong ramping up of government efforts in CCUS over the past 3 years. Historically however, the UK has had two highly prominent cancelled CCUS competitions, as well as inconsistent support and messaging that previously led to significant uncertainty in the industry.

On the whole (93%[36]) the public are either supportive or ambivalent towards CCUS, which bodes well. However, generally public awareness around CCUS is low with 69% having very little or no knowledge of it[36]. At present a public dialogue project commissioned by BEIS is ongoing with findings due to be reported in 2021[37].

This requirement category is rated 2 out of 4 – for CCUS to succeed, the current support needs to continue and there is significant scope for further public communication and engagement.

Building the industry

The process of building the CCUS industry is showing promising direction and momentum. With Track 1 underway and Track 2 already announced, this demonstrates there is a clear structure of Tracks taking place in phases, with potential for subsequent to follow on. Whilst there is a roadmap for Tracks 1 and 2, there is still a need for further detail on Track 2; and as described for offshore wind, the industry requires an ongoing consistent and long-term pipeline of procurement.

Given the funding recommendations above, one simple mechanism to indicate a long-term procurement pipeline would be to ensure that the funding framework increases over time, as occurred for the LCF. Whether the framework represents minimum, maximum or target funding levels, rising funding levels indicates scope for future allocation and an ongoing project pipeline.

This requirement category is rated 2 out of 4 as recent announcements are favourable – continual procurement will be required to deliver on the promising recent momentum, although this is an action that must be delivered over many years.

Financeable model

As BEIS have already produced three out of five business models planned for CCUS, this requirement category (financeable models) appears broadly in good shape. The business models released are: transport and storage; power carbon capture; and industrial carbon capture[38]. These have broadly been received positively, and the remaining two models are due to come out this year (2021). BEIS is actively involved in discussions with industry around these, although the lack of both detail and certainty at this stage presents issues for hydrogen and removals projects within the cluster allocation process.

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[36] Public Attitudes Tracker: Wave 37, BEIS, 13 May 2021: 35% of the public have never heard of CCUS and a further 34% are aware yet do not really know what it is.
[37] Public dialogue commences on Carbon Capture Usage and Storage, Sciencewise, 2020.
[38] Carbon capture, usage and storage (CCUS): business models, BEIS, 21 December 2020.

These models are also likely to need legislative action in 2021 or 2022.

This requirement category is rated 2 out of 4 as strong government work with industry collaboration has led to the release of 3 funding models. The expected release of 2 more in the near future is expected to reduce the gap and cover most potential sources of CO_2 capture, so with expected developments this category is 'on track'.

Broad industry buy-in

For CCUS, there is broad industry buy-in, as evidenced by recent highly collaborative work on the CCUS Cost Challenge Task Force report (2018) and the co-funding provided by industry as part of the Industrial Decarbonisation Challenge (Phase 2 saw £342m from industry, double that provided by government, £171m). Similarly to offshore wind, investing in CCUS is investing in the UK's future, and there is broad industry buy-in that it is not only for its essential role in reaching net zero, but also for the jobs it is likely to provide, as summarised in chapters 2 and 3.

This requirement category is rated 3 out of 4 as industry buy-in to the technology and need is high, although the other elements of support still remain unproven.

4.4 Key Messages

Offshore wind is a clear UK success story, delivering domestic jobs and cheap, clean electricity, and forming a cornerstone of the UK's decarbonisation efforts. There are a number of similarities between CCUS position now, and offshore wind's situation a decade ago. While only time will tell how CCUS develops, learning from the successes of offshore wind may allow some barriers to be removed from the development of this industry.

Looking at five key components behind offshore wind's success story, CCUS is performing well in two, with positive developments around financeable models and industry buy-in in particular, although work remains to be done. However, our analysis has flagged three areas that we consider need improvement. Two are largely long-term developments to continually deliver over the coming years:

- consistent supportive policy and messaging; and
- continual procurement of projects.

The third can be delivered in the short term: the CCUS industry needs visibility that there will be funding available in the long term to match the current volume targets. For offshore wind in 2011, this visibility was provided by the Levy Control Framework. Although this was imperfect in terms of an enabler, even acting as a barrier to new projects if the framework limit was exceeded, it provided early certainty of funds as the industry developed whilst also protecting the public purse. For CCUS, something similar is needed. Some examples of a form this could take include:

- a funding maximum similar to the LCF, which broadly describes an estimated funding path; or

- a funding range, with min / max limits acting to provide both surety to industry and consumers / taxpayers, whilst maintaining flexibility in future policy; or
- a minimum funding level declared in 2021, with a revised funding path to be released after the cluster allocation process provides better visibility on project costs.

Whichever format is chosen, two key features should be included. Firstly, the funding range should be clearly set-up to increase over time on an absolute basis as needed to support continual rather than stop-start procurement. Secondly, the framework needs to be sufficiently long-term to provide certainty to support the development of a CCUS industry and supply chain. For the LCF, foresight was around a decade; discussions with the CCSA and CCUS community suggest a similar timeframe is needed for CCUS, which would mean a funding framework specified to around 2030, in line with the timeline of the 10Mtpa target. This would provide the certainty industry needs that financial support will be available to back up the current volume-based target.

5 Funding framework required

When establishing a funding framework, it is key to understand how large it should be – too small risks halting the industry, while too large risks excess expenditure. Here we estimate required support levels for our two CCUS scenarios and discuss some of the uncertainties behind those funding needs.

Based on the costs used in the econometric modelling of Chapter 3, we are able to estimate the funding levels required for our scenarios. Section 5.1 presents our key assumptions and results. Section 5.2 discusses the assumptions behind these numbers and potential alternatives, and Section 5.3 shows a sensitivity analysis – given different assumptions, how different would total funding levels be?

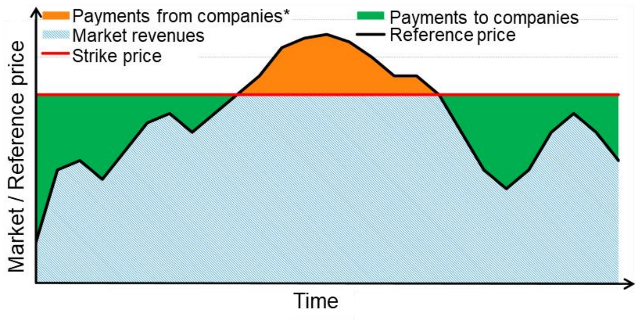
5.1 Funding principles and costs

In estimating the support required to deliver CCUS, we have in mind some fundamental principles similar to those involved in the Control for Low Carbon Levies (previously the Levy Control Framework – we use LCF for simplicity), used for delivering low-carbon electricity. These basic principles are:

- The framework covers all support payments paid to CCUS providers, through the CCUS funding models, regardless of who pays: treasury, electricity consumers, gas consumers etc.
- The framework considers support payments, NOT strike prices. Exhibit 5.1 demonstrates the difference for a baseload electricity CfD, where the support payment is the difference between the strike price and the electricity price. For 2-way CfDs, this includes payments from industry when the reference price is above the strike price; 1-way CfDs do not pay back in this way. Similar logic applies for CfDs against other references, such as the carbon price.

— All support payments relating to the CCUS facilities have been included for simplicity. In practise, overlaps with the hydrogen strategy (for hydrogen production) and the LCF (for removals and gas power) may mean that some support payment changes may be allocated to different 'pots'.

Exhibit 5.1 – Contracts for difference

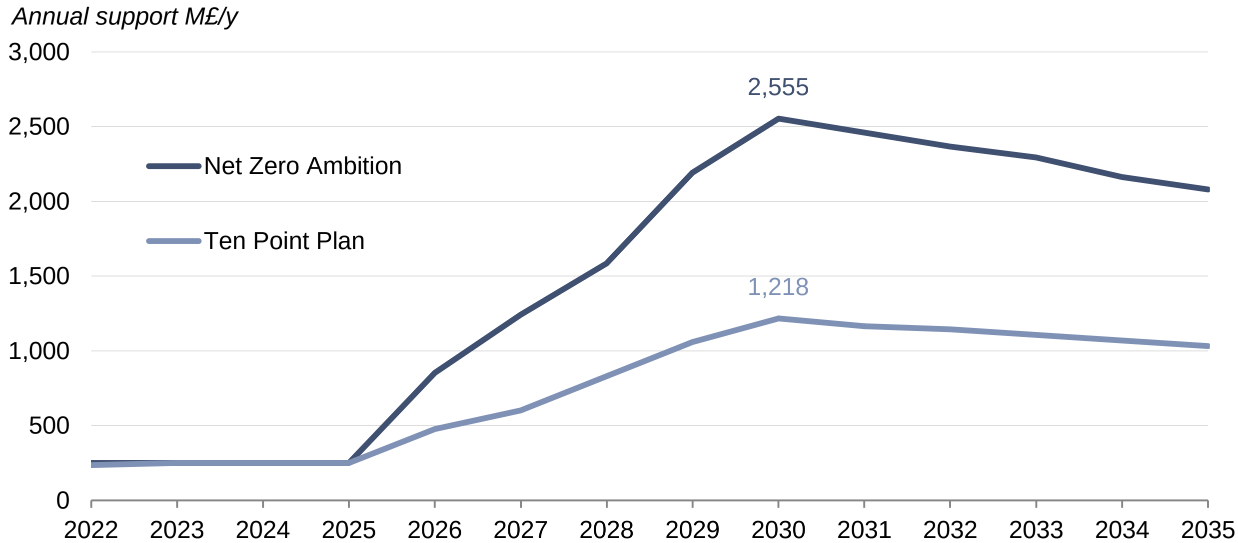


Notes: *Payments from companies are made in a 2-way CfD when the reference price exceeds the strike price, but not in a 1-way CfD.

We assume that funding support covers the "missing money" for each sector, based on the costs and required returns laid out in Exhibit 3.4. BEIS has laid out business models describing potential support mechanisms for industrial CC, gas power CC, and transport and storage. Absent formal BEIS business models for bioenergy CC and hydrogen with CC we have made our own assumptions about what the support structures will look like, liaising with BEIS and CCSA members to represent current best views.

The total support required for deploying CCUS by 2030 in the two scenarios is shown in Exhibit 5.2, representing the combined cost of funding all capture facilities and, through T&S fees, the transport and storage network. After spending through the CCUS Infrastructure fund between 2022 and 2025, support in the scenario rises over time to £1,218m in 2030 for Ten Point Plan, and £2,555m in 2030 for Net Zero Ambition. Ongoing support declines between 2030 and 2035 in both scenarios, as industrial facilities reach the end of their capex support periods, and then broadly remains steady until 2040 as other support payments continue under 15-year CfDs. We have not shown support requirements for facilities commissioned after 2030; these would be expected to be substantially lower on a per-unit CO_2 basis as learning and experience would reduce costs for follow-on facilities, while business models may also adapt to build in more market-based revenues (particularly for GGRs and hydrogen).

Exhibit 5.2 – CCUS support required for facilities operating by 2030



5.2 Support structure assumptions

In determining support levels required for CCUS, we have made various assumptions about the funding mechanisms involved. At a high level, the various business models we assume are outlined in Exhibit 5.3.

Exhibit 5.3 – Overview of support structures assumed in support calculations

Sector	Model for support	CfD against	Support term (years)	CfD direction
Industry	ICC CfD*	Carbon price T&S fee	5 (capex) 10+5 (opex)	1-way
Gas power	Dispatchable CfD (DPA)*	Reference plant cost T&S fee	15	2-way
GGRs**	CfD and negative emissions payment	Electricity price T&S fee	15	2-way
Hydrogen	CfD	Gas price Hydrogen price T&S fee	15	2-way
Transport and storage	Regulated asset model*	n/a	30***	n/a

Notes: All CfDs are assumed to be indexed to inflation.
* The models for Industry, Gas power and T&S are based on the BEIS draft models, including the May 2021 update.
** Modelled as BECCS within the power sector.
*** This refers to the asset economic lifetime used for depreciation within the RAV model, and represents a blend of assets which are likely to have lifetimes in the range of 20 to 40 years.

In all cases we have assumed that technical performance meets expectations for each facility. While the draft business models contain detail about risks and payment variations in case technical performance is not met, we do not model those potential outcomes.

Additional assumptions for the reference case presented in Section 5.1 are outlined in Sections 5.2.1 to 5.2.6. A number of these assumptions are also covered by sensitivities in Section 5.3 which outline how much the funding figures would change if a different assumption had been used.

5.2.1 CCUS Infrastructure Fund

We have assumed that £1b is allocated from the CCUS infrastructure fund and used to offset the capital costs of capture projects. We have allocated this money as follows:

— £200m is used to support capital expenditure for industrial projects commissioning in 2026 (Net Zero Ambition scenario) or 2026-27 (Ten Point Plan scenario). This corresponds to grant support of 37% and 44% of capital costs respectively.

— £800m is used to support capital expenditure for transport and storage infrastructure commissioning in 2026.

In both cases, the grant money is paid in line with capital expenditure assumptions – that is, flat in real terms over the 4 years prior to commissioning.

5.2.2 Industry

While basing our assumptions on the draft Industrial Carbon Capture business model from BEIS, we have additionally assumed:

— The combined payment (capital repayment plus operation payment including the free allocation adjustment) is modelled as a 1-way CfD; that is, the net annual payment to industry does not go below zero.

— The capital recovery strike price is calculated based on recovering capex spend, without considering extra value that may accrue due to the 1-way nature of the CfD, or the residual value of the CCUS facility at the end of the support period.

— The carbon reference price is equal to each scenario’s carbon market price.

— Free allowances are issued covering 50% of the emissions captured as part of CCS, the free allowance floor is not triggered, and free allowance compensation is kept in the business model for all projects to 2030.

— Any value to government from free allowances forfeited by industry (e.g. by adding these to auctioned volumes) is not counted against support costs. This means we include the cost of compensating industry for these allowances; but do not offset any savings that would accrue if these allowances were monetised.

— No increase in value due to producing ‘low carbon’ products.

— Industrial facilities are in the UK ETS. While this is true for most facilities, Energy from Waste plants are not currently inside the UK ETS.

— The counterfactual is that industrial plants continue operating profitably and emit CO_2 equivalent to that captured in the CCS scenarios.

— Electricity is charged at the wholesale price plus 2p/kWh.

We have also assumed that all industrial facilities have 'average' costs; it is possible that if CfDs signed are 1-way, and substantial opex differences exist between sites, then some additional support costs will accrue when some sites reach the CfD floor and others do not. Broadly these assumptions (particularly not monetising free allowances and assigning no additional value to low carbon products and no residual asset value) increasing support costs all else being equal, particularly at high expected carbon prices. Whether industries bid on this basis, or assign value to the above items, will be revealed through the contract allocation processes over 2021-22, while treatment of free allowances handed back is a policy decision.

5.2.3 Gas power

While basing our assumptions on the draft Dispatchable Power Agreement (DPA) business model from BEIS, we have additionally assumed:

- Our costs are based on a newbuild gas plant for simplicity. Some of the CCUS projects under consideration involve retrofitting existing CCGTs; these may have lower costs, but potentially also lower efficiencies. Modelling retrofits would also require a counterfactual value for the existing CCGT where these are competitive in the market without support.
- The reference plant has a 62.0% LHV efficiency (56.0% HHV), in line with the example provided in the DPA.
- CCGTs run 70% of the time they are available[39] and on average capture 120% of the baseload power price.
- Plants that sign a DPA will not be eligible for capacity payments, but as they provide firm capacity to the market they will reduce the volume of capacity that will be need to be procured at auction, and hence reduce capacity remuneration costs. We account for this saving in capacity support costs based on a capacity market clearing price of £15/kW.

5.2.4 Greenhouse gas removals

We have modelled greenhouse gas removals using a representative BECCS power plant, as the technology that is likely to dominate early capture volumes in this area. In the absence of a published business model, we have assumed that BECCS facilities will receive a baseload electricity CfD, and may receive additional payments, e.g. for negative emissions. As per the principles outlined in Section 5.1, we have included the cost of both payments within our calculations. It is possible that some of these support costs will be covered by the Control for Low Carbon Levies, which would reduce the spend assessed under a separate CCUS funding framework.

As with gas power, we assume that BECCS will not be eligible for capacity payments, but account for their reducing capacity procurement costs at a clearing price of £15/kW. Unlike gas power, we have assumed BECCS plants

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[39] As per the assumptions used in the Cluster Sequencing cost considerations template, BEIS, 2021.

will be retrofits and uneconomic without support, due to the large volume of biomass generation currently contracted under CfDs and ROs. Support payments cover opex of the full plant (including biomass costs) and capex of the CCUS additions.

Greenhouse gas removal technologies do not have a mechanism for funding to be reduced as carbon prices rise, because negative emissions are not awarded a value under the UK ETS. It is possible that ETS rules will change, that the business model will contains such a mechanism, or that selling allowances on voluntary markets is permitted, but in our base case we assume no revenue streams related to the carbon price.

The impacts of these assumptions are explored in the sensitivity analysis of Section 5.3.

5.2.5 Hydrogen

In the absence of a published business model for supporting hydrogen production from Autothermal Reformers (ATRs), we have assumed that ATRs will receive a CfD against both the natural gas price (representing their costs) and the hydrogen value (representing their revenues). In other words, support payments would rise if natural gas prices rose, and fall if hydrogen prices rose.

We have assumed that hydrogen prices move in line with natural gas prices, or equivalently, that hydrogen substitutes natural gas as a fuel. This means that the hydrogen business model does not have a mechanism for funding to be reduced as carbon prices rise. We recognise that not all hydrogen users will use hydrogen to substitute natural gas, while zero carbon fuels may also attract a premium beyond their substitution value, and some users may attract extra value from hydrogen if they are in the ETS (and hence pay lower emission costs). We explore some possible alternative assumptions within the sensitivity analysis in Section 5.3.

5.2.6 Transport and storage

While basing our assumptions on the draft Transport and Storage business model from BEIS, we have additionally assumed:

- Allowed revenues are recovered each year based on transport and storage fees; these transport and storage fees therefore vary year to year (and between clusters) depending on utilisation levels.
- Transport and storage fees are treated as pass-through (or a contract-for-difference item[40]) and hence ultimately recovered through other support payment streams.
- The backloading possibility raised in BEIS' May 2021 update is not implemented.

[40] While treatment as pass-through or CfD item provide very different contractual risk profiles, they only have a different funding implication where performance is not in line with expectations. Since we assume 'as expected' performance, the figures here could apply to either case.

— Although our costs are based on transport via pipes, we assume the same principles would apply where CO_2 is transported via ship.

— Asset lifetimes can be approximated as 30 years. This represents a blend of different asset lifetimes, such as (for example, drawing on natural gas equivalents) 25 years for compressors or 40 years for onshore pipes.

— We do not account for any CO_2 utilisation.

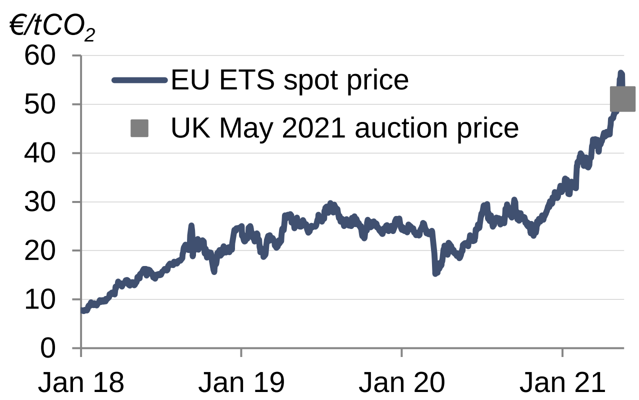
5.3 Sensitivity analysis

The overall funding framework costs presented in Section 5.1 are based on multiple cost, commodity price and business model assumptions. This section demonstrates the impact on funding levels that results from different assumptions, by exploring sensitivities that (except where indicated) change a single input assumption at a time.

5.3.1 Broader decarbonisation sensitivities

Given that three of the four business models presented contain a link to the carbon or electricity price, one of the key assumptions behind any framework cost is the carbon price trajectory. Carbon prices are heavily influenced by policy (including, for example, supported volumes of CCUS) and strongly influence other prices, particularly electricity prices. Here we explore two cases that shift both carbon prices and electricity prices in a consistent way.

Exhibit 5.4 – EU ETS prices compared to the UK May 2021 ETS auction



Notes: UK ETS auction price converted at 1.16€/£.

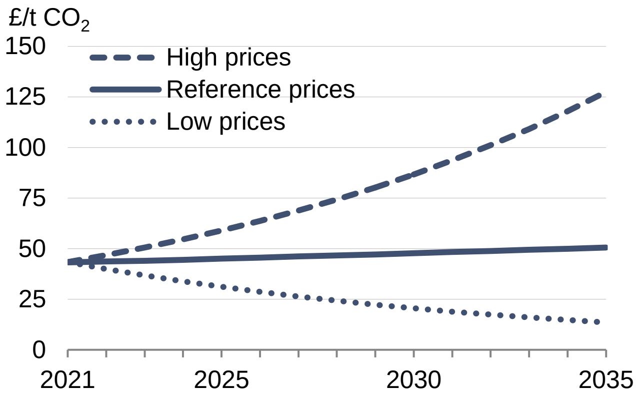
EU carbon prices have risen sharply in recent years, as presented in Exhibit 5.4. Many factors have driven this rise, the most important of which is the expectation of tighter targets under the European Green Deal. The broad market expectation is that prices will continue to rise as the stationary legal cap falls from 79% (of 2005 emissions) in 2020, to around 35%[41] in 2030. Prices are expected to continue to rise as the cap tightens, but at a slower pace than recent years.

While UK installations now come under the UK ETS, the initial UK auction cleared at a price close to the EU ETS. Depending on the outcome of the first cap revision process, UK targets may tighten in a similar manner, with the Climate Change Committee recommending a 2030 allocation at 22% of 2005 emission levels[42]. There is also a significant chance that the UK ETS will link to the EU ETS, equalising prices.

[41] Table 26 of the Green Deal Impact Assessment, Sept 2020. A formal recommendation has not been made and this figure may change.
[42] At current scope, or 21% if including engineered removals, p437 of The Sixth Carbon Budget – The UK's path to Net Zero, 2020, Climate Change Committee.

There remain uncertainties that could lower carbon prices. Rapid technology cost reductions may lower the cost of certain emissions reduction options, and policies that overlap with the sectors covered by emissions trading (including support for CCUS) tend to reduce prices as less additional abatement is required.

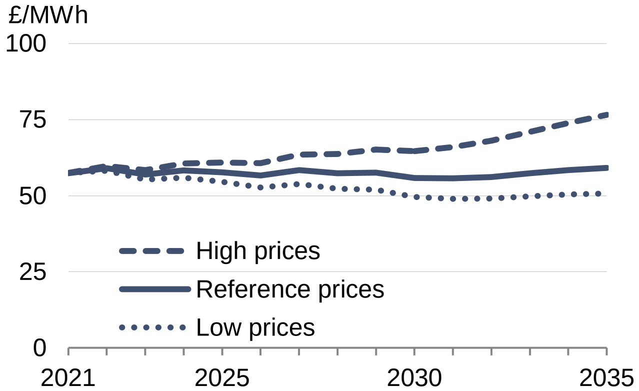
Exhibit 5.5 – Carbon prices in decarbonisation sensitivities



All prices in real 2020 £s.

Exhibit 5.5 shows the Reference scenario based on BEIS projections reaching £48/t in 2030, as well as two price sensitivities we have explored. The sensitivities both start in 2021 at the first UK auction price. One then falls 8% annually leading to a 2030 price of £20/t; the other rises 8% annually leading to a 2030 price of £87/t, and is capped at a maximum of £150/t from 2038. In both cases we have assumed that the same carbon price applies to both power and non-power sectors; maintaining the carbon price floor adder mechanism would reduce the funding impact.

Exhibit 5.6 – Baseload electricity prices in decarbonisation sensitivities

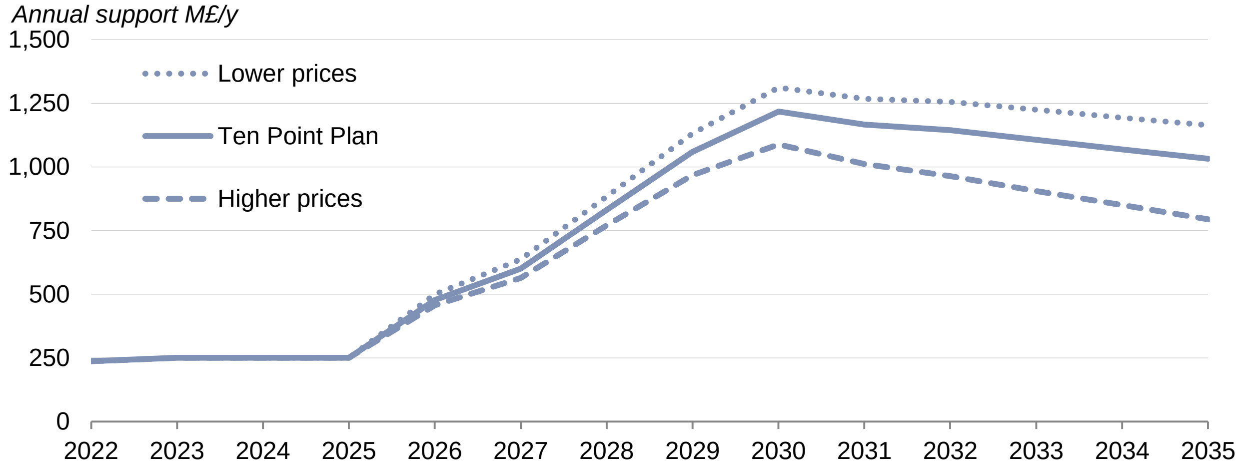


All prices in real 2020 £s.

Because of the strong links between carbon and electricity prices, we have assumed that a 'reference CCGT' (56.0% HHV efficiency) sets the electricity price 70% of the time, consistent with the load factor assumption for gas power with CCUS. The remaining 30% of the time is assumed to be insensitive to carbon prices. As such, for each £1/t difference from the BEIS reference carbon price, we have adjusted the baseload power price by £0.22/MWh, and the CCGT capture price by £0.32/MWh, to account for the higher cost of gas power generation. This is a highly simplified calculation not involving dispatch modelling or consideration of capacity mix changes.

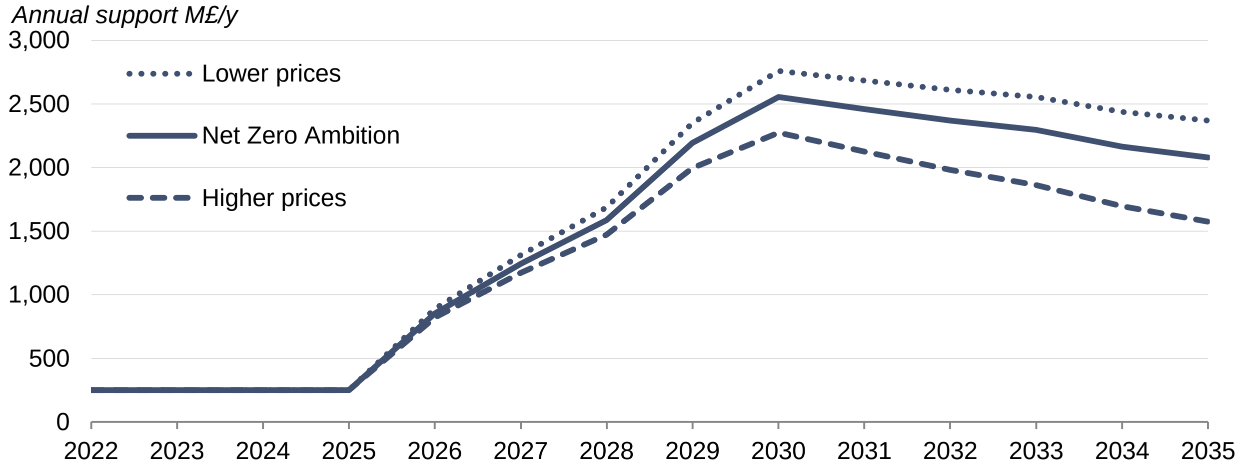
Exhibit 5.7 and Exhibit 5.8 present the impact of these sensitivities on the funding levels needed to 2030. Higher carbon and electricity prices reduce required support levels in all sectors, although even in the highest carbon price sensitivity examined, support payments remain through the 2030s for all sectors except industry.

Exhibit 5.7 – CCUS funding costs in sensitivities to Ten Point Plan



Notes: Support costs shown for facilities that begin operation by 2030.

Exhibit 5.8 – CCUS funding costs in sensitivities to Net Zero Ambition



Notes: Support costs shown for facilities that begin operation by 2030.

We note that a number of the funding models could contain links to carbon revenue streams that have not been included in our reference scenario but are examined in the sensitivities in the next section. Funding levels would be both lower and significantly more sensitive to carbon prices if:

- Free allowances from industry were monetised at the carbon price (e.g. auctioned) and this revenue was offset against funding costs. (or alternatively, if the free allowance transfer mechanism was removed from the industrial business model).
- CO_2 removals were rewarded with a commercial revenue stream, such as through an ETS rule change that allocated allowances for removing CO_2.
- The carbon value of low-carbon hydrogen, compared to the fuels it replaces (such as natural gas), was captured within the commercial hydrogen price.

These changes would significantly reduce funding levels required for their sectors at higher carbon prices; results from the next section indicate that in combination they would reduce support levels by around £280m in 2030 in the Ten Point Plan scenario, at the reference carbon price. Each additional 20£/t rise in the carbon price would reduce 2030 costs by around £120m. While the focus in initial business models is around allocating risk to deliver best value, in the long-term changes like these may assist the transition away from direct support.

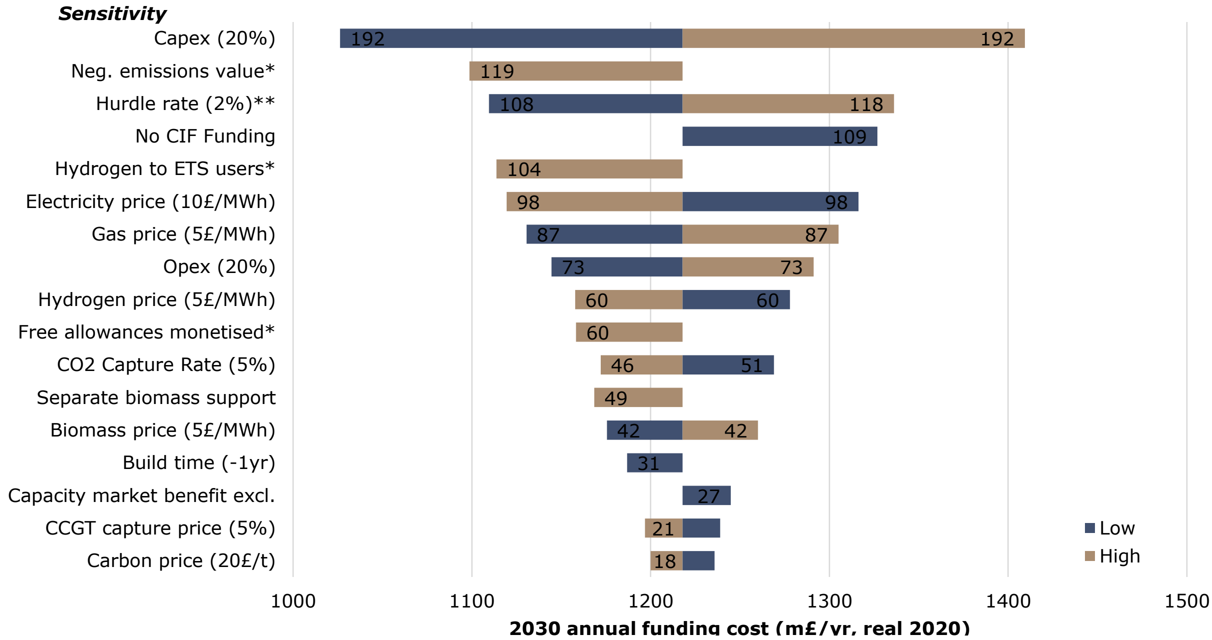
5.3.2 Other sensitivities

We have undertaken a number of other sensitivities, as shown in Exhibit 5.9 (Ten Point Plan) and Exhibit 5.10 (Net Zero Ambition). Each of these sensitivities is a simple change to one model input; so, for example, the sensitivities on gas and carbon prices keep electricity prices constant despite the expected links between these.

Details of what has been changed in each sensitivity are included in Exhibit 5.11.

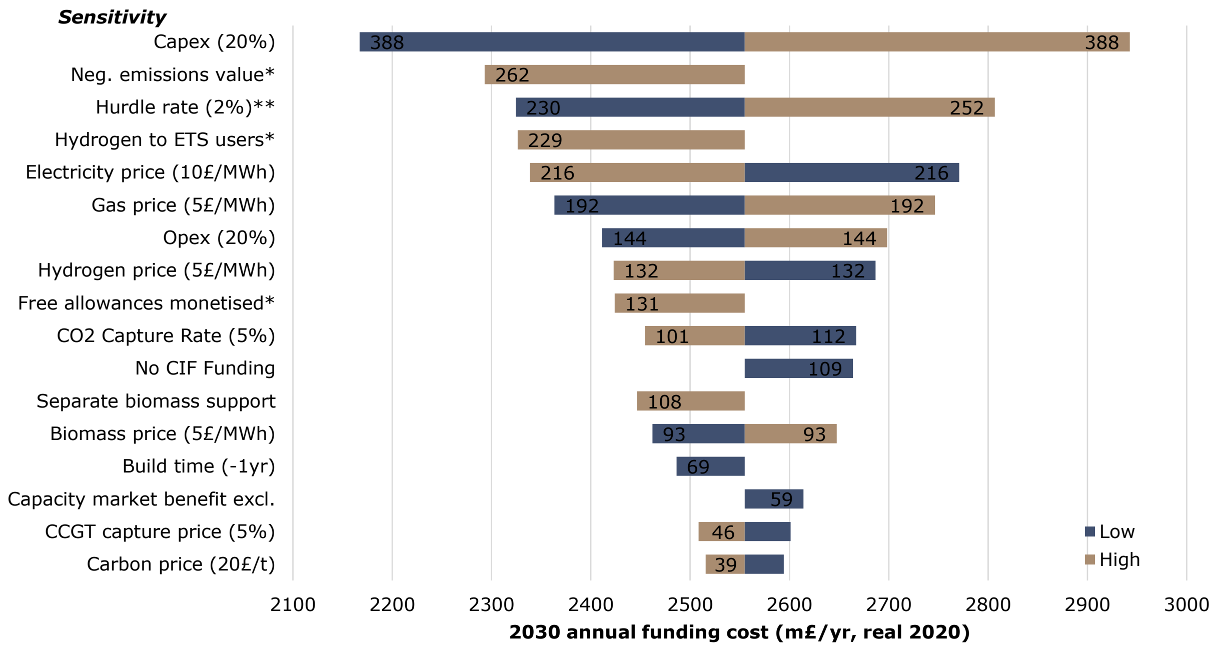
In all cases, we do not distinguish between expected and outturn prices, and these sensitivities hence assume higher or lower prices are expected when contracts are signed and also occur. In practise, contracts will be signed on the basis of expected prices; where outturn prices are different, the costs will typically accrue to support payments where the prices form part of the CfD reference price, and be borne by companies where they are not. The current structure of the gas power agreement (DPA) means parties will need to make an implicit assumption about the relationship between carbon, gas and captured electricity prices.

Exhibit 5.9 – Ten Point Plan cost sensitivities



Notes: Sensitivity descriptions are presented in Exhibit 5.11.
* The values of marked items are strongly dependent on carbon prices.
** Hurdle rate change is 2% for capture, 1% for transport and storage.

Exhibit 5.10 – Net Zero Ambition cost sensitivities



Notes: Sensitivity descriptions are presented in Exhibit 5.11.
* The values of marked items are strongly dependent on carbon prices.
** Hurdle rate change is 2% for capture, 1% for transport and storage.

It is clear from the sensitivity analysis that CCUS cost assumptions (capex, opex, cost of capital) are significant drivers of funding costs. While significant uncertainty on these remains in the public domain, there is expected to be significant revealing of costs through 2021 via the cluster allocation process.

This sensitivity to costs also provides reassurance that, should costs fall over time as expected, funding requirements will reduce significantly.

The next largest set of uncertainties relate to business model assumptions, particularly the potential for commercial remuneration of greenhouse gas removals, and uncertainties about the commercial value that can be extracted for hydrogen. Commodity prices also significantly affect the results.

Exhibit 5.11 – Sensitivity descriptions

Sensitivity	Description
Capex	±20% change to capital costs.
Neg. emissions value	By default, all remuneration for negative emissions comes from support payments. This sensitivity adds a commercial payment stream awarding negative emissions a separate value at the market price of carbon (such as if they were awarded allowances via a rule change to the UK ETS or could monetize negative emissions through sales in other markets).
Hurdle rate	±2% change to hurdle rates for capture projects, and ±1% change for transport and storage.
No CIF funding	Impact on funding if no CIF grants are included. These were modelled as £1b over 2022-2025, 80% to T&S and 20% to industry.
Hydrogen to ETS users	By default, hydrogen is sold at the natural gas price. This sensitivity assumes hydrogen is sold at the price of natural gas plus the carbon cost of burning natural gas, i.e. the value of hydrogen to users within the ETS.
Electricity price	±10 £/MWh change to the reference electricity price.
Gas price	±5 £/MWh (HHV) change to the reference natural gas price.
Opex	±20% change to operational costs (excluding electricity use).
Hydrogen price	±5 £/MWh (HHV) change to the hydrogen price.
Free allowances monetised	In the industrial business model, industries surrender allowances and are remunerated for them at the reference carbon price. In this sensitivity, these surrendered allowances are monetised (e.g. sold in the ETS) and the revenue used to offset the funding requirements.
CO_2 Capture Rate	±5% change to the capture rate for industry, gas power and GGRs. The capture rate for hydrogen remains fixed at 97%.
Separate biomass support.	In our default funding calculations, we consider all support payments to GGRs (modelled as BECCS). This sensitivity assumes a 'renewable electricity' payment part-funds BECCS and is ascribed to a different funding pot (such as support for low carbon levies) to CCS funding. It also assumes the corresponding strike price is set at the level required to support an unabated biomass plant.

Biomass price	±5 £/MWh (HHV) change to the biomass price.
Build time	Reduction in the assumed build time from 4 years to 3 years.
Capacity market benefit excl.	In our default funding calculations, we add the benefit of capacity provided by gas power and BECCS, which reduces capacity remuneration costs. This sensitivity excludes these savings.
CCGT capture price (5%)	By default, we assume the CCGT capture price is 20% higher than the reference baseload electricity price. This sensitivity adjusts this to 15% or 25% higher.
Carbon price	±20 £/tCO_2 change to the reference carbon price.

5.4 Key Messages

We have shown that CCUS could be delivered to 2030 with a funding cost peaking at around £1.2 to £2.6 billion per year. There remains substantial uncertainty around final funding costs, with the key uncertainties relating to the volume of CCS supported, costs of CCUS itself, the business model funding arrangements that will be put in place, and commodity prices: particularly natural gas, electricity and hydrogen. These funding levels could therefore move up or down, however many of these uncertainties will be reduced over the next year as business models are finalised and UK projects bid into the track 1 process.

Commodity prices themselves cannot be divorced from CCUS scenarios; the key driver for supporting CCUS is the rapid pace of decarbonisation planned in the UK. While we have used commodity price scenarios based on the BEIS Energy and Emission Projections, our market-based view is these are probably on the low side for carbon prices, and the high side for electricity prices. The sensitivities in Section 5.3.2 suggest that the effects of adjusting these in line with market views be in opposite directions, with the electricity impact larger resulting in an increase to funding levels under our assumed models, although stronger carbon linkage in policies (e.g. monetising free allowances) would compensate for this. Potential dependence of the funding levels on carbon prices also highlights a feed-back link in CCUS support. Because CCUS funding will directly decarbonise sectors covered by the ETS, it will also limit carbon price rises (or in extremes, lower carbon prices) and hence higher deployment may increase apparent support costs while lowering carbon costs elsewhere.

As well as uncertainty over costs and prices, the design of business models for greenhouse gas removals and hydrogen will affect both total costs and where they are "counted". Our figures above are best estimates for total support costs.

6 Conclusions

Global decarbonisation is driving the development of CCUS both in the UK and worldwide. CCUS acts as a cross sector deep decarbonisation tool and, in the drive to net zero, a generator of carbon removals. With ambitious climate targets and relatively favourable conditions, the UK is likely to be among the leaders in decarbonisation driven mass deployment of CCUS, but the global drive to net zero means we expect other nations to follow.

The Climate Change Committee has recommended developing 22Mtpa of CCUS by 2030, followed by a more than three-fold expansion in the 2030s, in order to meet the UK's climate targets at least cost. This level of deployment would generate eight to ten thousand net jobs, while protecting around 50,000 jobs in the high emission sectors of iron and steel, cement, chemicals and refining, as well as reducing risks to the broader manufacturing sector and opening up additional export opportunities. Current minimum ambitions, to deploy 10Mtpa of CCUS by 2030, would deliver around half the jobs and partial protection, since meeting the CCC's recommended emission limits would be more challenging for industries within the UK ETS.

A gap analysis against some of the key lessons from offshore wind suggests that in many areas the UK's deployment plans are now partly or mostly on track. The main ongoing requirements are to support continual procurement, deliver consistent supportive policy and messaging, and, critically and in the short term, provide certainty to the industry on minimum long-term funding levels out to around 2030.

Our best estimates are that deploying 10 to 22Mtpa of CCUS by 2030 would require a peak annual funding level of between £1 and £2.5 billion, although significant uncertainty over required funding levels remains with the key factors including CCUS and commodity costs, and policy choices around hydrogen and carbon removals. Many of these uncertainties should narrow over 2021 through the cluster sequencing process. Deployment beyond 2030 would increase the required funding levels, although cost reductions and likely carbon price rises will decrease unit support costs as the industry develops towards a long-term goal of market-funded deployment.

Annex A Technical, cost and scenario assumptions

A.1 Cost and technical assumptions

Our main cost assumptions are presented in Exhibit A.1, and technical assumptions in Exhibit A.2.

Exhibit A.1 – Main cost assumptions

Sector	Scope	Unit capex	Base opex (excl. fuel, elec, carbon)	Electricity use*	Total opex (excl. fuel, carbon)	Hurdle rate (pre-tax, real)
Industry	CCS unit	330 £/tpa	17 £/t	0.200 MWh/tCO_2	32 £/t	8.0%
Gas power	Whole plant	1730 £/kW	86 £/kW/y	-	86 £/kW/y	8.0%
	CCS unit	1100 £/kW	64 £/kW/y	-	64 £/kW/y	8.0%
GGRs	CCS unit	1640 £/kW	82 £/kW/y	-	82 £/kW/y	8.0%
Hydrogen	Whole plant	900 £/kW	88 £/kW/y	0.065 MWh(e)/ MWh(H_2)	88 £/kW/y	8.0%
Transport & storage	First 13.5 Mtpa	217 £/tpa	7.6 £/t		7.6 £/t	4.5%
	First 30 Mtpa	131 £/tpa	4.6 £/t		4.6 £/t	4.5%
	Subsequent development	70 £/tpa	2.5 £/t		2.5 £/t	4.5%

Notes: All costs are in real 2020 pounds, and energies are HHV.

Exhibit A.2 – Main technical assumptions

Sector	Build time (years)	Base efficiency	Efficiency with CC	CO_2 capture rate	Load factor*
Industry	4	-	-	90%	-
Gas power	4	54.2%	47.5%	90%	63%
GGRs	4	39.8%	28.4%	90%	90%
Hydrogen	4	-	80.3%** 84.7%***	97%	95%
Transport & storage	4	-	-	-	-

Notes: All efficiency figures are in HHV terms.
*Load factor includes an availability factor of 90%, so 63% represents running 70% of the time the plant is available.
**Efficiency including electrical inputs, i.e. energy out / energy in.
***Efficiency ignoring electrical inputs, i.e. hydrogen energy out / methane energy in.

Additional assumptions used in Chapter 5 to calculate required support levels are listed in Exhibit A.3.

Exhibit A.3 – Additional assumptions made

Item	Value	Notes
CCGT network costs	9 £/kW	Represents North England (~ zones 13-15), electricity & gas, 63% LF
BECCS network costs	7.5 £/kW	Represents North England (~ zones 13-15), electricity costs, 90% LF
Gas emission factor	0.182 tCO_2/MWh	
Biomass carbon factor*	0.329 tCO_2/MWh	Represents wood pellets
Biomass price	$200 /t, equivalent to 27.9 £/MWh	Represents wood pellets
BECCS base plant opex (i.e., excluding CCS unit)	61 £/kW/y	Cost of the base plant, expressed per kW of the combined CCS plant
Large industry electricity cost (industrial CC and hydrogen generation)	Wholesale baseload + 2 p/kWh	
Capacity market clearing price	15 £/kW/y	
Ancillary services value	3.4 £/kW/y	
Newbuild CCGT capital cost	550 £/kW	Total project cost
Newbuild CCGT opex	19 £/kW/y	Excluding network costs

Notes: All prices are real 2020. All energy figures are HHV.
* This represents the amount of CO_2 produced when 1MWh of wood pellets is completely combusted. In current UK accounting conventions, CO_2 emissions from biomass are accounted as zero in the energy sector. When captured and stored, this carbon is therefore considered a negative emission.

A.2 Additional scenario details

Section 3.1 presented the core scenarios. This section adds details for what has been assumed post-2030.

The sectoral split of capture volumes for 2030 is 25% from each sector (Industry, Hydrogen, Gas Power and Removals). For 2040 and 2050, we assume a split in line with that from the CCC's Balanced Net Zero scenario from the 6th Carbon Budget. Our Net Zero Ambition volumes match the Balanced Net Zero scenario volumes for 2040 and 2050 but assume linear growth in the 2030s and 2040s. After the first 30Mtpa, T&S expansions are in 10Mtpa increments as needed to keep system utilisation below 90%.

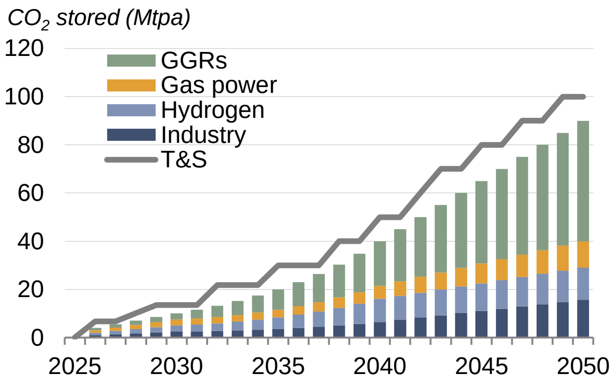
Exhibit A.4 and Exhibit A.5 show the capture and T&S volumes assumed to 2050 for the Ten Point Plan scenario. Exhibit A.6 and Exhibit A.7 show the same data for the Net Zero Ambition scenario.

Exhibit A.4 – Capture and T&S capacities to 2050 in Ten Point Plan scenario

Sector	2030	2035	2040	2045	2050
Industry	2.5	3.6	6.5	11.1	15.7
Hydrogen	2.5	4.8	9.6	11.5	13.4
Gas Power	2.5	3.2	5.5	8.2	10.9
GGRs	2.5	8.4	18.5	34.3	50.0
Total capture	10	20.0	40.0	65.0	90.0
T&S Capacity	13.5	30.0	50.0	80.0	100.0

Notes: All figures in million tonnes of CO_2 per annum.

Exhibit A.5 – Capacity evolution in Ten Point Plan scenario



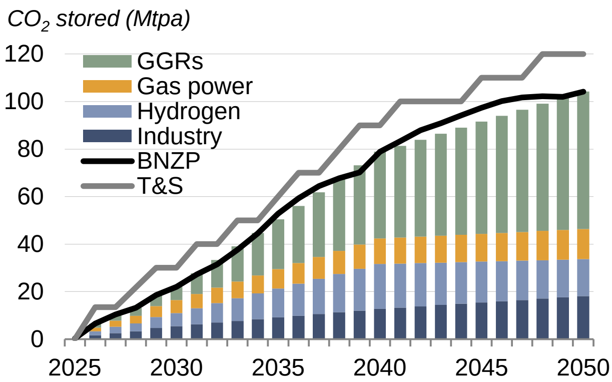
Notes: Stacked bars show capture volumes. T&S line shows system capacity.

Exhibit A.6 – Capture and T&S capacities to 2050 in Net Zero Ambition

Sector	2030	2035	2040	2045	2050
Industry	5.5	9.1	12.7	15.4	18.1
Hydrogen	5.5	12.2	18.9	17.2	15.5
Gas Power	5.5	8.1	10.8	11.7	12.7
GGRs	5.5	21.0	36.5	47.2	57.9
Total capture	22.0	50.4	78.9	91.5	104.2
T&S Capacity	30.0	60.0	90.0	110.0	120.0

Notes: All figures in million tonnes of CO_2 per annum.

Exhibit A.7 – Capacity evolution in Net Zero Ambition



Notes: Stacked bars show capture volumes. T&S line shows system capacity, BNZP shows the CCS levels assumed in the CCC's Balanced Net Zero Pathway.

GLOSSARY AND ABBREVIATIONS

ATR	Auto-Thermal Reformers (used to convert methane to hydrogen, with CO_2 as a by-product)
BECCS	CO_2 is captured from the atmosphere via bioenergy which is then used in a process with emitted CO_2 combined with carbon capture and storage
BEIS	(UK Government) Department for Business, Energy and Industrial Strategy, formerly DECC
CC	Carbon Capture (which will then feed utilisation or storage as part of CCUS)
CCC	Climate Change Committee (UK)
CCUS	Carbon Capture, Utilisation and Storage
CfD	Contract for Difference, a renewable energy support scheme used in the UK
DACCS	Direct air capture
DECC	(UK Government) Department of Energy and Climate Change, now BEIS
EINA	Energy Innovation Needs Assessments
ETI	Energy Technologies Institute
ETS	Emission Trading Scheme
FiDeR	Final Investment Decisions Enabling for Renewables
GGRs	Greenhouse Gas Removals
IEA	The International Energy Agency
IPCC	The Intergovernmental Panel on Climate Change
OWIC	Offshore Wind Industry Council
RED	Renewable Energy Directive
RO	Renewables Obligation (UK support scheme)
ROC	Renewables Obligation Certificates (part of UK support scheme)
TINA	Technology Innovation Needs Assessments

TABLE OF EXHIBITS

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