Evaluation of three Carbon Capture, Use and Storage (CCUS) Innovation Programmes

Final Evaluation Report
December 2023

Ipsos, Perspective Economics and Technopolis

Contents

List of abbreviations

ACT	Accelerating Carbon Capture and Storage Technologies programme
BECCS/BECCUS	Bio-Energy with Carbon Capture and Storage/Bio-Energy with Carbon Capture, Use and Storage
BP	British Petroleum
C&D	Construction and Demonstration
CCS	Carbon Capture and Storage
CCUD	Carbon Capture and Utilisation Demonstration programme
CCUS	Carbon Capture, Usage and Storage
CCUS-I	Carbon Capture, Usage and Storage Innovation programme
CEF	Connecting Europe Facility
CIF	CCS Infrastructure Fund
CLT	Carbon Limiting Technologies
DACCS	Direct Air Carbon Capture and Storage
DESNZ	Department for Energy Security and Net Zero
DPA	Dispatchable Power Agreement
EEF	Energy Entrepreneurs Fund
EIP	Energy Innovation Programme
EPSRC	Engineering and Physical Sciences Research Council
EQ	Evaluation Question
ERA-NET	European Research Area Network
FEED study	Front-End Engineering and Design study
FID	Final Investment Decision
FOAK	First-of-a-kind
GGR	Greenhouse Gas Removal (technologies)
GVA	Gross Value Added
ICC	Industrial Carbon Capture
IDC	Industrial Decarbonisation Challenge
IDRIC	Industrial Decarbonisation Research and Innovation Centre
IEEA	Industrial Energy Efficiency Accelerator
IETF	Industrial Energy Transformation Fund
IP	Intellectual Property
ISCF	Industrial Strategy Challenge Fund
KKDs	Key Knowledge Deliverables
KPI	Key Performance Indicator
m-CHP	Micro-turbine combined heat and power
MEA	Monoethanolamine
MO	Monitoring Officer
NAO	National Audit Office
NERC	Natural Environment Research Council
NGOs	Non-Government Organisations
NZ	Net Zero

NZIP	Net Zero Innovation Portfolio
O&G	Oil & Gas
OGCI	Oil & Gas Climate Initiative
ONS	Office of National Statistics
R&D	Research & Development
RAB	Regular Asset Base
RD&I	Research, Development & Innovation
SIC	Standard Industrial Classification (codes)
SICE	Science and Innovation for Climate and Energy (DESNZ department)
SME	Small and Medium-sized Enterprise
SPF	Strategic Priorities Fund
SRO	Senior Responsible Officer
T&S	Transportation and Storage
TCE	Tata Chemicals Europe
ThirdS	Third Party Support Contract
ToC	Theory of Change
TRI	CO_2 Transport & Storage Regulatory Investment
TRL	Technology Readiness Level
UK ETS	UK Emissions Trading System
UKCCSRC	UK CCS Research Centre
UKRI	UK Research and Innovation

Executive summary

This report presents the findings from the evaluation of three carbon capture, use and storage (CCUS) innovation programmes, namely, the CCUS Innovation (CCUS-I) programme, the CCU Demonstration (CCUD) programme and the Accelerating CCS Technologies (ACT 1 and ACT 2) programme. The three programmes were funded as part of the Energy Innovation Programme (EIP) run by the Department for Energy Security and Net Zero (DESNZ).[1] The evaluation aims to understand how the programme has been delivered (process evaluation), its results (outcome evaluation) and the extent to which it addresses economic barriers. This report is accompanied by a Technical Annex, published separately, which describes in detail the data collection and analytical methods employed in the evaluation and the limitations of the research.

The evaluation covers the time period from the launch of ACT 1 (2016) to the closure of the programmes in April 2021 and comprises all 26 funded projects. Two waves of data collection took place, in April-June 2021 and May-June 2023. Each wave involved the collection of data available from existing data sources (programme and project documentation, project data, and ONS data) and new qualitative data collected as part of this research (depth interviews with various stakeholders). This report draws evidence from both waves of research.

The EIP CCUS programmes – CCUS-I, CCUD, ACT 1 and ACT 2

The EIP CCUS programmes aimed to support the development, demonstration and commercialisation of CCUS technologies, from capture to transport and storage. The programmes sought to achieve these outcomes through slightly different routes: international collaboration (ACT), support for Small and Medium-sized Enterprises (SMEs), academic research / early innovation (ACT and CCUS-I) and intermediate-level deployment (CCUD). CCUD was focused on '*developing the capture side of things ahead of the policy and business models catching up*', at a bigger scale than CCUS-I and ACT.[2] ACT 2 held similarities to CCUS-I and was referred to as 'International CCUS-I' in its business case. Two applicants applied to more than one Innovation Programme with the same project, and only one, the ACORN project, was funded through both ACT 1 and CCUS-I.[3]

- **ACT**, funded and delivered with international partners, aimed to further all stages of CCUS technologies at low technology readiness levels (TRL)[4], through engineering studies as well as physical infrastructure support.

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[1] The Department was then called the Department for Business, Energy and Industrial Strategy
[2] As described by a Governance and Delivery Team stakeholder within the Department
[3] The other applicant applied to ACT 1 and ACT 2 with the same project, being unsuccessful in the first ACT call and successful in the second one.
[4] TRLs are a type of measurement system used to assess the maturity of a particular technology, ranging from a low 1 to a high 9. More information about each TRL can be found at the following URL: https://www.gov.uk/government/news/guidance-on-technology-readiness-levels

- **CCUS-I** was designed to complement ACT by covering the domestic space and look at full-chain CCUS. It aimed at advancing knowledge in the CCUS space, targeting technologies at TRL 3 or above. The programme encompassed feasibility studies, industrial research and experimental development to reduce costs and speed up technological progress and/or the progress towards the commercialisation of UK IP. It also funded physical research infrastructure.

- **CCUD** was designed to enable the demonstration of capture technologies at a commercial scale by relying on carbon utilisation to generate a revenue stream (i.e. from the sale of the CO_2 to carbon users, such as food growers, and food and beverage manufacturers), hence reducing the overall cost of carbon capture. CCUD aimed to monetise CO_2, as a means to achieving greater investment in carbon technologies and filling the gap left by the absence of business models, and to support the development of demonstration capture projects at a 'reasonable scale', to prove that the technology works before larger-scale investment is feasible.

Key findings from the process evaluation

Design and resulting portfolio

The three CCUS programmes supported a wide range of projects. However, the portfolio demonstrated the following gaps:

- Low participation of high-emitting or foundation industries, such as representatives from the steel, cement and glass industries.[5]
- A low number of greenhouse gas removal (GGR) technologies supported through projects.
- A disproportionately small amount of funding for transportation and storage (T&S) projects, considering stakeholders' views of this as a key stumbling block for CCUS deployment.
- Disproportionately large amounts of support given to carbon capture technology, given how relatively advanced capture technology is currently.

Finally, while stakeholders acknowledge the rationale for the CCUD programme and CCUS-I support for CO_2 utilisation as a means to generating a revenue stream to de-risk capture and encourage deployment, some have called into question the net environmental benefit of it, and hence its relevance to the overall net zero aim. Furthermore, the low number of CCUD applications suggests that there was limited maturity in the carbon utilisation market at the time beyond the successful applicant.

Programme delivery (set up, selection, management and external engagement)

Overall, the evaluation has found that delivery ran smoothly overall for the three CCUS programmes. In terms of the competitions' set up, DESNZ were effective in their awareness-

[5] The seven industry participants across the programmes were either from the chemical sector (petrochemicals and fertilisers) or lime suppliers.

raising and publicity around the programmes. ACT's approach for applications, whereby applicants submitted a simple application first, and only developed a more detailed one once they had been shortlisted, was considered by stakeholders interviewed for this evaluation as particularly effective in increasing the quality of proposals and providing learning to both successful and unsuccessful applicants. In comparison, unsuccessful applicants to CCUS-I and CCUD gave the view that the feedback received was too synthesised to allow them to improve their research proposals to forthcoming funding opportunities.

Governance across the programmes was lean which supported effective management, monitoring and decision-making. The DESNZ delivery team's dedication, experience and networks within the CCUS community played a major role in the success of the programme. However, some interviewees expressed the opinion that having more staff available within DESNZ could have been helpful to ensure a more efficient delivery.

Key findings from the outcome evaluation

The EIP CCUS programmes supported technologies advancement towards deployment

Evidence from this evaluation indicates that the programmes advanced technologies closer to deployment in several projects. Most projects advanced their technology by two TRLs through their delivery. Crucially, the programmes contributed to the three cluster-enabling projects, HyNet, ACORN and Clean Gas, now being part of three of the four clusters which have been shortlisted for deployment over the coming years as part of the Cluster Sequencing process. A few project leads interviewed argued that without the initial support and funding as part of the three CCUS programmes the cluster would not have been able to go ahead. In some cases, participants attributed this to increased awareness or interest in CCUS, while in other instances, participants argued the projects had allowed them to demonstrate their capability to deliver at scale.

The EIP CCUS programmes contributed to RD&I investment in the UK to some extent

The programmes contributed directly to RD&I investment through matched funding required by project participants. On average, £1.16 was raised for every £1 of DESNZ funding invested in projects. In addition, a total of £216 million in follow-on funding was reported by 14 out of the 27 projects supported by the EIP CCUS programmes, including £99 million in private funding. For ten of these, the funding included other public funding, including the Cluster Sequencing Process. Almost all the project teams that had received some follow-on funding accredited the CCUS programme for its contribution. While successful applicants have invested almost 2.5 times more in internal R&D than the unsuccessful ones over the same period, it has not been possible to link that difference to the three programmes.

The EIP CCUS programmes have likely contributed to changing industry's perceptions around CCUS deployment

The programmes were launched after the cancellation of two carbon capture and storage deployment competitions, in 2007 and in 2012, which had reduced stakeholder's certainty about UK government's investment plans. While stakeholders generally agreed that the scale of funding of the three programmes was limited in face of the challenge of progressing CCUS deployment, the EIP CCUS programmes provided a market signal that CCUS remained a priority. As indicated by the levels of private investment, there was a significant change in industries' acceptance of CCUS technologies over the evaluated period. Many of the projects contributed to overcoming information barriers around particular technologies. The Key Knowledge Deliverables publications, which compiled the results and lessons learned for eight projects, had been accessed hundreds of times each month; though the evaluation has not been able to assess their application or effects within its timeframe.

The EIP CCUS programmes contributed to UK research, innovation and deployment capabilities

This evaluation has found that the funded projects enabled growth in UK CCUS capabilities, with most projects indicating that the funding enabled participants to develop both soft and hard/technical skills, which in turn could support the delivery of future CCUS projects. Evidence is less clear in terms jobs generation, with interviewees suggesting that project team members tended to have been reallocated from existing posts into the CCUS projects rather than the projects leading to new jobs being created.

The progress towards deployment as enabled by the EIP CCUS programmes could contribute to improving the UK's position in the CCUS global landscape.

Policymakers and international stakeholders interviewed for this evaluation identified the UK as a leader in CCUS. They considered that this was evidenced by the level of international interest CCUS innovation projects had, but that this global leader role was driven by the large policy support and commitment assigned to CCUS in the wake of the 2021 COP26 in Glasgow.[6] Some stakeholders interviewed for the evaluation gave the view that the UK had been an early mover in CCUS internationally, and that the EIP CCUS programmes had helped the UK to maintain that position. On the other hand, interviewees flagged that other countries, such as the US, currently lead on commercial CCUS deployment, and that the EIP CCUS programmes could only be assessed as having an impact on the UK global leadership in CCUS if the technologies being developed were proven at commercial scale. In that sense, and to the extent that the programmes have been contributing to progressing CCUS towards deployment (see above), they can be said to be contributing to the UK advancing towards a strengthened position in the international CCUS space. Competitive CCUS policies and support programmes in other regions, crucially the US Inflation Reduction Act (US IRA), are seen as the main threat to the UK securing a leading edge in CCUS globally.

The EIP CCUS programmes contributed to some policy thinking on CCUS

In the years following the launch of the EIP CCUS programmes, UK CCUS policy has made great strides, which is acknowledged, in particular, by international actors interviewed. The EIP CCUS programmes contributed to a better-informed policy environment for CCUS and a more close-knit collaboration between industry and government. During the programmes' implementation, key members of the delivery teams held regular exchanges with policy teams to guide and support policy planning. Several project teams interviewed provided

[6] Conference of the Parties (COP) to the United Nations Framework Convention for Climate Change (UNFCCC).

evidence of how they had direct relationships with or had provided information on CCUS to policymakers. On the other hand, the extent to which the programmes influenced UK policymakers from outside DESNZ seems to have been limited.

Conclusions

Since the launch of the first of the EIP CCUS programmes, the CCUS landscape in the UK and globally has evolved significantly. The government's ambition is to connect two of the UK's major industrial clusters to decarbonisation infrastructure by 2025 and four by 2030, with an ambition of capturing 20 to 30 million tonnes CO_2 by 2030. The EIP CCUS programmes did not have the scale for or the intention of instilling transformational change in the CCUS landscape; and such change (which has been observed in the UK over the last three years) can be best attributed to factors beyond the EIP CCUS programmes. However, the evaluation evidence suggests that the programmes catalysed a momentum which was sustained, and which aided the landscape to evolve and develop when the right level of support and environment came about through the CCUS Implementation Fund, allocated through the Cluster Sequencing process, and the publication of CCUS-relevant business models. The EIP CCUS programmes encouraged and supported partnership-building across the supply chain, encompassing front-running industries, and developing the knowledge base for CCUS implementation. This ensured that those newly-formed and/or strengthened partnerships, reassured by the new evidence developed by the programmes' research, were ready to develop further when programmes such as the Industrial Decarbonisation Challenge and, most importantly, the Cluster Sequencing process were launched.

1 Introduction

1.1 The evaluation of the ACT, CCUD and CCUS-I

This report presents the findings from the evaluation of three carbon capture, use and storage (CCUS) innovation programmes, namely, the CCUS Innovation (CCUS-I) programme, the CCU Demonstration (CCUD) programme and the Accelerating CCS Technologies (ACT 1 and ACT 2) programme. The three programmes were funded as part of the Energy Innovation Programme (EIP) run by the Department for Energy Security and Net Zero (DESNZ).[7]

The evaluation aims to understand how the programme has been delivered (process evaluation), its results (outcome evaluation) and the extent to which it addresses economic barriers. Ipsos UK in partnership with Perspective Economics and Technopolis Group was commissioned by the Department to deliver the evaluation.

The evaluation objectives were to identify and assess the overall benefits of these programmes, including their effectiveness, efficiency, cost-effectiveness and impact. The evaluation also assessed how well the programmes were delivered. The purpose of the evaluation was to increase government understanding of the effects of research and development (R&D) spending in the CCUS field, support ongoing innovation programme delivery, support communication, and provide accountability for Government innovation spending. Overall, the findings are expected to support policy development to inform future innovation funding and state support, the pathway to net zero and regulatory frameworks for CCUS technologies and markets.

This report is accompanied by a Technical Annex, published separately, which describes in detail the data collection and analytical methods employed in the evaluation and the limitations of the research.

1.2 Evaluation scope and structure

The **evaluation scope** covers the time period from the launch of ACT 1 (2016) to the closure of the programmes in April 2021 and comprises an analysis of all 26 funded projects– 7 CCUS-I, 4 CCUD and 15 ACT 1 and ACT 2 projects. It also covers the ACT 3 call, from a design point of view (that is, it does not cover an analysis of the efficiency and effectiveness of projects funded within ACT 3). From the point of view of ACT, an international programme, the evaluation focuses primarily on UK-led projects and on the work packages delivered through UK organisations.

The evaluation is split into **three components**, process, outcome and economic, and research was conducted in two waves: wave 1, which took place immediately after the close of all ACT 1 and some CCUS-I and CCUD projects; and wave 2 which took place two years

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[7] The Department was then called the Department for Business, Energy and Industrial Strategy

later, once all CCUD and CCUS-I and most ACT 2 projects had closed. This Report synthesises the results from both of these waves.

The **longitudinal perspective** of this evaluation enabled the evaluation team to track change over time and to measure outputs at wave 1 (with a focus on answering process evaluation questions) and short- to medium-term outcomes at wave 2 (with a focus on outcome evaluation questions).

One of the primary challenges of this evaluation concerns attribution of observed change to the EIP CCUS programmes. These programmes operate in a complex environment, which means that a multitude of factors can affect the intended outcomes and, hence, isolating them can be challenging, especially when the intervention under analysis involved a relatively low number of beneficiaries (26 funded projects) and level of funding (£39 million).

In face of this challenge, the evaluation takes a **theory-based approach** to both understanding how the programme has been delivered (process), its results (outcomes) and the extent to which it addresses economic barriers (economic). Several **analytical approaches** have been applied, including Contribution Analysis, the main evaluation framework, complemented by Economic Barrier Analysis, Cost-Benefit Analysis and (unpublished) case studies. A Contribution Analysis approach enables the evaluation to make a qualitative judgement around the extent to which the EIP CCUS programmes may have contributed to the changes observed. However, it is not possible to directly attribute impacts to the EIP CCUS programmes with sufficient levels of certainty.

At the outset of the evaluation, it was envisaged that a relatively large pool of UK companies would be involved in CCUS Projects (estimated to be approximately 100). On this basis, the evaluation team considered it feasible to produce a comparative analysis of the economic performance of companies involved in the CCUS Projects against a group of similar companies that had not been involved in the CCUS Projects. The analysis was to use Secure Research Service (SRS) data, including a combination of survey-based and micro-data[8]. Ultimately, the pool of companies that could be identified in the databases and included in the analysis was considerably smaller than envisaged (~30). The evaluation team progressed with the proposed analysis, however, poor coverage of survey-based data across the pool of companies meant that no firm conclusions could be drawn regarding the comparative economic performance of participant and non-participant companies. The issue of poor data coverage was particularly pronounced with respect to the Business Enterprise Research and Development (BERD) survey where observations were below the disclosive threshold of 3 in all instances.

1.3 The purpose of this report

This report sets out the findings from the evaluation of three EIP CCUS programmes.

8 Annual Business Survey (ABS), Business Structure Database (BSD, micro-data), Annual Survey of Hours and Earnings (ASHE), Business Enterprise Research and Development (BERD, survey-based).

It provides insights into the results of the **process evaluation**, **outcome evaluation** and **economic barrier analysis.** In particular, it provides discussion and draws conclusions on:

- The extent to which the programmes have produced outputs (Evaluation Question (EQ) 1).
- The extent to which they have contributed to altering perceptions of CCUS across relevant stakeholder groups (industry, policy, investors) (EQ2).
- How the programmes contributed to stimulating investment and deployment of CCUS (EQ3).
- Whether the programmes are on track to deliver intended future impacts (EQ4)
- What can be learned for the delivery of future CCUS programmes (EQ5).
- What can be learned about the contribution of the programmes to the development of CCUS in the UK (EQ6).

These reports were developed based on data and insights collected through a range of activities:

- **Inception activities (wave 1)**, which aimed at deepening the study team's understanding of the context surrounding CCUS technology (landscape, policies, and innovation), and of how the programmes' design aimed to address the key barriers to CCUS progression.
- **Secondary data collection**, which included a review of programme and project documentation and data to build an understanding of the programmes and map data already available; it also included a review of official data from private sector participants, from the Office of National Statistics (ONS), available through Beauhurst, to feed into the profiling of participants and into the economic analysis.
- **Qualitative primary data collection**, through in-depth interviews (**82** in wave 1, **40** in wave 2) with a range of stakeholder groups, including those directly involved in the programmes. In wave 1, 10 interviews were conducted with DESNZ staff involved in the design and delivery of the programmes, 43 with project leads and partners, and 29 with external stakeholders, such as unsuccessful applicants (8 interviews), non-applicants (11 interviews), and key policy players and international actors in the CCUS field (10 interviews). In wave 2, 3 interviews were conducted with DESNZ staff involved in the management and delivery of the programme, 21 with project leads and partners and 17 with other stakeholders, such as policymakers (8 interviews), and industry stakeholders (7 interviews).
- **Analysis activities,** including the development of project-level case studies, which provide project-specific insights into the drivers of impact; internal analysis sessions

to synthesis emerging findings, as well as workshops and interviews with an external panel of experts from academia,[9] to validate and ground emerging findings.

1.4 Limitations of this study

As outlined above, the context in which this evaluation is developed means that it is only possible to assess the EIP CCUS programmes' contribution to the intended outcomes, but it is not possible to directly attribute observed changes to the programmes.

Beyond this, one of the primary limitations of the study revolve around the fact that many project leads and partners who were initially involved in CCUS project delivery during Wave 1 of the evaluation have since transitioned to different roles, either within the organization or externally with other companies or universities. As a result of this, we were able to conduct fewer interviews than initially projected, which in turn constrained the diversity of perspectives and insights across various projects.

The interviews conducted were qualitative in nature, designed to target and uncover comprehensive and detailed insights into individual experiences, behaviours, and contexts. This approach facilitated a thorough exploration of individuals' thoughts, behaviours, and experiences. While these qualitative interviews provided intricate insights into specific personal experiences, they may have limitations in drawing overarching conclusions and generalizations applicable to the entire population of interest, in this case, the leaders of CCUS projects and other broader stakeholders.

Similarly, since the inception of Wave 1, substantial changes have occurred in the overall decarbonisation policy and landscape. New CCUS programmes have been introduced, and additional public funding has been directed toward CCUS and industrial decarbonisation projects. These shifts in the policy landscape have added complexity to the evaluation process. They have made it more challenging to precisely gauge the overall contribution and attribution of the CCUS programmes to these policy changes, as these developments unfolded concurrently with project implementation. Furthermore, projects funded by the three CCUS programmes have also received public funding through alternate channels, leading to a more intricate scenario for isolating specific impacts.

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[9] The experts group comprised academic specialists in the field of carbon capture and storage in industry. Several of the experts were linked to the CCUS programmes; one of them submitted an unsuccessful application to one of the programmes, and another participated in one of the funded projects. While the latter was excluded from commenting on their own project, the unsuccessful applicant was not considered to be materially conflicted and was still invited to comment on the relevance of the programmes, their portfolios and impact.

2 The EIP CCUS programmes

2.1 Overview of programmes

The three CCUS programmes evolved from two separate origins:

- ACT was launched in 2016 as one of the European Research Area Network (ERA-NET) Co-Funds,[10] established by the European Commission under the Horizon 2020 programme.[11] A second call, ACT 2, launched in 2018 and expanded the fund's membership beyond Europe. Both calls received their UK contributions from the EIP.
- CCUD and CCUS-I calls were launched in 2018 as part of the £103m fund made available for industry and CCUS within DESNZ Science and Innovation for Climate and Energy's (SICE) Energy Innovation Programme.

Table 2.1 summarises the scope and objectives of each programme.

Table 2.1: Table 2.1: Programme scope and aims

Programme	Timeframe	Key aims and objectives	Project activities / investments
Accelerating CCS Technologies (ACT) **£11m**	September 2019 -Q4 2022	To support CCUS technologies' development in energy and industrial sectors globally, through international collaboration in: (i) Accelerating the development of CCUS technologies (ii) Demonstrating key component(s) of CCUS processes (iii) Advancing the development of Greenhouse Gas Removal (GGR) technologies and low-carbon hydrogen (iv) Developing intellectual property (IP), growing businesses, and increasing sales of CCUS processes.	Large international innovative projects covering entire CCUS chain, and smaller research projects focused on specific CCUS elements, all supporting international cooperation.
CCUS Innovation (CCUS-I) **£22m**	31 July 2018 – March 2021	To support cost reduction of CCUS technology and its deployment at scale during 2030 by: (i) Developing UK-based technologies and processes while reducing costs (ii) Supporting innovation across the full CCUS chain (iii) Developing UK IP and expertise.	Research infrastructure; industrial research, experimental development and feasibility studies; technology

[10] The ERA-NET Co-Fund funds collaborative R&D and innovation projects across a range of topics - only ACT focuses on CCS.

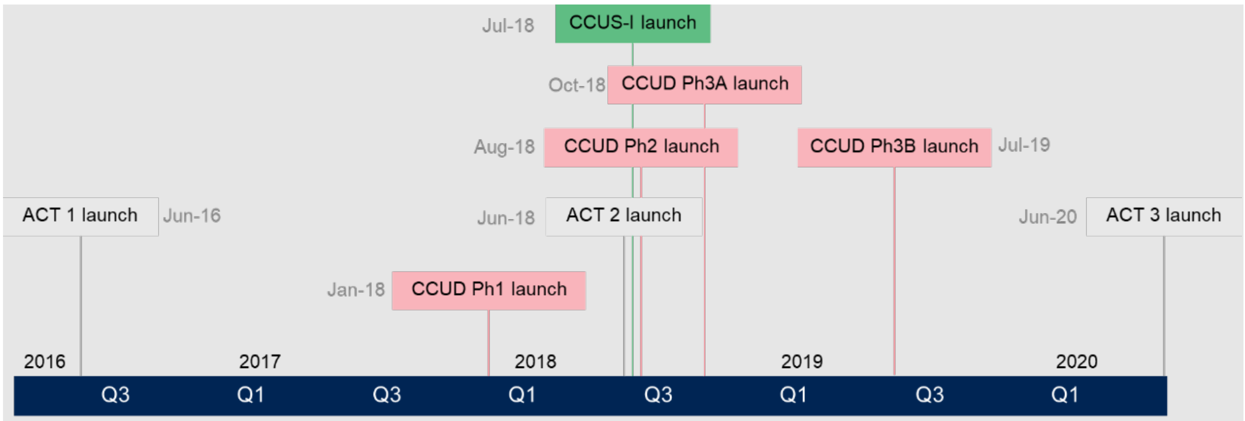
[11] https://ec.europa.eu/programmes/horizon2020/

			development; small innovative start-ups.
CCU Demonstration (CCUD) **£5m**	2018-2021	(i) Demonstrate CCU in key UK industrial sites (ii) Demonstrate and accelerate cost reductions (up to 20-45%) (iii) Encourage follow-on CCU projects (iv) De-risk capture technology.	Scoping study; FEED studies; and construction and demonstration of CCU projects.

Source: CCUS Programmes calls: ACT 1, ACT 2, CCUS-I, CCUD (Phase 2), CCUD (Phase 3A), CCUD (Phase 3B)

Figure 2.1 illustrates the timelines over which the calls under each programme were launched. Both ACT 1 and 2 had only one phase, as did CCUS-I; whereas CCUD was implemented through a staged process with three phases. CCUD Phase 1 was dedicated to developing scoping studies to determine whether projects should proceed to a front-end engineering design (FEED) phase (which corresponded to Phase 2). Phase 3 was dedicated to the construction and demonstration (C&D) of projects and split in two: Phase 3A was designed for applicants interested in proceeding to C&D without the need for Government funding for the FEED and Phase 3B was for projects progressing from Phase 2.

Figure 2.1 Competitions' calls timeline



2.2 Overview of the funded projects

An overview of the projects funded through each programme is provided overleaf in Table 2.2. The projects could be classified by the type of goal towards CCUS they were trying to achieve (supporting the development of industrial clusters, technological advancement, and research infrastructure).

Table 2.2: CCUS programme projects in scope

Programme	Project	Capture	Storage	Transport	Utilisation	Funding	Target Sectors	Starting TRL	TRL advancement	Project lead type
CCUS-I	ACORN CCS	■	■	■		£4.80m	Agnostic; using Oil & Gas Infrastructure	6	1	Other – private sector
	Allam Cycle/8Rivers	■				£1.36m	Agnostic; Power generation	6	2	Private technology developer
	C-Capture	■				£4.92m	Power & Electricity production	5	2	Private technology developer
	Clean Gas Project (OGCI/ Clean Gas)	■	■	■		£3.77m	Manufacturing; Industrial and heat sectors	7	1	Oil & Gas
	HyNet Ph1	■	■	■		£0.49m	Utilities; Heavy industry, heat and transport.	6	2	Private technology developer
	PACT-2	■			■	£7.00m	Agnostic; Research facilitation	3	3	Academic
	TiGRE	■	■			£0.16m	O&G, Offshore renewables & power supply	4	2	Private technology developer
CCUD-P2	CCU UK Manufacturing	■			■	£0.42m	Glass manufacturing	N/A	N/A	Industry
	Fuel Cell Biogenic CCD	■				£0.50m	Agnostic; Power generation; agriculture	N/A	N/A	Utilities
	Low Carb Integrated mCHP-CCS	■	■			£0.35m	Power; Utilities	N/A	N/A	Private technology developer
	OFF-CALC	■				£0.25m	Construction; Lime production	N/A	N/A	Private technology developer
CCUD-P3A	CCUD	■			■	£4.18m	Manufacturing (food, pharmaceuticals)	N/A	N/A	Other – private sector
ACT 1	ACORN	■	■			£0.92m	Agnostic; O&G	3	2/3	Other – private sector
	ALIGN CCUS	■	■		■	£1.40m	Agnostic; Industry & industrial regions; power sector	2	2	Other – research organisation
	DETECT		■			£0.46m	Agnostic; CCUS storage infrastructure	2	4	Oil & Gas
	ELEGANCY		■	■		£1.32m	Agnostic; CCUS storage & transport infrastructure	2	2	Other – private sector

Programme	Project	Capture	Storage	Transport	Utilisation	Funding	Target Sectors	Starting TRL	TRL advancement	Project lead type
	PRE-ACT		■			£0.28m	Agnostic; CCUS storage infrastructure	N/A	N/A	Other – private sector
ACT 2	ACTOM		■			£0.28m	Agnostic; CCUS storage infrastructure	3	2	Academic
	ANICA	■				£0.53m	Construction; Lime & cement	3	3	Academic
	DIGIMON		■			£0.87m	Agnostic; CCUS storage infrastructure	5	3	Other – research organisation
	FUNMIN		■			£0.38m	Agnostic; CCUS storage infrastructure	1	3	Academic
	LAUNCH	■				£1.24m	Agnostic	3	3	Other – research organisation
	NEWEST CCUS	■				£0.98m	Agnostic; Environmental; CCUS technology manufacturing	3	5	Academic
	PRISMA	■				£0.68m	Agnostic; Energy & industrial sectors	2	2	Academic
	REX-CO2		■			£0.44m	Agnostic; CCUS storage infrastructure	1	4	Other – research organisation
	SENSE		■			£0.29m	Agnostic; CCUS storage infrastructure	1	4	Academic
	SUCCEED		■		■	£1.11m	Environmental; CCUS storage technology	2	N/A	Academic
TOTAL		**16**	**16**	**2**	**8**	**£39.38m**				

The joint portfolio resulting from the projects can be classified as follows:[12]

- **Net Zero (NZ) Cluster-enabling projects:** Focused on assessing feasibility of full-chain CCUS in a specific region (HyNet, ACORN and OGCI/Clean Gas). A full-chain CCUS cluster involves at least one 'anchor' capture project, an onshore and offshore carbon transportation pipeline network that can be expanded as new capture project join in and on storage location.

- **Projects supporting technological advancement:** Examples of this type of project include C-Capture, Allam Cycle and OFF-CALC. These projects ranged from starting technology readiness levels (TRLs) 1 to 6. Eight focused on carbon capture, five on the deployment of a first-of-a-kind (FOAK) capture plant in the UK. Six projects covered storage and three utilisation. One of the utilisation projects (TCE CCUD) fully deployed the first at-scale capture plant in the UK (see section 4.2.).

Figure 2.2 Technological advancement projects within the CCUS portfolio

8 capture	**3 Utilisation**	**6 storage**
5 post combustion 1 Oxy-fuel 1 Waste-to-energy 1 Capture from calciner	1 Sodium bicarbonate 1 Magnesite ($MgCO_3$) 1 Other	4 leakage monitoring 1 pilot in geothermal site 1 site selection tool

Note: the waste-to-energy project assesses several capture options to select the most suitable for municipal waste to energy projects.

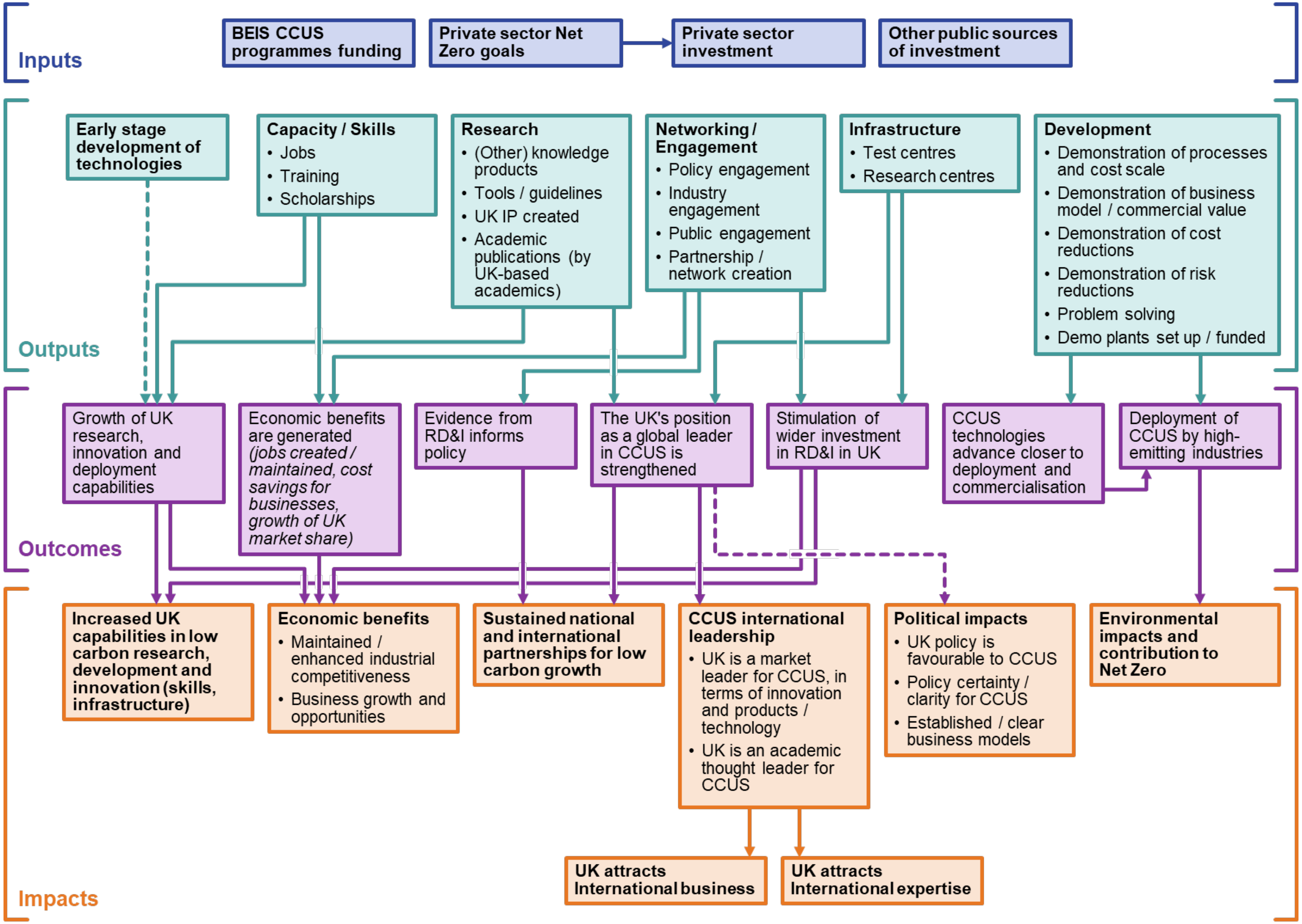
- **Research infrastructure:** These projects focused on developing physical infrastructure, or tools, protocols and collaborations that further CCUS research capabilities. Projects in this classification include PACT-2 and ELEGANCY.

2.3 Programme theory of change

Prior to the beginning of this evaluation, three programme-level theories of change had been developed. In the inception stage of the project, further work was conducted to understand the causal hypotheses underpinning all of the EIP CCUS programmes, which was developed into a cross-programmes theory of change. Following the interim evaluation and the analytical workshop held with our expert panel in December 2021, the theory of change was further refined to provide a framework for the evaluation. This went through two further iterations at the close of Wave 1 and the beginning of Wave 2. Its final form is presented overleaf (Figure 2.3).

[12] Note that this classification was set out as part of this evaluation, as an analytical approach to help assess their impact. It was not set as such in the programmes' call documents.

Figure 2.3: DESNZ CCUS Programme Theory of Change



Source: Ipsos UK

3 Process Evaluation

3.1.1 Overview of the programme rationale

The rationale for the programmes was set out in their business cases and call documentation. Critically, the programmes aimed to address some of the key barriers to CCUS deployment in the UK, as summarised in Table 3.1. Table 3.1 also details the assumptions or hypotheses that underpin each programme.

Table 3.1: Rationale for the three programmes

	Barriers targeted by the programmes	Underpinning assumptions and hypotheses
CCUD	• **Market failures**: carbon emissions from industry are a negative externality which was un/under-priced at the inception of the programmes; there was also a lack of business drivers to promote carbon capture for use; the spill-over benefits of demonstrating new technologies was not (yet) valued in the market. • **Market barriers:** a high upfront capital cost of CCU technologies, combined with higher interest rates; barriers to finance for emitting industries with the potential to capture and use the carbon; uncertainty for industry around the demand for captured carbon; unstable carbon and energy prices.	• Carbon capture process technologies for CCS and CCU are analogous. By deploying capture technology commercially at an intermediate scale, cost reduction and early learning can be achieved (e.g. on the optimal way to configure the plants, or on operational data on performance and degradation). • There are UK industrial sites that currently pay a premium for carbon dioxide and would consider capturing their own CO_2 to reduce costs, so the cost of demonstrating the technology could be partially funded by the host site having to pay less for the CO_2 they currently use. • Demonstration will de-risk the technology at-scale, which will encourage take-up of the technology within similar projects in the UK and internationally, and pave the way to larger-scale demonstration. • Support through the programmes could establish a pipeline of carbon capture and use projects could generate novel configurations, processes, materials and technology that act as an early market pull to accelerate carbon capture technology development and the development of a CO_2 utilisation market in the UK.
CCUS-I	• **Market failures**: imperfect information about technology cost and performance; unvalued RD&I knowledge spill-overs. • **Market barriers:** high upfront capital costs; barriers to finance for emitting industries with the potential to capture, use, transport and store the carbon.	• Developing and demonstrating CCUS technologies may lead to CCUS being proven as a viable way, which would eventually help decarbonise the economy; this would help reduce the impact of carbon emissions. • Government support enables CCUS technologies and processes to reach higher TRLs and commercialise sooner than they would otherwise. • Supporting CCUS innovation may provide a signal of government commitment to CCUS, potentially unlocking further private sector investment. • UK expertise in CCUS, along with offering export opportunities, will also be boosted. • Further development and demonstration of CCUS technologies will help inform future policy decision on CCUS.
ACT	• **Market failures:** imperfect information about technology cost and performance.	• An international collaboration targeted on CCUS will pool resources and is likely to lead to advancements in the technologies. • Supporting such projects may provide a signal of government commitment to CCUS, potentially unlocking further private sector investment. • UK involvement in international CCUS projects will also allow the UK to identify areas where it could establish capacity in the CCUS pipeline, potentially offering future export opportunities.

Barriers targeted by the programmes	Underpinning assumptions and hypotheses
	• Further development and demonstration of CCUS technologies will help inform future policy decision on CCUS.

Whilst not explicitly stated in the programme documentation, programme governance and delivery teams have explained that a key rationale for the programmes was: '*keeping the work progressing [on CCUS] and keeping industry working on it'*[13] while policy was being established, as well as about '*reinvigorating confidence in UK businesses*' around carbon capture and storage when industry was sceptical of new government policies in this area.[14] This understanding is aligned with some participants' views on the programmes.

3.1.2 Programme complementarity, coherence and scope

This sub-section provides a response to evaluation sub-EQ 6.1: To what extent does the portfolio of programmes that comprise the CCUS theme act as a coherent and complementary approach to supporting the development of a pathway to widescale deployment of CCUS?

The majority of evidence reviewed indicates a strong coherence between the programmes by design. Each business case was overseen by the same Deputy Director, and each was reviewed and approved by the EIP board, made up of members of the CCUS policy team at DESNZ and representatives from Innovate UK and HM Treasury, who had a role in assessing coherence and complementarity. The CCUD and ACT 1 business cases are mentioned in those of ACT 2 and CCUS-I, and the business cases of both ACT 2 and CCUS-I cross-reference each other.

Ultimately, the programmes sought to achieve the same outcomes through slightly different routes: international collaboration (ACT), support for Small and Medium-sized Enterprises (SMEs) and academic research / early innovation (ACT and CCUS-I), and intermediate level deployment (CCUD). As put by one policy officer involved in programme design, CCUD was focused on '*developing the capture side of things ahead of the policy and business models catching up*' and then the CCUS-I and ACT were about building the pipeline of projects.[15] Stakeholders report that the projects funded in the CCUD call would have been unlikely to have been successful in the CCUS-I calls given their (larger) scale.[16]

The CCUS-I and ACT programmes shared the most in common: ACT 2 was referred to as 'International CCUS-I' in its business case, and the CCUS-I call highlighted that applicants interested in developing international projects may apply to ACT 2. However, a key rationale for funding both programmes was to gain the advantages of international collaboration and of pooled funding through ACT alongside the advantages of national programming through CCUS-I (e.g. the ability to develop patented / protected IP. Only two applicants applied to more than one programme with the same project, and only one - the

[13] Governance and Delivery Team stakeholder
[14] Governance and Delivery Team stakeholder
[15] Governance and Delivery Team stakeholder
[16] The CCUD programme targeted as project lead UK-registered SMEs or large enterprises capable of constructing the CCUD plant applying alone or alongside UK academic, research, public, third sector or community organisations as technology supplier(s) who can implement the CCU technology solution. It was focussed on 'experimental development', defined as: 'acquiring, combining, shaping and using existing scientific, technological, business and other relevant knowledge and skills with the aim of developing new or improved products, processes or services'.

ACORN project - was funded through both ACT 1 and CCUS-I, with ACT 1 funding the feasibility and pre-FEED studies and CCUS-I the FEED studies.[17]

3.1.3 Relevance of the programmes and of the resulting portfolio

This sub-section provides a response to sub-EQ 6.2 To what extent did a coherent and appropriate portfolio of projects emerge from the three CCUS programmes? Were there any important gaps or duplications? Was there sufficient diversification of risk?

While the evaluation design did not foresee a specific question around the programmes' relevance (that is, the extent to which its design was appropriate to achieve its intended impacts), this aspect is also covered within this sub-section, for completeness in line with the Magenta Book Guidance.

An analysis of programme documentation and DESNZ stakeholder descriptions of the design process against the CCUS policy landscape at the time of programme launch suggests that the programmes were relevant in their design, although there was an acknowledgement that the scale of the programmes was not coherent with the scale of the challenge. The EIP CCUS programmes (ACT 2, CCUS-I and CCUD) were developed to accelerate the commercialisation of innovative clean energy technologies and processes into the 2020s and 2030s[18] in response to the Government's renewed commitment to CCUS, as set out in the Clean Growth Strategy.[19] The Strategy highlighted the need to '*lower the cost of capture compared to the current best performing technologies, [conduct] small-scale industrial capture demonstrations to reduce the risks associated with carbon capture on an industrial site, [support] the application of CCUS in low carbon hydrogen production, develop our understanding of the role of GGR [greenhouse gas removal] technologies […], and support innovations that reduce the cost of transporting and storing carbon dioxide*,' all of which were covered in the programmes. The programmes were also developed in the wake of the cancelled CCS competitions. For ACT 1, it was the only opportunity available at that time for DESNZ to work on CCUS.

However, there was overall acknowledgement that the challenge of de-risking of CCUS and crowding in investment was too big to be sufficiently tackled by a £39 million fund. As stated by one DESNZ stakeholder involved in the programmes' design: '*There was insufficient money to do 'the big bang', so it was about building capabilities in industry and with a view to longer-term funding … to get [them] to an investable stage / a stage when they could put together decent funding applications for the larger pots*'.[20] The programmes offered maximum funding grants per project of between £4 million (ACT 1 Call) and £10 million (CCUD Phase 3a competition). This enabled the portfolio of projects across the three programmes to cover a diverse range of projects and organisations with the total aggregate grant of £54m that has overall supported the development of a supply chain.

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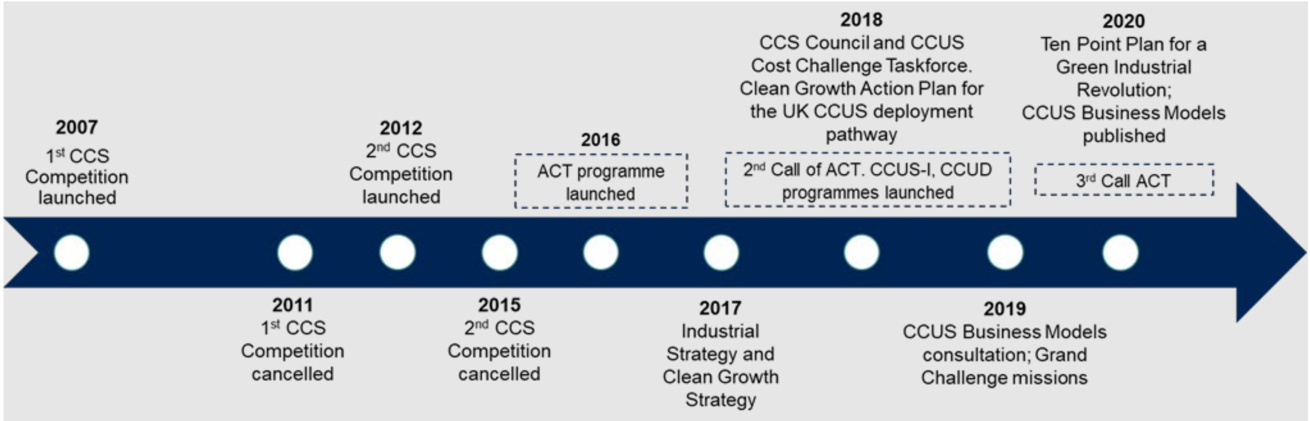
[17] The other applicant applied to ACT 1 and ACT 2 with the same project, being unsuccessful in the first ACT call and successful in the second one.

[18] DESNZ, 2021. Guidance. Energy Innovation. Available at: https://www.gov.uk/guidance/energy-innovation (accessed: 27 June 2021)

[19] DESNZ, 2018. Policy Paper. Clean Growth Strategy. Available at: https://www.gov.uk/government/publications/clean-growth-strategy (accessed 27 June 2021)

[20] Governance and Delivery Team stakeholder

Figure 3.1: Timeline of CCUS-related policies and programmes



Overall, the focus of the programme aligned with the needs at the time of programme inception: knowledge development, advancement and further testing of technologies to reduce uncertainties and costs, and strengthening pathways to cluster deployment. Several policy stakeholders have highlighted the CCUS-I and ACT support for cluster development projects under the Industrial Decarbonisation Challenge (IDC) as one of the major achievements of the programme; in this way the programmes helped lay the groundwork for current advancements to deployment.

> ***'The biggest achievement [of the programmes] has to be the contribution towards a pretty dynamic set of projects going ahead in the clusters. At the moment, we're looking to fast track two clusters and the UK has about twice that number. [Through the programmes] DESNZ came up with money in an early stage when people didn't really have that to pull the projects together. Early money is pretty useful.'-*** *CCS academic expert*

One policymaker commended the international approach of ACT. According to them the UK benefited significantly from its involvement in this international programme, because for a relatively low investment from the UK our teams were involved in delivering large projects which had substantial benefits.

The expert panel conveyed for this evaluation also raised a few concerns regarding the EIP CCUS programmes' relevance, most crucially, its focus on innovation. According to the panel '*it was clear from the CCS competitions that the key barriers to deployment were regulatory and commercial*'. The evidence reviewed for this evaluation shows that whilst the projects indeed did not target these critical barriers, they did generate knowledge which has supported the Government's development of the business models.

The key gaps that the expert panel identified in the portfolio were:

GGR technology coverage: Only one of the CCUD Phase 2 projects applied direct air capture (DACCS) technologies with three CCUS-I applications in this area being unsuccessful. This led to some project participants, and the expert panel brought together for this evaluation, perceiving the programmes to be too cautious or even low in their ambition. On the one hand, the limited coverage of DACCS in the portfolio was most likely a reflection of the low maturity of the DACCS technology and players in this field at the stage the calls were live. This in turn meant that the (few) applications received for GGR technologies were reportedly low quality. On the other hand, one such project funded within CCUD Phase 2 did not evolve to Phase 3B due to a range of contextual factors (see Box 3.1). Given that only GGR technologies have the potential to create negative emissions (and therefore support a more rapid reduction of carbon in the atmosphere), greater support for GGR projects might have had a greater impact on carbon emissions reductions.

Engagement of key industrial players: While CCS end-users, such as manufacturing industries, oil & gas and utility companies, participated in the programmes, the participation of key players in high-emission foundation industries, such as steel, cement and glass, was limited across the portfolios. Foundation industry participants were either from the chemical sector (petrochemicals and fertilisers) or lime suppliers. Across unsuccessful applicants, only one was a cement manufacturer, indicating limited interest of these foundation industry players in progressing CCUS when the competition calls were launched. Speculatively, this gap in coverage may be linked to the current lack of mature capture technologies for these industries, which may have meant that committing match-funding represented a higher risk investment to these industries than to the other more-represented ones.

Under-representation of transportation and storage: Whilst several CCUS-I and ACT projects covered T&S, most of them (particularly under ACT) focussed on developing leakage monitoring tools, which are relevant for minimising costs of storage development, but fall short of developing UK storage capacity. While two of the projects, Clean Gas Project/OGCI and ACORN, included an element of storage development, CCS experts consulted for this evaluation expressed the view that the programmes could have done more to support the development of UK-pilot underground storage *sites* and/or offshore carbon storage demonstration. This is both because the development of storage capabilities is a critical step in advancing CCUS deployment in the UK, and because the UK has an offshore storage comparative advantage (built on decades of exploring the North Sea's oil and gas (O&G) reserves). While the design of both ACT and CCUS-I enabled participants to propose projects with such focus, the funding available for an individual project within each competition was not suited to attract such proposals. However, the IDC has been supporting such projects since 2019, making available £10m and £20m to two projects developing offshore storage infrastructure (respectively, ACORN, which was previously supported by ACT 1 and CCUS-I, and the Northern Endurance Partnership).

Box 3.1: Reasons for no applications to CCUD Phase 3B

According to several CCUD stakeholders, market risk and uncertainty driven by policy changes were the major reason for the lack of applications to Phase 3B. The launch of Phase 3B coincided with the UK negotiations to exit from the EU, creating considerable uncertainty for UK industries considering committing to further investments. At the same time, the environment for CCUS had recently become more welcoming overseas, with the US passing a regulation that provided tax relief for businesses capturing carbon equivalent to \$50 on the tonne for carbon capture. This resulted in a perception amongst project developers that they would lose money by running the capture projects in the UK. While the UK Emission Trading System (UK ETS) encourages industries to cut their emissions, historically, the cost of industrial carbon capture has been greater than can be incentivised at previous EU ETS allowance values.[21] This picture might, however, be changing. In the first UK ETS auction, carbon prices reached over £50 (\$70.77) per tonne,[22] which is within the range set by specialists as the carbon price level consistent with the climate ambitions set by the Paris Agreement.[23]

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[21] According to the Carbon Pricing Leadership Commission, "the explicit carbon price level consistent with achieving the Paris temperature target is at least US\$40 – 80/tCO_2 by 2020 and US\$50 – 100/tCO_2 by 2030", while EU ETS allowances (EUA) prices in 2019 have fluctuated between €20 – 30 /tCO_2, or US\$ 22 – 34 /tCO_2 (see: https://markets.businessinsider.com/commodities/co2-european-emission-allowances)

[22] Reuters, 2021. Britain's carbon market begins trading at higher prices than EU. Available at: https://www.reuters.com/business/sustainable-business/britains-carbon-market-begins-trading-higher-than-eu-prices-2021-05-19/

[23] According to the Carbon Pricing Leadership Commission, "the explicit carbon price level consistent with achieving the Paris temperature target is at least US\$40 – 80/tCO_2 by 2020 and US\$50 – 100/tCO_2 by 2030".

Interviewees also suggested that the conditions of the call, the timeline for preparing application, timeline for delivering the project and the match funding required, posed a barrier to the applicants' ability to prepare an application.

3.2 Competition set-up, publication and promotion

This sub-section contributes to our response to the following sub-EQs (which are also covered under section 3.3 on the resulting portfolio):

5.1 Were the programme launches, calls and associated communications successful in **reaching target audiences**? Why / not?

5.2 Did the programmes receive a sufficient number and range of high-quality **applications**? Why / not?

Overall, the evaluation evidence suggests that DESNZ were **effective in their awareness-raising and publicity around the programmes**. DESNZ actively engaged stakeholders, for instance, prior to the development of the business cases. DESNZ held an open engagement day following the CCUD business case approval, and prior to designing the CCUS-I call, to provide an opportunity for potential participants (industry, academics and devolved government bodies) to feed back on the CCUS-I proposed design and upcoming stages of the CCUD programme.

'In terms of engaging business, a fair bit of it was around using the stakeholder networks that some of the programme managers had from previous programmes, with the CCUS policy team who had been engaging key industry.' – *DESNZ official involved in the design process*

Participants learned about the programmes either directly through their networks with DESNZ or indirectly through their networks with other players in the CCUS landscape. Additionally, one of the successful CCUS-I projects had learned about the programme via the DESNZ website, suggesting it was not only already-connected applicants whose projects succeeded. Several stakeholders were aware of the programme but opted to not apply as they considered the offer was 'too commercial' for their line of research. In terms of points that could be improved, one interviewee suggested that the **EIP lacked a branding that could have helped get the message across to participants** about how DESNZ innovation funding worked – and how it differed from the UKRI programmes with which these participants tended to be familiar.

3.3 The application process

3.3.1 Applicant experiences of the application process

This sub-section provides a response to the following sub-EQs:

5.3 Was the **application assessment process** efficient and effective? Why / not?

6.3 What have been the advantages and disadvantages of different approaches to **phasing** programme funding?

Overall, applicants did not have major problems with the application process and gave the view that the application guidelines were clear. They also commented that **DESNZ was readily available to discuss and answer questions** on the application process and forms. However, some expressed the opinion that **the time required to prepare the applications was a challenge**. This issue was raised by about a third of successful applicants interviewed[24] – with a balanced split across programmes meaning that no particular programme was evidenced to require more resources to apply for than the others. This issue was particularly acute amongst industry and small business applicants (five out of eight of those raising this as an issue), who have limited number of staff to dedicate to developing applications. While the rate of success across SMEs was aligned with the average across all applicants (10 out of 17 SMEs were successful against an overall 35 out of 62 across all private companies submitting an application) the point still stands: the tight resources of SMEs mean that the strain of putting in an application can be higher for them than for other private applicants.

Interviewees offered suggestions as to how the process could be improved by implementing a two-stage process (now incorporated into the CCUS 2.0 call), or by interacting earlier on with applicants to explain the process in more detail, either in the form of training or one-to-one guidance. For instance, in some UKRI programmes, applicants can rely on guidance support from an external specialised consultancy.

Across the three CCUS programmes, CCUD was the only one to adopt a phased approach, where projects are taken through stages for technological development with a view towards achieving deployment at the last stage. Despite this approach, none of the two Phase 2 projects (OFFCALC and Fuel Cell Biogenic Carbon Capture Demonstration) progressed to Phase 3B; only the Tata Chemicals project, supported under Phase 3A progressed successfully to deployment (see section 4.2.3 for more detail). While the ambition of accelerating the less mature projects towards deployment did not come to fruition, there is no indication that it was the phased approach in and of itself that led to the absence of applications to Phase 3B (see Box 3.1 above on reasons for the absence of applications for CCUD Phase 3B).

Unsuccessful applicants of the CCUS-I and CCUD programmes converged in their negative views on the feedback received from assessors. They described it as very short and unhelpful for continual project development. At its most extreme, one applicant stated the following:

'The fact that it was so short, less than half a page, it was 3 or 4 sentences, is a primary reason why the project died. There was no way to go back to the other potential investors and sell this story that was in any way encouraging to carry on.' – *Unsuccessful applicant CCUS-I / CCUD*

By contrast, unsuccessful ACT participants reported a very positive experience and had used the feedback to develop their bid for entry under ACT 3:

'We used feedback to make changes. We submitted the proposal to a company (hired by DESNZ), they were very helpful and gave very timely feedback – it was reviewed within a week. Our project is now highly improved.'- *Unsuccessful applicant ACT*

3.3.2 The quality and spread of applications

This sub-section contributes to our response to the following sub-EQs:

5.1 Were the programme launches, calls and associated communications successful in **reaching target audiences**? Why / not?

[24] Surprisingly, only two unsuccessful applicants raised the resourcing to prepare applications as an issue.

5.2 Did the programmes receive a sufficient number and range of high-quality **applications**? Why / not?

In total, 56 applications were received across the three programmes, of which 25 were approved for funding. Applications for CCUD Phase 2 were below the total expected, as highlighted previously. The quality of applications varied across the programmes. ACT 2 received the most applications that passed the minimum score threshold for funding (16 of the 21 scored above the 'pass' mark), resulting in the highest average score (11 out of 15, or 77 out of 100) across the three programmes. CCUD applications scored the lowest on average (48 out of 100).

Call	Applications received (average score)	Scored above threshold	# Successful (and average score)	# Unsuccessful (and average score)
CCUS-I	20 *(60/100)*	9	7 *(69/100)*	13 *(52/100)*
CCUD – Phase 2	4 *(48/100)*	0	2 (*)	2 (*)
CCUD – Phase 3	1 (*)	1	1 (*)	0
ACT 1	10 *(N/A)*	*N/A*	5 *(N/A)*	5 *(N/A)*
ACT 2	21 *(11/15)*	16	10 *(13/15)*	11 (*10/15*)

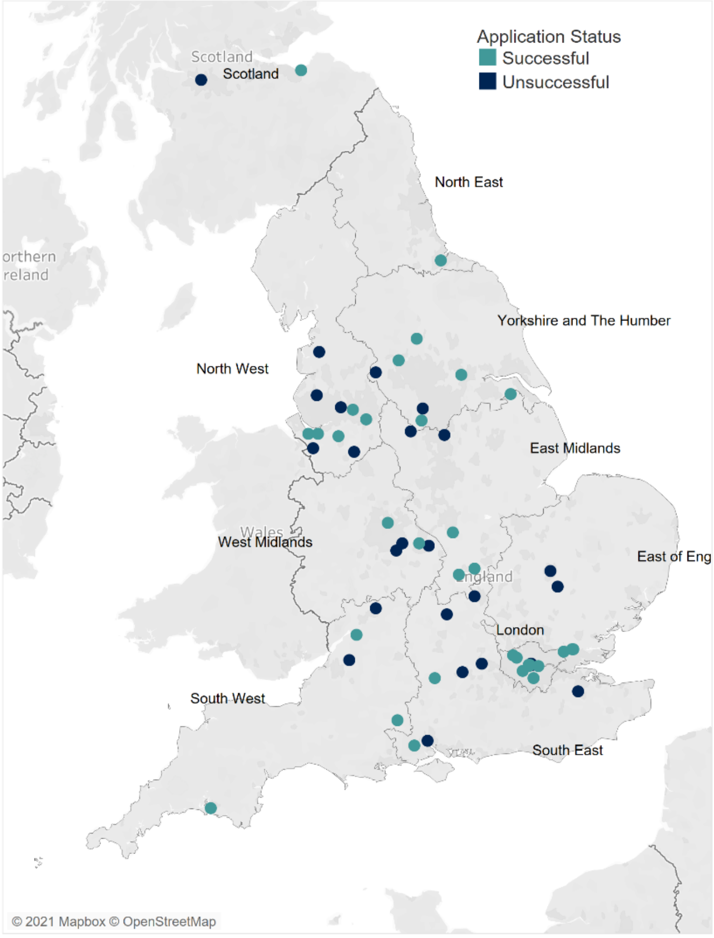
Notes: 1. Values for ACT calls consider only applications involving UK partners. 2. CCUD Phase 3A and 3B are not shown as only one application was received across the two, and it was successful. 3. No scoring information was available on ACT 1. *Information not included as it may be disclosive.

While there was a good spread of applications across the three programmes, in terms of the type of organisation, 45% academic or research and just under 40% were from industry, across both ACT calls, academic and research organisations made up over half of all organisations funded. This was highlighted by several stakeholders as a **shortcoming in ACT.**

> ***'[ACT] was highly academic, purely academic projects. If done again, we would promote industry engagement more.' -*** *DESNZ member of staff involved in competition design and delivery*

Figure 3.2 overleaf shows the location of private sector entities involved in both successful and unsuccessful applications across the three programmes. The data demonstrates that the CCUS programmes received interest from private sector energy companies across England and Scotland, with companies involved in successful applications spread across regions.

Figure 3.2: Geographic spread of applicants of the three CCUS programmes



Application Status	Region Name	Count	%
Successful	Scotland	1	2%
	East Midlands	3	5%
	East of England	3	5%
	London	9	15%
	North East	1	2%
	North West	6	10%
	South East	2	3%
	South West	3	5%
	West Midlands	2	3%
	Yorkshire and The..	5	8%
	Total	35	56%
Unsuccessful	Scotland	1	2%
	East Midlands	2	3%
	East of England	2	3%
	London	3	5%
	North West	6	10%
	South East	6	10%
	South West	2	3%
	West Midlands	3	5%
	Yorkshire and The Humber	2	3%
	Total	27	44%

Source: DESNZ CCUS Programme Monitoring Data, Perspective Economics

3.4 Governance, management, monitoring and reporting

This sub-section provides a response to the following sub-EQs:

5.6 To what extent were applicants / beneficiaries **satisfied** with programme processes?

5.7 Was **governance** of the programmes efficient and effective? Why / not?

5.4 Was the programme **management / monitoring** (including monitoring of risks) efficient and effective? Why / not?

5.5 Were appropriate / sufficient mechanisms in place to share progress and insight from the programmes to **support ongoing development of policy**?

6.5 Were opportunities for learning across the programmes and projects (and beyond – e.g. across DESNZ policy teams and other programmes) maximised?

More analysis on sub-EQ6.5 is provided in section 4.4.5

3.4.1 Governance and monitoring

Most participants across the three programmes were complimentary of the monitoring processes, which were predominantly described as proportionate and appropriate. In particular, many leads of ACT projects praised the programme monitoring and support, highlighting that the team at DESNZ were engaged and interested in all individual projects, ensuring a close and productive relationship with them.

'[The programme monitoring] was useful; there is not a lot of bureaucracy involved, they [DESNZ] are fair and good.' *- ACT project lead*

'DESNZ are very forthcoming, if they have concerns about anything, they will let you know. That gives us the opportunity to address those concerns and make sure they are happy with progress being made and the outcomes of the project they are founding.' - *ACT project lead*

'(…) it's only a couple of people making those decisions, but it's efficient' *- DESNZ staff involved in programme design and delivery*

'European projects tend to have weaker project management as more of a 'box-ticking' exercise, whereas ACT is more worried about what something is rather than delivering something on time.' *- ACT project lead*

Across the three programmes, DESNZ staff would often attend the regular project monitoring meetings on site, which enabled the programme management staff to be up-to-speed with the project implementation, and to make timely decisions on project direction. In several instances, projects made changes to the design and reported that the process of discussing and agreeing with DESNZ was seamless. In particular, participants reported that DESNZ reaction to the COVID-19 pandemic outbreak was appropriate, in that it was timely, flexible and cognisant of the challenges it posed to some projects. A small number of interviewees (three of the 17 that provided views on the monitoring process) raised issues with the reporting and, particularly, with financial reporting requirements, which they considered could have been more flexible to small deviations from the budget set out in their application. Others gave the view that the level of reporting was appropriate and that international colleagues (from ACT) faced a higher burden.

Despite the overwhelmingly positive feedback on monitoring processes from participants, DESNZ members of staff involved in delivery reported that the teams were understaffed, and that, while this did not impact delivery per se, it was a key risk that they had to manage throughout programme delivery.

3.4.2 Support and guidance to projects

CCUS-I SMEs were offered incubation support, which was led by Carbon Limiting Technologies (CLT) and aimed at helping participating innovators commercialise products and grow their companies[25]. The form of support was decided between the SME and CLT. Amongst the seven CCUS-I projects funded, only three took up incubation support. This covered the development of a business plan for one of them and market review for another; no details were available from the third SME. Their views of the process are not reflected here due to disclosure risks. Participants that were not eligible for this kind of support did not identify areas where additional support from DESNZ would have been welcome. Only one participant suggested that they expected the monitoring officers (MOs) to have provided greater 'added value' as part of their feedback. Similarly, in interviews, MOs also expressed that the budget available to them did not enable them to provide detailed feedback; it was only sufficient to allow them to track progress and risks, and feed back to DESNZ.

[25] https://carbonlimitingtechnologies.com/incubation-support/

3.5 Knowledge sharing processes

An analysis of the knowledge outcomes of the programmes is provided in section 4.3.5. This section discusses the relevance and effectiveness of the processes set up for knowledge-sharing.

All programmes were required to have built-in knowledge sharing as part of the project closure reporting. Within CCUS-I and CCUD, these were the Key Knowledge Deliverables (KKDs): all projects had to agree to publish non-confidential project outcomes and learnings as KKDs to ensure information was shared with the wider CCUS community while preserving confidential details. Within ACT the sharing of research results is the main objective of the final report. ACT have also hosted annual workshops to promote knowledge sharing. The overall aim of these knowledge sharing mechanisms was to accelerate CCUS cost reduction, benefit academia and the CCUS industry and raise the public profile of CCUS. By collating and disseminating this knowledge, these outputs were expected to contribute to the collective understanding of CCUS and provide valuable insights into potential mitigation strategies, best practices, and challenges associated with the deployment of these technologies.

Despite the existing structures for knowledge sharing, the fact that most knowledge sharing provisions were planned for the final stages of the projects initially led to **an overall sense across policy and academic stakeholders that such external knowledge sharing within the CCUS community was still insufficient,** particularly at the early stages of the programme. During Wave 2 of the research, the stakeholders' perspective did not change. This could be attributed partially to the reports from projects not having been published in full at the time that interviews took place. However, overall there was a sense across policy and academic stakeholders (and the expert panel consulted for the evaluation) that knowledge sharing was still insufficient and that more could have been done through projects to disseminate knowledge between projects and to the general public.

Webpage traffic data from the UK.gov page[26] shows that, following the publishing of the CCUS Innovation KKDs for the 7 projects in May 2022, the page visits peaked at 554 per month in June 2022, before dropping to an average 100-200 monthly page visits. This indicates that there is some broad interest in seeing the publications, but it remains unclear to what extent users are downloading the reports from the site.

In Wave 1, when KKDs had not yet been published, a few interviewees were sceptical about the relevance of the final KKDs. For instance, one interviewee argued that the KKDs from the 2012 CCUS Competition fell short of providing sufficient levels of detail that would make them useful to other researchers and developers. This interviewee was also wary that this could also become the case for the CCUS-I and CCUD KKDs. These concerns seem to have been somewhat mitigated, with stakeholders expressing positive views around the overall usefulness of the KKDs. They gave the view that the KKDs provided general understanding of the validity of the technology and some guidance and frameworks for implementation, albeit at a high level. This is expected, since there is a fine balance between securing commercial advantages for participants and providing the counterpart of public funding by making knowledge available to others.

In terms of knowledge sharing with policymakers, regular updates to the thematic committees were the main way that the programmes provided updates to policy teams. However, there is limited evidence of

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[26] https://www.gov.uk/government/collections/carbon-capture-and-storage-knowledge-sharing

substantive learning from the programmes that have been reflected in policy design, except for the fact that the Tata Chemicals CCUD project was included as a case study in the UK Government 10 Point Plan (supporting the commitment to *'facilitate the deployment of CCUS in 4 clusters by 2030'*).[27] While the IDC built on the progress enabled by CCUS-I and ACT, there is no evidence that its design was informed by the CCUS-I and ACT experiences, and one interviewee described the complementarity between IDC and the EIP CCUS programmes as a "*happy accident*". Similarly, there has been further development of CCUS programmes including the launching of NZIP and the Cluster Sequencing process. Policy stakeholders highlighted that the investment done as part of the EIP CCUS programmes allowed them to move the research forward and has enabled the demonstration of the importance of these technologies, bringing cost curves down.

[27] www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution/title

4 Outcome Evaluation

4.1 Introduction

The following sections describe the evidence of progress in the outcome areas targeted by the three CCUS programmes (as defined in the Theory of Change) and evidence of the programmes' contribution to these. The outcome evaluation applies a contribution analysis approach to assess the extent to which evidence collected through this evaluation supports the hypotheses around whether and how the EIP CCUS programmes were expected to reach their long-term goals.

- The ACT/ CCUD/ CCUS-I supported technologies advance closer to deployment;
- The ACT/ CCUD/ CCUS-I programmes grow UK research, innovation and deployment capabilities;
- The ACT/ CCUD/ CCUS-I projects contribute to stimulating wider investment in RD&I (industry, supply chain, academic) in the UK;
- ACT/ CCUD/ CCUS-I projects convince industry to deploy CCUS technologies;
- The ACT/ CCUD/ CCUS-I projects influence policy thinking on CCUS; and
- The ACT/ CCUD/ CCUS-I programmes strengthen / increase the UK's position as a global leader in CCUS.

Additionally, this section presents an overview based on the evidence gathered on the following areas:

- Any unintended outcomes of the programmes (positive or negative);
- What additional evidence or effort is needed to achieve impact (in the longer term); and
- (Based on evaluation evidence) the contribution that the rollout of CCUS can be expected to make towards the UK's decarbonisation target of net zero by 2050.

4.2 Technological advancement, cost reductions and demonstration of key components of CCUS

4.2.1 Advancement towards deployment

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would reach the following outcome:

The ACT/ CCUD/ CCUS-I supported technologies advance towards deployment

There was no explicit sub-EQ associated with this causal pathway.

As CCUS policy – and the market for CCUS – has developed since 2020, the technology is most likely to be deployed at one of several industrial clusters located around the UK (see Figure 3.2 in section 3.3.2). Evidence from this evaluation suggests that **the programmes played a clear role in advancing these clusters**, given that several of the projects funded were later incorporated into the clusters and the project teams and stakeholders consider that the programmes made a contribution to their deployment process (see Box 4.1); though they were not the sole contributing factor.

The early EIP CCUS programme support helped these net zero cluster projects to de-risk and thus demonstrate a clearer pathway to deployment. For example, detailed FEED studies produced in support of the Allam Cycle technology helped its operators and investors to understand more about what commercial scale deployment would look like on a specific site at Teesside. A two-year construction project is planned from 2024, with the expectation that the power plant will be operational by 2027. Further, other utility companies and developers around the globe are expected to announce their own plans for the project developer's plants (e.g. Net Power). Other projects also pointed to notable technological progress including, for example, the development of more efficient and effective solvents for capturing carbon.

"[We] went from stuff we'd just done in the lab to real world flue gas on a real industrial plant. Went to a TRL 6 or 7 – a significant step change."
- CCUS-I Project Lead, interviewee 1

Five projects funded by DESNZ CCUS programmes are part of three of the four clusters shortlisted as part of the Cluster Sequencing Process.[28] The first two clusters to be deployed, East Coast Cluster, and HyNet, are expected to be rolled out by the mid-2020s. Each cluster involves at least one 'anchor'[29] capture project, connected to a storage location by onshore and offshore pipelines and/or shipping logistics.

Both Clean Gas/OGCI and Allam Cycle integrated into the East Coast Cluster plan, capturing carbon to be stored at the Northern Endurance storage location, while ACORN and HyNet developed into their own individual clusters. The TATA project has led to carbon capture and usage in a commercial environment and is now part of the HyNet cluster.

A few project leads interviewed gave the explicit view that, without the initial support and funding as part of the three CCUS programmes, the cluster would not have been able to go ahead. These leads explained that this was either because the CCUS programme support increased stakeholder awareness or interest in CCUS, or because the support allowed them to demonstrate their capability to deliver at scale. Box 4.1 below outlines the causal links between the EIP CCUS projects which were investigated as part of analytical case studies conducted for this evaluation, and the current East Coast Cluster and the ACORN cluster.[30] While it is possible that these clusters may have still gone ahead without the contribution of the EIP CCUS funding, it is clear that the CCUS innovation support catalysed partnerships and FEED studies that contributed to the clusters design and progression to at least some extent.

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[28] https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-2
[29] An anchor industry within a cluster is the main site at which carbon capture and transport infrastructure is based and developed, with high emitting industries and/or carbon capturers linking up to its infrastructure. The 'anchor' plays the role of attracting other contributors to the CC(U)S system.
[30] This evaluation did not run a case study of HyNet. Therefore, this report is not able to provide an in-depth assessment of the linkages between the CCUS-I funded project and the HyNet cluster shortlisted under the Cluster Sequencing process.

Box 4.1 – The causal processes underpinning the contribution of the CCUS innovation programmes to clusters shortlisted under the Cluster Sequencing process

The developers of the OGCI/Clean Gas project reported that the EIP CCUS funding helped pique interest from key industrial partners, which ultimately helped OCGI pass ownership of the project to member companies to take it forwards as 'Net Zero Teesside' (NZT). The NZT project eventually developed into the East Coast Cluster. According to stakeholders, the CCUS-I funding helped build momentum towards deployment, as it "*gave legitimacy to the work that was being done at NZT*". While the cluster may have been able to go ahead without the EIP CCUS funding, it is likely that the momentum built by it contributed to the establishment of the East Coast Cluster and its scope to at least some extent.

The East Coast Cluster also encompasses the Allam Cycle project (also known as the Whitetail Clean Energy project), which was funded by CCUS-I. Allam Cycle was a detailed pre-FEED feasibility study that helped to enable the further development of the CCUS power plant, which will now contribute to the overall volume of carbon captured at the East Coast Cluster. The project is expected to receive a Dispatchable Power Agreement (DPA) – a contract between electricity generator and government which sets the terms for capturing and storing carbon and the compensation the generator will receive in return.

ACORN received funding from both ACT 1 and CCUS-I, which enabled the project to demonstrate commercial viability and thus advance closer to deploying a full-chain carbon capture and storage (CCS) system. It enabled the project to bring more industry and funding partners onboard. Before being shortlisted for funding, ACORN had also secured public funding from the Government of Scotland (which was conditional to the Cluster Sequencing shortlisting), and private funding from Ineo. The project also continues to be further developed through IDC funding, with the aim of achieving a final investment decision (FID) by 2030.

As stated above, overall, the evidence from stakeholders and the case studies of these projects suggests that the EIP CCUS programmes played a role in advancing some of their supported projects towards CCUS deployment within the CCUS clusters.

4.2.2 'Pure' technological advancement

This sub-section provides a response to the following sub-EQ:

1.2 Have projects provided evidence to demonstrate the development of CCUS technologies (e.g. increased TRL)?

Whilst the EIP CCUS programmes set up monitoring frameworks that would measure the technological advancement within projects as increases in 'technology readiness levels' (TRLs), interviewees often argued that TRLs might not be the best way to evaluate progress. Given that CCUS is not a single technology, but the application of a chain of technologies (capture, utilisation, transportation and storage of the carbon) some of the projects were targeted at advancing the demonstration of full-chain CCUS. Similarly, some projects intentionally started with proven technologies but sought to combine them in innovative ways which made it difficult to show technological advancement through an increased TRL. One policymaker argued that the most incremental gains in innovation programmes come from improving proven technologies rather than returning to the drawing board.

Nonetheless, 21 out of the 26 funded projects set out explicitly to increase their TRL and, based on interview findings, ten projects met or potentially exceeded their target TRL (PACT2, ACTOM exceeded, ELEGANCY, ALIGN CCUS, ACORN, ACORN CCS, TiGRE, SENSE, FUNMIN, CCUD delivered). A further six increased their TRL by at least 1. Due to gaps in available monitoring and interview data, it is not clear if the other five changed their target TRL or did not achieve it. For those projects that did not increase their TRL from their original target, at least three teams were continuing with the work, building on the learning to develop their technology further with new funding. There were also five projects which were not seeking to improve their TRL and as a result did not report a baseline value for this variable.

In terms of scale of advancement, most projects advanced their technology by two technology readiness levels (TRL) and the average end-point was between TRL 5 and TRL 6. Many commented that the limiting factor for further advancement was the significant level of investment required to get to the next phase.

Table 4.1: TRL Progression by type of project supported

	Number of projects	Most common TRL increase	TRLs most commonly reached at end of the project
Capture	9	1 or 2	>6
CCUS Cluster enabler	4	Varied (>1)	>7
Research infrastructure	5	1 to 2	Varied (>3)
Storage	6	2	6 or 7
Utilisation	1	3	4
Overall	**26**	**2**	**6**

Source: DESNZ EIP KPI Tracker. For information on the project groupings by type, see section

Two businesses were able to register patents as a result of their projects (TATA chemicals and TiGRE), and one of these businesses is awaiting the outcome of two other patent applications. A third business involved in the C-Capture project also reported having applied for a patent while, according to interview data, a fourth project based in a university expressed an interest in registering for patents but had not yet done so at the time of interview. Finally, some of the academic led projects are providing consultancy based on the models developed. Other projects are still on the look-out for opportunities to demonstrate technologies and solutions at scale before their companies can grow.

From the Wave 1 research, at least four out of seven unsuccessful applicants consulted for this evaluation had not achieved technology advancements since applying for funding, as they were unable to secure funding elsewhere to take the project forward. One of these commented that one of the reasons for being unable to secure other sources of funding was the lack of confidence in the project among partners due to the rejection of government funding, which created greater uncertainty for investors:

'If we would have got the Government funding, […] we would have got the match funding. But when the Government funding fell through, then there was no chance to get investment in the UK because confidence was gone. There was a feeling that the UK government was not interested in the project.' *- Unsuccessful applicant*

Another unsuccessful applicant who had managed to secure funding suggested that the process of developing the application for CCUS-I contributed to them becoming successful in their next application. During Wave 2 of the research unsuccessful projects were not contacted.

Overall, the evidence from project reporting and interviews suggests that **many funded projects did advance the technologies through the EIP CCUS programme support though this may not have always been to the extent anticipated**.

4.2.3 Technological demonstration

This sub-section provides a response to the following sub-EQ:

1.4 Have projects successfully demonstrated key components of CCUS (technologies, deployment, operation) to relevant stakeholders?

Several of the projects funded under the EIP CCUS programmes have either obtained follow on funding to continue progressing their technologies or clusters, or are seeing their outputs, deliverables, models or workflows being applied or close to being applied. For instance, Tata CCUD deployed their capture plant in 2021 and is utilising CO_2 on site, instead of having to buy it from other sources; workflows developed through DETECT are being utilised within their commercial partner; the approach to satellite monitoring developed in the SENSE project is now being incorporated in other projects; and, the ACTOM project developers are hopeful their decision support tool will be used and is in dialogue about it with several countries. Those still looking for funding seem to be facing the innovation 'valley of death': while the funding enabled them to prove that their solution could work at a small scale, the capital expenditure required for a commercial scale pilot remained prohibitive without them achieving more public funding (as they did not necessarily feel their projects had gone (or could have gone) far enough to address investors' concerns).

Project teams working on lower TRL projects, i.e. aiming to develop more fundamental knowledge, have largely dispersed, having published their findings. In most instances, there was limited evidence that the tools developed with the funding were being actively used by others, although the teams were hopeful that this would still happen in the coming years. Some had plans to sell consultancy services based on their tool(s), but this work had been limited to date. One project described a mismatch in what the market needed and what they could provide: universities were seeking projects to support a PhD or Postdoc student (which would typically need to last a year or more), while commercial companies would need much shorter projects in which the tool was applied to a specific business question. Under their current model, the research teams did not have the resource to support these shorter projects.

Others suggested that the work they had done had proved their original hypothesis (for example, demonstrating that the risk of leakage was low), which in turn generated the knowledge to increase the confidence on other researchers to sustain the focus on CCUS.

"For an academic institution it's appropriate to stay at TRL levels below 8, as otherwise it requires a lot of operational cost and expenditure. It's then down to industry to push it to higher TRLs. If they implement as part of their CCS projects then they can easily get to levels of 10, but that requires £100s millions to deploy the monitoring, drill etc. So a university could never do this."
- ACT1 Project lead

Some projects sought to develop infrastructure that could be used by other organisations involved in CCUS. These were largely successful and are continuing to develop. Of the three projects for which project team members were interviewed, one (PACT2) is now providing facilities for new projects to utilise. Two others (HyNET and ACORN) had progressed with their business case for developing infrastructure, which is ultimately intended to lead to deployment. In both instances, the development of infrastructure was seen as the enabler of further collaboration and innovation activity as part of the broader ambitions of all organisations involved to develop and deliver CCUS.

Box 4.2 outlines findings from analytical case studies conducted for this evaluation on how projects have advanced specific CCUS technologies. This, and other evidence from stakeholder interviews indicates that **several projects did advance CCUS technological and commercial readiness**.

Box 4.2 – Technical and commercial progression of projects

DETECT has developed a range of tools to improve CO_2 storage operators' ability to evaluate risks of leakage and inform strategies to mitigate risks, including fracture leakage modelling, guidance for selecting and assessing containment monitoring technologies, and CO_2 leakages risk assessment tools. The team are being invited to deliver site-specific consultancy based on their model and workflow developed as part of the ACT programme.

ELEGANCY has advanced TRLs for blue H_2 production technologies with selected components progressing from TRL 2-5, simplifying H_2 production with CCS technologies. It has also developed an open-source tool for the industry and policymakers to assess CCS development options, including uncertainty risks, in H2-CCS chains. The tool has been applied by industry partners within the ALIGN project. According to ALIGN stakeholders, the tool was found beneficial and helped to understand and optimise the application of CCS-H_2 in some sites. Several of the academic papers produced under ELEGANCY also had a significant reach.

PACT-2 infrastructure is contributing to new projects in industry: they now have a list of companies from a range of sectors (green and blue hydrogen production, gas turbine technology, production of sustainable aviation fuel from carbon capture) using the facility. Some have already successfully used the facility to increase their TRLs, including at least one UK-based company that has now received private sector investment to expand their activity. PACT-2 has now combined with other initiatives to become part of a new national energy research facility known as the Translation Energy Research Centre (TERC).

ALIGN has demonstrated the full CCUS chain, including CO_2 utilisation for synth fuel production, yet longer tests are still required to move towards higher TRLs, as gaps do remain on preparing for large-scale capture demonstration. The results from the pilot-scale demonstration were applied by Dutch companies for CO_2 capture. The design/development of Storage Readiness Levels (SRL) as an approach is notable as a key project output and as a framework and tool for standardising identification of the level of development for storage sites . However, the ALIGN case study conducted for this evaluation found that there is limited evidence of clusters indeed using ALIGN project's findings to inform storage location decisions.

4.2.4 Cost reductions

This sub-section provides a response to the following sub-EQ

1.3 Have projects demonstrated actual (or the potential for) cost reductions in the deployment of CCUS that improve upon the current state of the art? Have projects provided robust, detailed data about the costs and benefits associated with the deployment of CCUS in the UK through their technologies?

Projects funded through the programmes were expected to generate cost reductions in two ways:

- By covering the costs of developing and/or utilising CCUS technologies resulting in lower overall costs of total CCUS deployment.
- By reducing the need for potentially higher cost emission reduction technologies.

DESNZ CCUS programmes were expected to contribute to reducing the cost of deploying the several stages of CCS (capture, transportation, injection and storage) through technological advancement and/or by designing and demonstrating models of revenue generation from carbon utilisation. However, interviewed policymakers contest whether this should have been the main aim given the (then) stage of CCUS policy and market in the UK. They reflected, in line with the feedback from the project leads, that true cost reductions would only be quantifiable once full-scale pilots are underway.

In total, 17 out the 26 projects funded across the three programmes were expected to lead to cost reductions. Yet, the evidence from projects to assess the extent to which cost reductions have been achieved is limited, not least because projects were not required in project reporting to provide verifiable evidence of cost reduction claims.

Findings from case studies indicate that some projects may have reduced (or have the future potential to reduce) costs. In the project lead interviews, only a couple of the project leads explicitly mentioned potential cost savings:

- One of the projects hoped to demonstrate significant savings but reported that they were unable to achieve these without applying their solution to a larger (industrial) scale, which was not possible nor foreseen within the EIP CCUS project lifetime. However, project leads argued that the pilot demonstrated a positive direction of travel.
- Another project outlined how their solution, if implemented, would enable storage facilities to place sensors efficiently, thus potentially reducing the cost of monitoring. Additionally, they argued that their solution reduced the need for the super-computer processing time required.
- Three of the projects also claimed to have enabled cost reductions for the development of new CCUS solutions by developing research infrastructure (see 4.3.4) or developing the business case for cluster sites. While these may not reduce the cost of deployment per se, it was argued that they would reduce the investment required to develop new solutions, thus encouraging innovation and helping ensure research and development is cost effective in the UK.

Overall, **evidence indicating either cost reductions over the lifetime of the EIP projects, and any contribution of the programmes to cost reductions is very weak** suggesting that this outcome was not achieved.

4.3 Capacity-building

This sub-section provides a response to the following sub-EQ 1.5 Have projects contributed towards capacity building (skills development, new posts, retention of expertise, dissemination of knowledge)?

It also provides a further response to sub-EQ 6.5 Were opportunities for learning across the programmes and projects (and beyond – e.g. across DESNZ policy teams and other programmes) maximised?

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would reach the following outcome:

The ACT/ CCUD/ CCUS-I programmes grow UK research, innovation and deployment capabilities

The EIP CCUS programmes aimed to grow the UK research, innovation and deployment capabilities through three mechanisms:

- Providing investment in projects fully equipping them with the right skills and personnel, hence increasing the organisations' overall capabilities in innovation which can sustained over time.
- Development of research infrastructure to be used for ongoing research, innovation and deployment.
- Development of sustainable (and productive) collaborations and partnerships.

As outlined in the following sub-sections, the projects have enabled growth in UK CCUS capabilities, with most projects reporting to have achieved their objectives in this space, and indicating that the funding enabled participants to develop both soft and hard/technical skills, which in turn could support the delivery of future CCUS projects.

Nearly all projects achieved or exceeded their original goals in terms of capacity building (according to project reporting) and claim to have added to the CCUS capabilities along different parts of the chain. Some have made this information widely available and are encouraging others to use their findings. Projects seeking to commercialise their learning are less forthcoming, since they hope to leverage the knowledge and intellectual property (IP) developed to achieve further funding and to profit from their discoveries.

4.3.1 Projects' contribution to new jobs

In terms of supporting UK capability through funding new jobs for the duration of the project which are sustained, evidence is mixed. For the majority of project leads, funding was not used to create new jobs but to redeploy existing posts. Interview evidence therefore weakens the hypothesis of contribution of the programmes towards this outcome. Interview evidence is also mixed as to whether any new roles have been retained post-project. Some have retained new jobs or made the job transfers permanent. In other instances, staff working in the projects have transferred to academia from industry, and others have returned to their existing roles to manage other projects. In total, five projects said that their teams had continued to grow after the funding programme ended, growing from an initial 30+ people to approximately 215 people employed across these five projects, with an additional 500 having access to the programme:

- ACORN grew from 15 employees before the funding to a current headcount of over 80 staff in long term posts.
- C-CAPTURE grew from approximately 10 staff when funded to over 40.
- HyNet employment was dispersed across 40 member organisations. The organisation integrating the different members doubled in size since the original investment and gained around 40 employees, while over 500 people gained access to the programme SharePoint.
- PACT-2 started with just two non-academic roles and now employs 14 people. It also had by the close of the project between 8 and 12 research fellows and 28 PhD students involved in various studies.
- Allam Cycle gained just one additional role in 8Rivers and an unknown number of roles in Whitetail over the project period.

4.3.2 Individual skills development

Beyond job creation, self-reported evidence from interviews suggest that **skills were developed and retained.** For some, the new skills were developed though due to a 'learning by doing' approach taken to deliver some of the projects, rather than a result of an explicit investment in skills.

In-depth interviews with successful project stakeholders, relevant CCUS actors, and the project documentation review indicate that project funding enabled project participants to develop both soft and hard/technical skills supporting the delivery of future CCUS projects. Some skills described include project management skills, communication, reporting, research, engineering, information technology, and technical project-related skills and knowledge. These were mostly developed through hands-on experience (e.g. management and delivery of work packages) rather than formal training. No project participants mentioned offering project-specific formal training. The technical skills gained were different for each project and largely developed as a result of the interdisciplinary nature of many of the teams. Many described 'learning by doing' rather than more formal learning. Skills developed included:

- **Development of early careers** including apprentices, chemists and engineers who learned on the project as they considered it was hard to find experienced people with these skills who were interested in working in CCUS. The pool of people with these skills and already working in the sector was also limited. Most academic teams included PhDs and Postdoc roles who gained valuable experience including exposure to applied CCUS.
- **Practical skills and knowledge** of gas handling (Hydrogen and CO_2) including conducting risk assessments and developing familiarity with relevant legislation and hydrodynamics, and understanding of fluid and thermo-dynamics for CO_2 transport and storage.

"We all know a lot more about CCS and hydrogen than we did when we started!"
\- Project lead

- **More sophisticated use of IT solutions** including computer simulations, modelling and machine learning for purposes including hydrodynamics, mineralisation and storage. One interviewee also mentioned gaining increased knowledge and experience of a container-based approach and its benefits over the more standard GIS approach which came through working with an IT specialist.

- **Improved approach to interdisciplinary working**, for example bringing together geologists and engineers to develop shared understanding of a problem, or geophysicists and seismologists working together, or understanding of whole chain as result of discussing and debriefing with partners.

Additionally, some projects specifically talked about how the projects had set them up for future work:

- **Track record:** Once the team has delivered something once it makes it more credible in future funding applications.

- **Models and tools:** Those who had developed models and tools planned to use them in future work.

CCUS-I incubation support, granted to some SME applicants, reportedly helped recipients to develop their market research skills, determine a route to market, and to understand their intellectual property rights. Participant interviews suggest that the support was valuable for those projects which received it.

'Incubation support has been immensely valuable. The work they've done to support us over this past year – market review, replicability – is really valuable.'
- Project lead

Finally, one project lead (academic) developed a new Masters course on the energy transition and made CCS a key component of it, as a direct result from working as part of the project.

4.3.3 Capacity-building / workforce development

As outlined above, many projects involved young professionals, such as Masters or PhD students, and in this way may have **contributed to generating a pipeline of skilled professionals in the CCUS field**. The projects' contributions towards a larger CCUS community in the UK was recognised by one CCUS technology developer not directly involved in the delivery of a DESNZ funded project:

'One achievement [of DESNZ CCUS programmes] has been capacity development; through these projects we have a bigger CCUS community in the UK. Now, we have undergraduates thinking of CCUS as a proper industry they aspire to walk in.' –
- CCUS technology developer

However, the projects had differing views on the extent to which it was possible to attract and retain good people in the CCUS industry. While nine of the fifteen projects interviewed did not identify any challenges building a team with the required skills, six projects had found this to be an issue. Some of those that did not have difficulty brought in skills from contractors where required.

The six projects which described difficulties reflected that it can be hard to attract and retain talented people, particularly as the required skills are in high demand. They thought that if candidates were comfortable working in industries such as oil and gas or mining, they could find higher salaries in the private sector. For candidates not comfortable working in these industries, CCUS is not sufficiently distinct from the oil and gas sector to provide a fulfilling alternative. Equally, while computing and specifically machine learning skills are very valuable to the CCUS sector, they are also in high demand across the economy. The conclusion was that it was best to start with younger candidates passionate about CCUS who could be taught additional skills, such as machine learning so that they would be less likely to move on. One interviewee commented that increasingly they are being asked to find British candidates for PhD and postdoc roles but find that while there are plenty of EU candidates, very few are British.

Most of the projects utilised existing staff who typically worked across several projects, combined with graduates, PhDs and postdocs. As a result, at the end of the projects, the team members went on to work on new projects or found new roles elsewhere. Five projects explicitly described how new people had been taken on as a result of the funding and had continued in post, as part of a growing organisation, as a result of the project's success.

4.3.4 Contribution to collaboration and partnerships

This sub-section provides a response to the following sub-EQ 1.7: Have new collaborations, partnerships and networks been established?

The scale of the CCUS deployment challenge requires wide-ranging collaborations and partnerships across industry, academia, local government and wider CCUS stakeholders to enable the technology to progress from RD&I towards real-life applications. Such collaboration is needed at both national and international levels, as international technology collaboration will be key to enabling costs and opportunities to be shared internationally.[31] Indeed, within the Wave 1 evaluation research, almost two fifths of Project Leads interviewed, when asked about their motivations for applying to the CCUS programmes and the challenges being addressed through the programmes made explicit reference to imperfect information, with around one quarter making reference to co-ordination failure.

Acknowledging the importance of establishing networks and partnerships, the three CCUS programmes under EIP had collaboration requirements. ACT required applicants within 'large projects' to involve industrial partners and encouraged such partners to lead bids. Multi-disciplinary applications were encouraged. It also required projects to involve partners from at least three different countries. The CCUD Phase 2 and 3 calls stated that '*successful applications (…) are likely to include*' a technology supplier and an organisation that can build a CCU demonstration plant (though single applicants were also allowed). Finally, the match funding requirement under the CCUS-I call acted as an incentive for involving private sector organisations.

Overall, the evaluation has found that **the programmes played a role in forming new partnerships that could catalyse new collaborative research and innovations**. One interviewee considered that the ACT programme was particularly good at encouraging the academic community to work with industry. Partnerships formed were seen as a key factor facilitating the projects' progress. Some of the key benefits of establishing these partnerships include the ability to secure the right skill set within the consortium and the possibility to increase the dissemination of project findings across countries.

> ***"[The key drivers of success are] strong background and the ability to bring in all these partners with different skills; existing networks were very important"***
> - *ELEGANCY Project Participant*

Evidence from the case studies, in-depth interviews and project reporting on new partnerships established suggest that most projects across the three programmes created new collaborations,

[31] IEA (2020) Energy Technology Perspectives. Available at: https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf

partnerships and networks.[32] According to project reporting, 195 formal relations and 246 informal relations were created across the 26 projects.

- For the eight projects[33] that have ended with no follow-on work, these partnerships have now disbanded, but the relationships remain. Many interviewees describe how the world of CCUS is relatively small and they anticipate working with the same people in future when an opportunity requiring their skillsets presents itself.

- For the eight projects that have continued, the partnerships mostly remain in place and in many cases have expanded as the projects become more ambitious or seek to expand into new sectors. One mentioned that they lost a commercial partner as it went out of business.

The projects helped develop cross-organisation collaboration and enhanced organisational capability, which in some cases has been sustained as these partners became part of larger consortia in follow-on projects. Project leads referred to the fact that projects demonstrated that they could get multiple partners to work together and share risk / cost, and come up with integrated networks, which has become the template for CCS across the UK. In most cases, stakeholders reported that investments in the projects created new partnerships which would not have been developed without the programme, particularly in the case of academic-industry collaborations. This suggests that the CCUS programmes have supported the development of sustainable (and productive) collaboration and partnerships.

"If you were to look at the reports of [CCUS project], you would see that as a whole the project engaged many industrial partners. We had a strong panel of industrial stakeholders who attended our meetings and engaged with some of the research". "It was quite a significant project involving many partners who actually worked very well together. I've been involved in many of these projects, and sometimes they're just a bunch of people going after their own thing and pretending to be a project. [CCUS project] actually was a project team which worked together quite effectively.

- ACT 1 Project Lead

"We're working with several of the partners in other projects and I guess it's the [funding for] common interests in CCS and hydrogen that does that."

- ACT 1 Project Lead

As well as addressing information and coordination failures in a broad sense, these new connections also generated tangible benefits. For example, interviewees involved in the ACORN project pointed to the existence of an offshore storage license[34] as strong evidence of the tangible impact that CCUS project collaborations have had.

"The evidence exists now because there is an offshore storage license. [There is also] an industrial partnership and significant inward investment in the [Scottish Cluster] project. Without the [CCUS programme], the Scottish cluster wouldn't exist."

- ACORN stakeholder

[32] It should be noted that the quality of self-reported data on new partnerships formed is limited by the fact that different reporting parties will have different interpretations of what constitutes a 'new partnership'. Some might consider only those formal partnerships built as part of the funding application and sustained through the CCUS projects, while others may also formal partnerships built during the project implementation, and others yet may consider informal partnerships as well as formal ones.

[33] Eight projects that took part on the Wave 2 interviews

[34] https://www.offshore-energy.biz/20-carbon-storage-licenses-offshore-uk-offered-to-12-companies/

4.3.5 Knowledge dissemination

This sub-section provides a further response to sub-EQ 6.5 Were opportunities for learning across the programmes and projects (and beyond – e.g. across DESNZ policy teams and other programmes) maximised?

As set out in section 3.5, each of the three EIP CCUS programmes had knowledge sharing requirements built into their design. Their overall aim was to accelerate CCUS cost reduction, benefit academia and the CCUS industry and raise the public profile of CCUS. By collating and disseminating this knowledge, these outputs were expected to contribute to the collective understanding of CCUS and provide valuable insights into potential mitigation strategies, best practices, and challenges associated with the deployment of these technologies.

Findings from programme documentation and project stakeholder interviews show that there was a concerted and successful effort of capturing the knowledge and information generated from within the projects, either through the final reports (ACT programmes) or through the KKDs (CCUS-I and CCUD).

Projects disseminated knowledge to some extent and that this was, at least partly, driven by the programmes' design. Most of the projects were seeking to disseminate to raise awareness of their work with potential partners and funders. Additionally, many of the academics intended to keep publishing papers beyond the end of the funding; they noted that the data gained as part of the projects will continue to keep them and their students busy.

In terms of knowledge dissemination *within* the programmes, there were mixed views as to whether this could be achieved. While some were interested to hear what the other funded projects had achieved, others gave the view that the projects in the funding stream were very diverse and were not clear what benefits they would derive from knowledge sharing. This was particularly true for projects focussed on developing a specific technology, who would see projects working in a similar area as competitors and those working in different areas as less directly relevant. These projects were keener to promote their outputs to industry, where they might find future uses for their work.

ACT project final reports and knowledge sharing workshops

ACT applicants were required to produce final reports, which are then made publicly available on project websites, and to host a knowledge sharing workshop. These annual workshops were designed to provide project stakeholders with the opportunity to present their work, learn from other projects, and further connect with other CCUS stakeholders. However, they perceived that these opportunities were sometimes only available to the overall project leads (who could be based in another organisation or country) and not all workstream leads, leading to mixed levels of awareness. Some gave the view that the pandemic had limited opportunities for in person meetings which might have been helpful.

Rather than network with other ACT projects, the teams typically continued to use relationships and networks they already were linked to in order to share their project and learn about others. Examples include conferences run by CO_2 Geonet, the International Energy Agency's Greenhouse Gas R&D Programme (IEAGHG), Greenhouse Gas Control Technologies (GHGT) Conference, and the Trondheim Conference on Carbon Capture, Transport and Storage (TCCS).

All the ACT projects had presented their findings in webinars and conferences and had published papers relating to their work in addition to producing their final report. Some had targeted high profile publications, while others had spread their efforts more widely. One project specifically targeted more operational journals to reach the audience most likely to learn from their findings. The number of papers written ranged from a handful to over 80 per project. ELEGANCY, which closely tracked its outputs, reported having published in over 40 scientific journals, which achieved hundreds of citations.

CCUS-I and CCUD Key Knowledge Deliverables

Projects were expected to produce several KKDs for publication at the end of the project, and all seven projects produced KKDs amounting to 39 reports in total, covering over 3,000 pages.[35] The eight KKDs are summarised below in Box 4.3.

Box 4.3 – Summary of KKDs

Allam Cycle (now known as the 'Whitetail Clean Energy Project'): The 8 Rivers CCUS initiative spans various aspects of developing advanced CCUS technology, including power generation, carbon capture and utilisation, infrastructure requirements, and policy considerations. These knowledge deliverables contribute to the broader understanding of CCUS and aim to support the advancement of clean energy technologies in the UK. The project also aims to demonstrate the technical and economic feasibility, potential benefits and challenges associated with the implementation of the Allam Cycle, a high-efficiency, low-cost natural gas power generation technology with inherent carbon capture, providing insights into the design, optimisation and performance of the Allam Cycle technology. The project examines the infrastructure requirements for large-scale deployment of CCUS, including CO_2 transportation, storage, and monitoring. It also assesses the policy and regulatory landscape for CCUS deployment and provides recommendations to facilitate its implementation.

ACORN: The ACORN project aims to develop a low-cost, low-risk CCUS system in the UK, and to establish a carbon capture and storage hub in northeast Scotland, creating a pathway for decarbonising industrial processes. The Acorn Project produced a comprehensive feasibility assessment, a key knowledge deliverable to evaluate the technical, economic and environmental aspects of implementing CCUS technology in the region. The project also implemented a robust stakeholder engagement plan which was developed to foster collaboration with various stakeholders (such as local communities, industry partners and government entities). Efforts were made to secure funding and explore innovative financing models to support the implementation and operation of the Acorn CCUS hub. The project also focused on integrating CCUS technologies with existing industrial processes and exploring synergies between carbon capture, utilisation, and storage.

C-Capture: The key knowledge deliverables report from C-Capture focuses on the CO_2 compression and dehydration unit, which is considered a crucial component of CCUS systems. The report provides insights into the development and performance of this unit, highlighting its importance in capturing and preparing CO_2 for storage or utilisation. The report discusses the key design considerations for the unit, including capacity, efficiency, reliability, and safety, to ensure optimal performance and integration with other CCUS components. C-Capture also includes a performance evaluation which includes the results of energy consumption, CO_2 capture efficiency, and emissions reduction potential. Other key areas in the report include operating conditions, process optimisation, technological innovations, scale-up and deployment and lessons learned.

HyNet: A project focusing on decarbonising the North West of England through the use of CCUS technology. The HyNet CCUS initiative involves multiple aspects of CCUS implementation, including carbon capture, storage, and utilisation. The key knowledge deliverable report for the pre-FEED stage provides information about the technical and economic feasibility of the project. It

[35] https://www.gov.uk/government/collections/carbon-capture-and-storage-knowledge-sharing

serves as a foundation for further engineering design and development, helping to advance the deployment of CCUS technology within the HyNet project and contribute to the broader knowledge base of CCUS implementation.

The Northern Endurance Partnership & Net Zero Teesside (NEP/NZT): The NEP/NZT KKD outlines the technology plan for the development of CCUS infrastructure in the northeast of England and Scotland. The overall aim of the project is to facilitate the decarbonisation of industrial clusters and support the transition to a low-carbon economy. The report provides insights into the project's objectives, strategies, and KKDs. The NEP/NZT report explore different technical pathways for CCUS deployment, including options for carbon capture, transport and storage. The report also considers infrastructure planning, industrial clusters, technology readiness, cost and financing, policy and regulatory framework and knowledge sharing and collaboration.

TiGRE Technologies: KKD report focuses on the design and implementation of seals for CCUS applications, highlighting the significance of seals in preventing leakage and maintaining the integrity of CCUS systems. The report provides insights into the basis of design for seals and their importance in ensuring the safe and effective operation of CCUS infrastructure. The report outlines an overview of sealing technologies and their application to CCUS infrastructure, considering factors such as pressure, temperature, chemical compatibility, and long-term performance. The report also considers in more depth seal design, testing and validation and seal installation and maintenance, performance monitoring operational challenges and mitigation strategies and collaboration and knowledge exchange.

Translational Energy Research Centre (TERC, formerly PACT-2): The TERC is a project aimed at facilitating research, development, and innovation in sustainable energy technologies. It aims to foster collaboration between research institutes and accelerate the commercialization and adoption of these technologies by commercial and industrial businesses. The project received funding from the 2018 'Call of CCUS Innovation' fund, which contributed to the creation of a £21m research facility and the investment of £4.7m in four pilot-scale research facilities. These facilities include the Sustainable Aviation Fuels Production Facility, Molten Carbonate Fuel Cell, Shock Tube Chemical Kinetics Test Facility, and High-Pressure High-Temperature Heat Exchanger Test Bed (HEX Facility). The KKD report provides a post-project analysis of each of the four project equipment, focusing on project management aspects. It covers aspects such as the original project intention, procurement activities, legal matters, project budgets, and programmes. The document also includes qualitative analysis of project history and lessons learned.

The key knowledge deliverables provide important inputs in the field of CCUS, representing the outcomes of specific research, development and demonstration projects related to CCUS technologies. The KKDs are important for the following reasons:

- The KKD reports contribute to **technological advancements** through the providing insights into the design, engineering, and technological aspects of CCUS projects, whilst offering valuable information about the development, performance and scalability of various components and processes involved in CCUS.

- They are useful for **informing policy and regulatory decisions**, a number of the KKD reports include assessments of policy and regulatory considerations relevant to CCUS deployment. This is evident through the analysis of the barriers, opportunities, and impacts associated with CCUS projects, helping inform decisions made by policymakers and regulators. The reports provide recommendations for policy development, support mechanisms, and regulatory frameworks to facilitate the implementation of CCUS technologies.

- **Assessing the environmental impact**: CCUS projects typically have environmental implications associated with them, particularly in relation to carbon storage. The KKD reports include assessments of the environmental impacts and risks associated with CCUS technologies. They provide insights into potential mitigation strategies and best practices to ensure the safe and sustainable deployment of these technologies.

- **Contribution to cost analysis and economic viability**: in some areas, the KKD reports include cost and performance analyses of CCUS systems. The report provides information about the economic viability, cost effectiveness and potential benefits of implementing CCUS technologies, this is an important aspect for evaluating the feasibility and commercialisation potential of any CCUS project.

Other dissemination efforts

A few projects deployed some knowledge sharing activities beyond the KKDs. For instance, the PACT-2 facility entered a new partnership to increase the procurement and use of equipment leading, which led to range of academic articles were produced with results of research developed within the facilities.

In terms of the dissemination of results from the Tata Chemicals CCUD project, views were mixed. One interviewee suggested dissemination efforts needed to be improved, while two DESNZ staff highlighted that Tata Chemicals had been offering guided visits to the capture facility, which they commended as a positive approach to dissemination. The interviewees involved in the Tata Chemicals project reported that they were open to doing this but emphasised that they would share an overarching picture of what they were doing, as they were wary of giving away commercial advantage by sharing the specifics of their approach. Similarly, members of the HyNet project team commented that they are in high demand as conference speakers, and often give tours to foreign delegations. However, they gave the view that this was typically a one-way relationship and they felt a mutual benefit for their efforts.

Overall, however, many stakeholders interviewed for the evaluation thought that knowledge and lesson dissemination have been lacking. Several stakeholders criticised the lack of information and lesson learning from the projects. They criticised the lack of technical dissemination (critical for an accelerated pathway to net zero). On technical lesson learning, interviewees suggested that the commercial interests in the CCUS programmes hinder the public disclosure of findings, but some policy stakeholders challenged this viewpoint, with one defending the programmes' approach of including disclosure as a condition to receiving funding.

Finally, one of the policymakers consulted, as well as expert panel members, stressed the importance of CCUS programmes in disseminating understanding on CCUS to the general public. They believed this has thus far been lacking in the programmes. Several ACT projects included a module on public awareness raising, but emerging evidence is that this was not very impactful.

4.4 Private finance leveraging and RD&I investment

4.4.1 Contribution to wider investment in RD&I

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would reach the following outcome:

The ACT/ CCUD/ CCUS-I projects contribute to stimulating wider investment in RD&I (industry, supply chain, academic) in the UK

The key barriers for private actors to fully invest in CCUS include:

- High up-front capital costs for innovative, early stage CCUS technology companies seeking to produce at the scale required to service existing markets.[36]
- The capital required to deploy new CCUS technology may also be prohibitively high relative to developers' size and their expected return on investment.
- Availability of patient capital, the need for further demonstration of the efficacy of CCUS technologies at scale requires patient capital (i.e. private investment that has a longer-term (e.g. 10 – 20 years) expectation of return on investment).

The CCUS programmes aimed to stimulate wider investment in RD&I across industry partners, the CCUS supply chain and in academic research, through de-risking the technologies and reducing the commercial uncertainty that is attached to these initiatives.

The programmes have contributed to stimulating wider investment in RD&I in the UK both public and private, through the development of research infrastructure, creation of further partnerships and securing further funding. Crucially, and as outlined in section 4.2.1, the continuation of some of the projects into UK CCUS Clusters, is a notable achievement.

An analysis of wider CCUS investment data also suggest that there has been a notable increase in the number and value of fundraising by CCUS-oriented companies, indicating a more favourable investment environment than there was at the programmes' outset. While it is not possible to attribute the positive developments within the UK landscape for CCUS technology to the CCUS programmes, the CCUS programmes have likely made a positive contribution to the overall CCUS funding landscape.

The investment data (see Table 4.2) demonstrates that between Wave 1 and Wave 2, there was an overall increase in the number of CCUS-oriented fundraising UK companies, from only eight (out of a pool of 1,308 'CleanTech' companies in the dataset) to 31 (out of 1,562 companies in the dataset), meaning 23 additional fundraising CCUS companies. Further analysis of fundraising activity by these companies shows that 21 of these 31 companies (68%) have secured grant funding (typically from UKRI / Innovate UK), and that several of the investors in these companies have been engaged in the EIP CCUS programmes. Similarly, the number of fundraising rounds secured by CCUS companies has increased more than three-fold; and the value of CCUS fundraisings has increased by more than 13 times, from £22 million in 2021 (average of £1.6m and median of £562k) to £319 million in 2023 (average of £5.6 million, median of £595k).

While only a small number of the EIP CCUS programmes' participants are represented in the fundraising data, evidence of other linkages to the CCUS programmes exist including: the presence of CCUS programmes' participants as named funders of investment-raising companies (e.g., Drax, Equinor, BP, OGCI); reference to CCUS investors within interviews and involvement of other investment-raising companies in CCUS-programme-funded initiatives (such as Carbon Clean Solutions Limited

[36] Indeed, the analysis of fundraising rounds by 'CleanTech' companies, including CCUS-oriented companies, has revealed that, between 2021 and 2023, the average investment in CCUS oriented companies was almost double the average level of investment in wider 'CleanTech' companies.

engagement with PACT2). In fact, of the top 20 CCUS funders by value of fundraisings, at least six have some linkage to the CCUS programmes.[37]

Table 4.2: Summary of Change in Fundraising Metrics: CleanTech vs CCUS

Fundraising Metric	(Wave 1) 2021	(Wave 2) 2023	Change
Number of investment raising CleanTech companies	1,308	1,562	+254 (19%)
Number of investment raising CCUS companies	8	31	+23 (290%)
CCUS investment raising companies as a % of CleanTech investment raising companies	0.6%	2%	+1.4%
Number of fundraisings secured by CleanTech companies	2,600	3,301	+701 (27%)
Number of fundraisings secured by CCUS companies	14	59	+45 (320%)
CCUS fundraisings as a % of CleanTech fundraisings	0.5%	1.8%	+1.3%
Value of fundraisings secured by CleanTech companies	£5.8bn	£9.2bn	+£3.4bn (59%)
Value of fundraisings secured by CCUS companies	£22m	£319m	+£297m 1350%)
Value of CCUS fundraising as a % of CleanTech fundraising values	0.4%	3.5%	+3.1%
Average value of CleanTech fundraisings	£2.2m	£2.9m	+£0.7m (32%)
Average value of CCUS fundraisings	£1.6m	£5.6m	+£4m (640%)
Median value of CleanTech fundraisings	£400k	£440k	+£40k (10%)
Median value of CCUS fundraisings	£562k	£595k	+£33k (6%)

Source: Beauhurst (2023 data as of 30th June).

Several project teams reported positively on the benefits that the financial support generated for them in terms of advancement to employment and commercialisation:

> ***"The size of the grant was attractive to us because it allowed us to take a big step forward and work towards a full-scale solution, and because it was multiyear."***

[37] Considering the sensitiveness of this data, it is not possible to disclose who these funders are.

"Since [the Project] completion [CCUS Programme Partner] announced that its funding pipe has increased [by c.$225m] and that its market capitalisation is up to $2bn from $1.48bn."

"What we've done is have pre-FEED money [via CCUS-I] and then rolled into a big fund called Industrial Decarbonisation Challenge funded through UKRI."

"We applied for the financial support - it was an expensive study; the capital cost was very expensive. Because of the capex at the time we thought the project would have been outside our budget."

4.4.2 Match funding achievements and additionality

This sub-section provides a response to sub-EQ 1.1: What is the total amount of private finance leveraged through the projects? How much of this would have been invested anyway, without the programme?

Projects can leverage private funding through match funding (direct route) and through follow-on funding (indirect route), as well as wider investment raised or made by UK-based companies participating in the CCUS programmes. This section focuses on matched funding, while the next one explores the progress made in terms of follow-on funding. The findings build on the CCUS portfolio analysis and in-depth stakeholder interviews.

On average, private funding represented just over 40% of the total project value across all projects and programmes, while DESNZ funding represented just under half of it (49%). The remainder came from other public funding sources (10%). With this, on average, for every £1 of DESNZ, 85p of private funding was raised, across all programmes and projects. Considering all funding raised by projects, both private and from other non-private sources, **£1.16 were raised for every £1 of DESNZ funding invested in projects**. Although it is not possible to attribute the funds raised directly to the DESNZ funding, **findings from interviews with unsuccessful applicants suggest that funded projects might not have gone ahead without the DESNZ funding**.

While interviews with a few non-applicant stakeholders suggested that match funding requirements might restrict or hinder participation from small organisations or international partners, the fact that the programmes generally managed to attract a diverse range of applications,[38] challenges this perspective. Across successful and unsuccessful applicants who were able to raise match funding to apply to the three programmes, only three reported that the requirement was a challenge to meet, and only one of them reported that it had had any impact on the scope of their project.

In the Wave 2 interviews, in addition to the investment set out above, several projects highlighted in-kind support offered by their commercial partners, in the form of staff time and access to valuable data. The commercial partners were driven to contribute due to their increased prioritisation of CCUS as an area of

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[38] With the exception of the CCUD programme.

interest and out of interest in the projects' findings. In at least one case, the project directors had self-funded the project and were now looking to sell on their IP to recoup the investment.

4.4.3 Follow on funding and CCUS project pipelines

This sub-section provides a response to the following sub-EQs:

3.1: Have the programmes leveraged follow-on funding for the projects concerned?

3.4: Have the programmes resulted in a pipeline of other projects (i.e. outside of the programmes) engaging in activities to deploy CCUS technology at scale in the UK?

According to self-reported KPIs, 14 out of the 26 funded projects had received follow-on funding valued at £216 million in total. Ten of the 14 reported at least some public funding (amounting to £117 million), including from the European Commission, and seven had secured a total of £99 million private follow-on investment. Beyond these, interviews have revealed that PACT2 has now, in addition to £15 million included in the figures above, created an estimated £38 million of inward investment and companies are coming on board as funding members as the centre is now ready. They have already secured £1.5 million of projects to deliver within the next 18 months, and are confident of reaching their £4 million-per-year membership income.

In total, six of the organisations interviewed for this evaluation were continuing to receive public funding through different funds including ACT3, IDC, IDRIC. Several were part of Cluster Sequencing process: HyNet and Tata Chemicals are now part of the HyNet Cluster, ACORN has evolved into the Scottish or ACORN cluster and OGCI and C-Capture are now part of the East Coast Cluster.

Four projects had achieved their original objectives but mentioned that, in part due to the skills and knowledge built as a result of the programme, they continued to receive CCUS funding for related projects, including some government funding (e.g. IDRIC). A few mentioned that they had returned to projects that were at lower TRLs which are considered more appropriate for academic and research institutions. A couple also commented that while the original funding had ended, they would continue to use the data obtained through their project to publish further academic papers and articles.

Almost all the teams that had received some follow-on funding credited the CCUS programmes for its contribution. Typically, they considered that having a complete project put them in a good place to leverage further funding, on the same or adjacent topics.

Participants that did not secure follow-on funding expressed the opinion that the lack of clear routes to commercialisation, due to the high level of investment required and the high risk involved in scale up are currently limiting their potential for growth. Finally, some projects never intended to continue past the end of the funding: they set out to find the answer to a question, for instance around risks of CO_2 storage –, have answered it, and are now moving on to new projects.

4.4.4 Investment leveraged by participating companies

This sub-section provides a response to sub-EQ 3.3: Have the programmes contributed to stimulating wider investment in RD&I (industry, supply chain, academic) in the UK?

Investment leveraged by participating businesses

Investment leverage data suggests that since the beginning of the CCUS programmes in 2018 there has been a notable increase in external investment raising activity among both successful and unsuccessful CCUS applicants. Increases in the value of fundraising secured by both successful and unsuccessful applicants between 2020 and 2022 were not significantly different (both showing a c.600% increase). However, successful applicants have completed marginally more funding rounds than unsuccessful applicants since the interim evaluation and have seen a notably larger increase in the median value of investments.

Prior to the start of the EIP CCUS programmes, four UK companies involved in the applications had secured external investment. Two of those companies were involved in successful EIP CCUS programme applications and two were involved in unsuccessful applications. One of the successful CCUS programme applicants had successfully completed one external fundraising process, securing £235k in 2011. Companies involved in unsuccessful EIP CCUS programme applications had successfully completed eight fundraisings to the value of £6.8m prior to 2018, with a median investment value of c.£470k.

At Wave 1,[39] when some of the projects were still ongoing, companies involved in successful CCUS applications had successfully completed ten fundraisings to the value of £27m, with a median investment amount of c.£701k. Companies involved in unsuccessful applications had completed seven fundraisings since 2018 to the value of c.£21.8m, with a median value of c.£1m.

At the final evaluation stage,[40] when funded projects had already closed, companies involved in successful CCUS applications had successfully completed 17 fundraisings to the value of £189.6m since 2018, with a median investment amount of £3.4m. Companies involved in unsuccessful applications had completed 10 fundraisings to the value of £155m, with a median investment amount of c.£1.1m. The change in fundraising metrics for successful and unsuccessful applicants is summarised in Table 4.3 below.

Table 4.3: Change in Fundraising Metrics (2020 - 2022)

	Fundraising Metric	2020	2022	Change (%)
Successful	Companies Securing Fundraising	5	5	-
	Number of Fundraisings	10	17	+7 (70)
	Value of Fundraisings (£m)	27	189.6	+162.6 (600)
	Median Fundraising (£m)	0.7	3.4	+2.7 (386)
Unsuccessful	Companies Securing Fundraising	3	3	-
	Number of Fundraisings	7	10	+3 (43)

[39] Reporting in June 2021 based on company data up to 31st December 2020.
[40] Reporting in August 2023 based on company data up to 31st December 2022.

	Fundraising Metric	2020	2022	Change (%)
	Value of Fundraisings (£m)	21.8	155.4	+133.6 (613)
	Median Fundraising (£m)	1	1.1	+0.1 (10)

Source: Perspective Economics, Beauhurst

Investment made by participating businesses

Over the entire evaluation period (data relating to between 2018 – 2022), successful CCUS applicants invested a total of c.£88.5m in internal R&D – almost 2.5 times the investment made by unsuccessful CCUS applicants over the same period (c.£26.9m).

Prior to the CCUS programmes, between 2015 and 2017, thirteen of the companies involved in either successful or unsuccessful applications invested c.£73m in internal R&D. Six of these companies were involved in successful CCUS applications and had invested c.£29m in internal R&D between 2015 and 2017, and seven companies involved in unsuccessful applications had invested just over £44m in internal R&D over the same period.[41]

At the interim evaluation stage (data relating to between 2018 and 2020, when funded projects were ongoing), six companies involved in CCUS applications (both successful and unsuccessful) had invested c.£64.1m in internal R&D. Three of these companies were involved in successful applications and had invested c.£37m in internal R&D; three companies were involved in unsuccessful applications and have invested c.£27m in internal R&D over the same period.[42]

At the final stage of the evaluation (data relating to between 2018 and 2022), no additional companies (i.e., no companies over and above those that invested in R&D in previous reporting periods) had invested in R&D. Two of the three successful CCUS applicant companies (i.e., those that had also invested in previous reporting periods) invested an additional £51.2m in R&D; one unsuccessful CCUS applicant company invested a further £186k between 2021 and 2023.

4.5 The direction of travel

4.5.1 Policy and Decarbonisation Targets

This sub-section provides a response to the following sub-EQs:

3.2. Have the programmes influenced UK policy thinking / development?

4.1.What contribution can rollout of CCUS be expected to make towards UK decarbonisation targets (net zero by 2050)?

[41] This analysis excludes one outlier successful applicant who invested more than £283m in internal R&D in 2015.

[42] Source: Beauhurst, 2021. Company registration numbers for companies involved in successful and unsuccessful applications were to search for company data using Bureau van Dijk. Company data includes information on investment in R&D, as recorded within the profit and loss fields of company data.

It also provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS Programmes would achieve the following three outcomes:

ACT/ CCUD/ CCUS-I projects convinced industry to deploy CCUS technologies

The ACT/ CCUD/ CCUS-I projects influenced policy thinking on CCUS

The ACT/ CCUD/ CCUS-I programmes strengthened / increased the UK's position as a global leader in CCUS

All EIP CCUS projects aimed to influence the CCUS sector. Most did not mention specific activities, but expressed the impression that by contributing to the body of evidence relating to CCUS they would be influencing confidence in CCUS and consequently supporting the direction of travel of UK policymakers. As outlined above, many are seeking to share the knowledge gained through their work at conferences as well as publishing papers and believe this will help contribute to policy development.

Some described taking a more proactive approach, for example by contributing to thought leadership papers such as a recent policy briefing developed by the Royal Society. A couple suggested that investors and industry were their primary audience but one thought keeping policymakers on board would also be vital to their success. A couple noted that it was particularly important to work with regulators to ensure that the regulations were keeping pace with the technology.

Only one project mentioned to have effectively worked closely with policymakers. They considered this was important, not least as they considered regulatory hurdles as a key issue for delivery timelines. They noted that policy engagement had been made more difficult by the UK political instability seen during 2022.

Interviews with the DESNZ delivery team also indicated close collaboration between them and the DESNZ CCUS policy team, in particular, in the development of the Cluster Sequencing process. **However, overall the evidence base from this evaluation of the contribution of CCUS towards UK decarbonisation is weak.**

4.5.2 Supporting CCUS development pathways

This sub-section provides a response to the following sub-EQs:

2.1.Have the programmes altered industries' and investors' perceptions of CCUS as a viable pathway to achieving future decarbonisation at scale?

3.4.Have the programmes resulted in a pipeline of other projects (i.e. outside of the programmes) engaging in activities to deploy CCUS technology at scale in the UK?

While the EIP CCUS programmes did not have a scale, and a scope, that would have enabled them to significantly drive a shift in the CCUS landscape, they created the conditions that allowed projects to seize CCUS opportunities as soon as a new paradigm became available.

Several of the project leads and partners were confident that their projects had demonstrated findings which would contribute to the evidence base for delivering CCUS at scale, with the monitoring projects expressing confidence that their work contributed to the evidence that storage could be done safely. Apart from the cluster-enabling projects previously mentioned, most of the technology projects reported that they still had more to do before their solution was proven at an industrial scale, and some commented that until they had a full-scale pilot it was difficult to leverage investment and support as the technology was still very high risk (the 'valley of death' as noted in 4.2.1 above). However, nearly all the project leads interviewed said that they intended to continue to be involved in CCUS projects in the future and many were hopeful their projects would be transformative.

Two project leads commented that they perceived that attitude towards CCUS in industry was changing, but none of them attributed this shift to their projects directly; even if they thought their own projects were contributing to the evidence base for delivering CCUS at scale (see above). Firstly, the move from an 80% reduction target to a net zero target made it clear all industries should be seeking to decarbonise and none would be able to 'hide' behind the 20% emissions that would still be allowed. Secondly, they described companies and banks seeking to decarbonise their supply chains, thus incentivising businesses to explore CCUS solutions or risk being left behind. Finally, policy stakeholders suggested the Cluster Implementation Fund (CIF), worth £1 billion in funding, was available to support final investment decisions towards CCUS cluster projects, as an additional key factor to generate confidence in the sector.

As above, overall the evidence base from this evaluation of the contribution of CCUS towards UK decarbonisation is weak.

4.5.3 Contribution industry's perspectives on CCUS deployment

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would achieve the following outcome:

ACT/ CCUD/ CCUS-I projects convince industry to deploy CCUS technologies

The EIP CCUS programmes aimed to contribute towards deployment of CCUS technologies across industries mainly by addressing barriers to CCUS deployment, including commercial uncertainty, high costs and other (perceived) risks. Indeed, as evidenced by the levels of private investment as outlined in section 4.5.3,the EIP CCUS programmes have likely contributed to changing industries' perceptions around CCUS technologies' deployment. As previously highlighted, there is a conjunction of factors at play that help explain such shift, and decoupling the effects of the EIP CCUS programmes from external factors may be challenging.

There are, however, key mechanisms identified by this evaluation which have **likely contributed to the observed changes in industry perceptions**:

- **Market-signalling:** Evidence from both successful and unsuccessful applicants points to the Government's backing of CCUS as pivotal to industry participation / trust in the UK future of CCUS and therefore points to the CCUS programmes; as vehicles for / representations of such Government support, as influential on industry.

'[I cannot say] that the [Government] money was really critical, and [that] this project would not have gone ahead without that money… But what that money signifies is infinitely more important… [it shows] support from the government for this type of project […] The money's good – it helps – but it's really that signal of seriousness, interest, support particularly in an area where the industry has been burned [before].'
- Project lead

- Direct involvement of industries in the projects. Most directly, many projects influenced (or aimed to influence) industry by involving industry as partners in the project, or by engaging them through project advisory boards, hence enabling industrial partners to pilot / test aspects of CCUS deployment for themselves. Whilst such a mechanism has, at least in the short term, worked to draw industry in (and incentivise them to participate in CCUS development), it is not clear *how sustainable* that involvement will be.

"Without ACT1 it would have been very difficult to wake up certain industries."
- Project lead

- **Supply-chain development:** The three cluster-enabling projects (ACORN, OGCI/Clean Gas and HyNet), as well as the C-CAPTURE project had specific objectives to build partnerships to build the supply chain and strengthen demand for and buy-in to the decarbonised cluster or capture technology.[43] The ACORN project had a specific KPI around building partnerships to create a 'seed market' for CCUS and to 'convince' relevant industry to (help) deploy CCUS. According to the baseline ACORN case study, the project partners have '*built over 20 stakeholder relationships so far with industry partners, supply chain actors and wider stakeholders*' and is showing strong progress in building the supply chain (as evidenced by the cluster's selection for the CCUS Cluster Sequencing process). Evidence from the OGCI/Clean Gas and ACORN case studies (namely the projects having demonstrated sufficient industry engagement to be successful in being shortlisted as part of the CCUS Cluster Sequencing process) suggests that the partnerships formed to implement these projects might have played a role in changing industry perceptions. By bringing together well-respected organisations from across the stakeholder spectrum (industry, utilities, academia, policy, etc.) they increased the credibility of the project, and the CCUS endeavour. Similarly, C-CAPTURE has claimed to be close to achieving investment from O&G industries in the next funding round thanks to the progress they have achieved in perfecting and testing their capture technology.

- **Overcoming information barriers:** The KKDs seem to also have contributed at least indirectly to affecting some industries' perspectives of CCUS. As outlined in section 4.4.5, while the KKDs page has been accessed hundreds of times each month, this evaluation was not able to uncover evidence of industries' use of these deliverables outside of the funded projects. On the other hand, for some stakeholders, KKDs have been useful to facilitate conversations with relevant parties, with their comprehensive outline of technical and economic feasibility of CCUS technologies offering a source upon which to base such exchanges. For instance, DETECT reported being approached by "*quite a few*" industrial actors interested in exploring CO_2 storage leakage risk, a knowledge that they developed as part of the ACT 1 funded project.

  Tata CCUD project deployed CO_2 production through capture from their combined heat-and-power boiler, which can be integrated into manufacturing units. The assumption is that, through successful demonstration, the programme will convince other industrial carbon users to employ similar capture technologies at commercial scale. Indeed, as described previously, the plant is

[43] A primary aim of the OGCI/Clean Gas project is to bring in multiple emitters to feed in and to 'create a mature supply chain' and users of the technology.

now object of site visits by interested parties (not limited to industries) which can be expected to help demonstrate this arrangement as a viable business model.

Some interviewed carbon users/capturers who did not receive funding nor were part of any projects tended to agree that the knowledge generated through the projects contributed to their wider understanding and demonstration of CCUS technologies (e.g. which technology to apply for capture and whether this can be made commercially feasible, etc). According to one user/capturer, the programme has been "*absolutely pivotal*" and they "*don't know what they would have done if CCS programmes had not been funded*".

4.5.4 Contribution to policy thinking on CCUS

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would reach its long-term goals:

The ACT/ CCUD/ CCUS-I projects influence policy thinking on CCUS

The three CCUS programmes were expected to contribute to policymaking, by increasing Government's access to data, evidence, lessons, and networks that inform Government thinking and policymaking on CCUS. Such inputs would be expected to inform policy from the point of view of effectiveness and value of stimuli to support the CCUS sector, but it was also expected to inform government's planning and increase confidence in the CCUS as a viable technology to support net zero ambitions.

In the years following the launch, UK CCUS policy has made great strides, which was acknowledged, in particular, by international actors interviewed. In the run up to the UK hosting COP26, the Government launched its 10 Point Plan, followed by its Net Zero Strategy, which established (and reinforced) the target of delivering four CCUS clusters by 2030 and pledged £1 billion to be invested in deploying these transport and storage infrastructure and some industrial capture projects,[44] as part of a CCUS Implementation Fund (CIF). The Cluster Sequencing process, of which the three cluster-enabling projects are part, was established as a mechanism to allocate this fund.

While it is clear that the EIP CCUS programmes did not have the scope nor aim to influence policy to the extent that policy change has been observed in the past few years, **the programmes did make a contribution to a better-informed policy environment for CCUS and a more close-knit collaboration between industry and government**. In particular:

- At a 'working level', key members of the CCUS programmes delivery teams – a couple of whom have been in post since the 2012 CCUS Competition - interacted regularly with the policy teams to feed into their plans and provide updates on project progress and results. This interaction was to a large extent due to the dedication and initiative, as well as the duration in position, of these team members, rather than by design. They retained (and shared) institutional knowledge, were able to effectively network.

[44] https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund/the-carbon-capture-and-storage-infrastructure-fund-an-update-on-its-design-accessible-webpage

- Similarly, the dense and relatively close-knit nature of the CCUS community meant that several stakeholders now involved in developing current CCUS policy in other parts of Government were involved in the design of the DESNZ CCUS programmes, and had a key role in creating information channels between those involved in developing ongoing CCUS policy.

- Finally, the established networks and links between project teams and DESNZ played a role in spreading information from the programmes through policymaking sections of Government. Several of the applicants to the CCUS programmes learned about the programmes because of their own industry networks / groups with which Government regularly met. Through these links, policymakers were able to learn about the projects being funded through the CCUS programmes. And most importantly, through these links, projects have been able to feed key insights that support government policies, programmes and enhance confidence in CCUS. In a few instances, project leads whose projects continue to be funded by government programmes claim that this collaboration has been sustained.

"I have worked in industry 25 years and over past few years the relationship between industry and government in terms of building [a CCUS] policy framework has been the strongest and best I've ever seen: [rather than] adversarial, it's joint working. We don't apologise for asking them to go faster, they don't apologise for pushing us to give them more information, competition, etc. It has moved forward well."

- *CCUS-I Project Lead*

"Last year we contributed to a policy report by the Royal Society[45] on CCS as a whole - how to get CO_2 underground and the leakage risks. The project was integral to the report so [it is] definitely influencing policy that way (…) If we hadn't done the project we would have been able to say something [e.g. leakage] is unlikely to happen but your argument is stronger with more evidence and the ACT project helped strengthen the argument – [it] increased the certainty."

- *ACT 1 Project lead*

"I think policymakers who are looking at designing industrial CCUS schemes, for them to understand the main risks that people still feel are relevant and they could be exposed to, and how you manage those, [they can find] lots of clues in our work about communication […]"

- *ACT 1 Project lead*

On the other hand, **the extent to which the programmes influenced UK policymakers from outside DESNZ (including managers of other innovation initiatives and relevant sector associations) seems to have been limited**. Those stakeholders had relatively low awareness of the specifics of the different funding programmes and their outputs. Although there was some (patchy) knowledge of specific projects, policymakers were not necessarily seeing the projects as part of a programme of work. Policymakers had potentially had slightly higher awareness of ACT than the CCUD and CCUS-I programme across this group.

Despite their lack of awareness of the specific programmes, policy stakeholders were typically quite optimistic about the UK's comparative advantages in the CCUS space. Natural advantages including used oil wells and a shallow sea, combined with investment and research in the sector have helped the

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[45] https://royalsociety.org/-/media/policy/projects/geological-carbon-storage/Geological-Carbon-Storage_briefing.pdf

UK get to a strong position. However, some describe this as precarious, with factors such as the slow speed at which legislation is changed or permits are granted putting the UK's position at risk as the USA, Norway and others are already delivering CCUS at scale.

4.5.5 Contribution to increased public acceptability of CCUS

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would reach its long-term goals:

The ACT/ CCUD/ CCUS-I projects contribute to increased public acceptability of CCUS;

While increasing public acceptability of CCUS was not an explicit goal of the EIP CCUS programmes, the CCUS 'systems level' theory of change set out at the inception of this evaluation acknowledges that the general public plays a major role in any future scaled-up deployment of CCUS in the UK. Therefore, it is critical to investigate the EIP CCUS programmes contribution to public perceptions.

Some of the projects supported (e.g. ACORN, OGCI/Clean Gas, ELEGANCY and ALIGN) did aim to engage local communities on CCUS; specifically, local policymakers or the general public. **Most of these projects seem to have made some progress towards their objective, as outlined below, particularly with regard to raising public awareness in their region**. For example:

- Pale Blue Dot, as part of the ACORN project, held a virtual town hall to increase public knowledge and engagement around the project. They also have public-facing materials, e.g. media articles, for public audiences. Additionally, the company employed a communications officer who had been working on engaging different sectors of the general public in CCS for over a decade, further contributing to building CCUS awareness across the general public.
- Similarly, one interviewee noted that OGCI/Clean Gas '*had a very active engagement programme with local authorities and stakeholders in Teesside, both of whom were very interested in the project*'.
- The ALIGN project developed surveys to test messaging and approaches to engaging communities with CCUS. This has generated some relevant evidence and insight for use by Government and developers on public perception of and acceptance of CCUS projects (and thereby also contributing to influencing policy thinking on CCUS; see section 4.5.4).

However, not all the projects delivered their anticipated public engagement activities. While ELEGANCY set out specifically to 'broaden public awareness of CCUS' through dissemination activities, the project subsequently placed very little emphasis on this strand and this was not actively pursued as a key outcome. The outputs developed were very academic and no dissemination activities (including publications) seem to have been targeted towards stakeholders beyond the scientific community. Project dissemination to wider networks was also insufficient to reach the general public. As noted above, most of the other projects did not try to engage the public.

4.5.6 Contribution towards strengthening the UK's position as a global leader in CCUS

This sub-section provides our assessment of the extent to which the evidence supports the key hypothesis on how the EIP CCUS programmes would reach its long-term goals:

The ACT/ CCUD/ CCUS-I programmes strengthen / increase the UK's position as a global leader in CCUS

This hypothesis relates to the following sub-EQs:

1.6 Have the programmes increased the international visibility and reputation of the UK in relation to CCUS capabilities?

4.3 To what extent have the programmes contributed to establishing the UK as an international hub for CCUS sector development and innovation?

The CCUS programmes also aimed to consolidate the UK's position as a global leader in CCUS through supporting and strengthening international partnerships, developing CCUS technologies in the UK and knowledge sharing across international boundaries, attracting talent and becoming a role model in CCUS pathways.

On the one hand, the UK has been seen as a leader on CCUS due to the large policy support and commitment assigned to CCUS in the wake of COP26,[46] and the level of international interest projects have had. Some thought that the UK had been an early mover in the field and this funding had helped maintain that position, particularly in the face of the cancellations of previous CCS competitions.

On the other hand, interviewees flagged that moving forward with deployment will be critical for the UK to assume a leading technological position. As such, interviewees expressed the opinion that the EIP CCUS programmes would only have an impact once the technologies being developed were proven at commercial scale. In that sense, and **to the extent that the programmes have been contributing to progressing CCUS towards deployment (see section 4.2.1), they can be said to be contributing to the UK advancing towards a strengthened UK position in the international CCUS space**. The establishment of PACT-2 (now part of the Translational Energy Research Centre – TERC) was also intended to help raise the UK profile across the international CCUS research landscape. The laboratory is currently a member of the European Centre of Excellence for Carbon Capture and chairs the International Test Centre Network, suggesting that it is at least at par with other similar facilities in other countries. Interviews have also indicated it is regularly visited by international researchers interested in the facility. However, these visits do not yet seem to be converting into international collaborations: of the 15 projects which were live at the time of writing, only one explicitly mentioned a collaboration with an international research organisation.[47]

Finally, interviewees also expressed some concern that, despite recent market signals by the UK Government to the UK CCUS supply chain (CIF and the £20 billion pledged in the Spring Budget 2023 to CCUS deployment), recent developments in the international landscape would potentially harm the UK's position going forward. The US Inflation Reduction Act, which establishes tax credits for captured CO_2, and the UK not being committed to being part of current EU funding schemes, were seen to risk making

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[46] See section 4.6.4 for a summary on the recent progress in CCUS policy.
[47] https://terc.ac.uk/current-projects/. See project NEWEST, a collaboration with the Research Council of Norway..

the UK a less attractive environment for CCUS businesses or projects compared with US and Europe. For instance, a few of the projects with ACT funding had already noticed a change in their relationship with partners because it was not clear if the UK would be part of the Clean Energy Transition Partnership (CETP), a multilateral partnership for innovation. As a result, they were concerned that they were losing ground as they were not offered work package leadership roles, which are vital for shaping the research agenda.

"Since Brexit, people say 'we can't have you', and I agree because it's a project risk. How can they be ensured of the funding? That's the concern and we know what we are missing out on [opportunities]."
- Project lead

4.5.7 Unintended outcomes and lessons learnt

This sub-section provides a response to sub-EQ 4.3: Have there been any unintended outcomes of the programme (positive or negative)?

Through the case study work undertaken for this evaluation, no major unintended consequences have emerged. Some project developers were surprised by how far CCUS has progressed as a sector and how the support for it has increased in industry. Others commented on the strengths of the partnerships developed as a result of the project. Perhaps the biggest unanticipated impacts occurred where teams explored the transferability of their projects to other high carbon sectors. While typically the projects started in one or two sectors, some are now extending their reach by building new partnerships (see also sections 4.3.4 and 4.4). However, the downside of this is that they perceived themselves to be spread thinly and pulled in different directions, without necessarily knowing which to prioritise.

The projects also learned some lessons about developing and scaling their projects, which are likely to be relevant to other projects in the sector:

- When scaling up, it can be difficult to identify appropriate suppliers. The waiting lists for existing technology can be long, and it can be difficult to find suppliers for new products such as solvents at the scale required outside a laboratory setting. Some policymakers thought this could become an increasing problem, along with inflationary cost pressures which are particularly impactful as in the case of imported inputs. Similarly, disposal of solvents and emission of other components (e.g. ammonia or NO_X) is likely to become an issue as projects start to scale up.

- The capital expenditure or investment needed to scale up from a feasibility study to a pilot can be overwhelming. Without the first pilot at scale, it can be hard to convince investors to back a particular solution, especially when other more proven solutions exist. Some found the lack of clarity on business models (as concerns carbon pricing) reinforced that difficulty. That is, beyond investment for capital expenditure challenges, there are still uncertainties whether revenue streams will be sufficient to even cover the operating expenditure.

- There is learning from adjacent sectors (e.g. gas) which can be transferred to the sector. Having team members from a diverse range of professional backgrounds, enabled the projects to build on the existing knowledge from other sectors, and helped them to exceed their original plans. For example, the capstones used in the gas sector are significantly less substantial than those being considered for CCUS.

Some aspects of the programme potentially made delivery more challenging:

- A couple of the teams involved in larger consortiums found it unwieldy and difficult to keep track of who was doing what, and who needed to be updated. In contrast, smaller teams who knew each other well commented that working in smaller teams worked well, as long as they had the range of expertise required.
- Teams who needed licences, permits or changes to legislation found that different regulatory bodies were not necessarily joined up, which generated challenges to deploying CCUS at scale. They found that some regulators worked to different timelines or had different priorities leading to their project stalling at the deployment stage. They also commented that the UK is not necessarily aligned with the EU on regulation which could mean a technology developed in the UK might not be transferrable.
- A couple of funded projects that had been unsuccessful in securing follow-on funding were left feeling frustrated. They suggested that it was important to have a long-term strategy and a plan for how to reach the decarbonisation targets and considered that instead DESNZ was currently working reactively or was favouring the solutions preferred by big business to the exclusion of their more disruptive technologies. As such, it meant that these projects, which achieved their stated aims, then fell by the wayside as the direction of travel shifted.

Looking ahead, interviewees agreed that the key thing needed for ongoing success was a strong commitment to CCUS and a clear financial cost for industry producing CO_2 emissions, which would make it attractive for them to invest in capture to avoid that cost. Without this, they considered that businesses would continue to put off investment. With utilisation being currently the main source of revenue for CO_2 capture, interviewees across several of the stakeholder groups argued that carbon pricing was particularly necessary because the size of the market for utilisation was too small to support the at-scale capture required to meet UK's net zero targets. One stakeholder suggested that with the right incentives in place, the funding programmes would be less relevant as industry would be clearly motivated to invest in finding solutions.

Some of those involved in transport and storage thought there were further questions to be answered about who would get the credit for carbon sequestered, and who would be liable for leaks. They stressed the importance of considering this not just in the near term, but also for the future when the cap rocks are in place and the companies involved in storage have moved on. Others, particularly policymakers, were concerned about whether sufficient thought was being given to solutions for businesses which could not relocate to a physical cluster site.

Finally, the fact that innovations along the chain are being developed separately to de-risk the individual projects means that additional issues might only become apparent much further down the line, for example around impurities in the CO_2 being captured. For those with an interest in hydrogen, there were questions about whether the energy needs of the sector had been taken into account and could be met alongside other additional demands on the energy grid arising from the move to net zero.

5 Conclusions

5.1 Process evaluation conclusions

The process evaluation found that the EIP CCUS programmes were relevant in their design. Their scope and objectives cohered with policy objectives at the time, as set out in, for example, the Clean Growth Strategy, and continue to be largely relevant to more recent policies around net zero, industrial decarbonisation and green growth. The programmes were built, by design, upon lessons learnt from the cancellation of the two previous CCUS programmes (launched in 2007 and 2012) and they attempted to address outstanding challenges to CCUS deployment identified through these programmes. The programmes were designed coherently and they complement each other. The evaluation has identified some gaps in the portfolio and stakeholders and experts consulted have identified others, but, overall, the portfolio does not demonstrate significant bias to any particular type of project / objective and the gaps that exist have not prevented the programmes from working towards stated objectives.

The processes that the programmes employed were largely effective, with some areas for improvement / lessons learned identified. One of the success factors behind the programmes' effectiveness appears to have been the dedication of the team, several of whom have been working in the department for a number of years and are well networked within the CCUS community, as well as DESNZ's existing links to industry groups and associations that facilitated programme publicity. Overall, successful as well as several unsuccessful applicants to ACT report satisfaction with programme processes. They commend in particular the responsiveness of delivery teams, the application guidance and (for ACT) the two staged approach to applying to the programme. By contrast, areas for improvement highlighted by applicants and other stakeholders include: the depth and relevance/utility of feedback provided to unsuccessful applicants to the CCUS-I and CCUD programmes; the involvement of DESNZ staff (rather than independent assessors) in the project application assessment and selection process; and the post-application feedback processes.

5.2 Outcome evaluation conclusions

One of the key aims of the EIP CCUS programmes was to support CCUS technological progress. Evidence indicates that most projects across the three programmes advanced technology readiness levels, and in some cases have contributed to progressing the technology towards deployment. Crucially, the programmes contributed to the initial coordination, research and planning for three of the four CCUS clusters which were shortlisted to under the Cluster Sequencing process, which creates mechanisms to fund the deployment of these clusters by 2030 at the latest. Similarly, the CCUD programme enabled the deployment of UK's first-of-a-kind capture plant, part of Tata Chemicals, which now utilises the captured carbon in their production processes. Beyond these notable success cases, research and coordination undertaken as part of supported projects also contributed to lowering deployment barriers by enhancing coordination, generating evidence on technology performance and unveiling the intricacies of practical application of CCUS initiatives.

A crucial element in enabling progress towards deployment was the programmes' contribution to catalysing collaboration across sectors, which in turn could catalyse new research and innovations. In total, 15 out of the 26 projects reporting established new formal and informal collaborations and partnerships over the course of the programmes, totalling 195 formal relations and 246 informal relations formed. In some cases, the partnerships have been sustained in follow on projects. Contribution to skills development and jobs creation is mixed. The skills were indeed developed and retained, but they mainly related to soft skills, whereas technical skills development occurred less often. In those cases the interdisciplinary nature of the teams and on-the-job learning was the main mechanism of skills transfer. In terms of job creation, most projects allocated funds not to create new jobs, but to reallocate existing posts. However, following project closure, five out of the 26 projects said that their teams had continued to grow after the funding programme ended, from an initial 30+ people to approximately 215 people employed within these five projects, with an additional 500 having access to the programme. Findings from programme documentation and project stakeholder interviews also reveal the programmes successfully captured the knowledge and information generated from within the projects, either through the final reports (ACT programmes) or through the KKDs (CCUS-I and CCUD), and this knowledge was disseminated to some extent.

Industry's confidence in CCUS as a viable pathway to decarbonisation has changed over the last five years covered in this evaluation and the programmes are likely to have made some contribution to that, but it is not clear to what extent this would have happened anyway without the programmes / whether other factors / policy measures have a greater influence. Overall, the fundraising by CCUS-oriented businesses has expanded by most metrics (number of successful rounds, number of companies raising funds and volume of funds). Several of the EIP CCUS programme beneficiaries have secured follow on funding, including from the private sector in a couple of cases. This is on top of the private funding provided as matched funding during the projects' delivery. The evidence linking the observed change in industry and finance sector perceptions and the EIP Programmes relate to a range of mechanisms, including matched funding requirement, along with the direct involvement of industry, and the overcoming of information barriers as set out in the previous paragraph.

There are other areas where the EIP CCUS programmes had intended to have an impact, but for which evidence is weaker.

- The programmes had intended to contribute to policy making. While the CCUS policy environment has developed significantly in the years covered by this evaluation, hard evidence of the programmes contribution to this shift is lacking. The evaluation did identify, however, positive mechanisms that could favour future contributions, including close collaboration across the DESNZ teams involved in policy on the one hand and on the programmes delivery on the other.

- The programmes had also intended to contribute to enhancing UK's position as an international leader in the CCUS space. This evaluation has found that this outcome is a function of two key factors, namely the UK policy commitments towards CCUS (where UK fairs well, according to interviewees), and its progress towards CCUS technology deployment. To the extent that the programmes have been contributing to progressing CCUS towards deployment, they can be said to be contributing to the UK advancing towards a strengthened UK position in the international CCUS space. But full deployment will be needed for the UK to consolidate its position.

- The evaluation has also investigated the programmes contribution to social acceptability of CCUS. While improving acceptability was not among its explicit objectives, this was investigated since it is a necessary condition for progressing projects towards deployment.

- Indeed, some of the projects supported did aim to engage local communities on CCUS and most of these made some progress, but most projects did not aim to engage the public so there is more left to do.

In conclusion, the evaluation has found that the CCUS programmes have made a meaningful contribution to the development of CCUS technologies and the CCUS sector in the UK. They have helped build momentum after the false starts of the early CCS funding and many of the projects are finding ways to sustain that momentum.

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