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Bridging the Gaps
Enhancing CCUS and engineered GGRs through collaborative discussion

Workshop Output

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Disclaimer – Please Read

This document is a record of the discussions held in the 'Bridging the Gaps – Enhancing CCUS and engineered GGRs through collaborative discussion' workshop on 16 January 2025.

This records the views of the stakeholders participating in this workshop; this document does not represent policy position, research plans or innovation plans for the Department of Energy Security and Net Zero.

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Overview

On 16th January 2025 (2.5-hour workshop), the Department for Energy Security and Net Zero, CO2RE, and IDRIC held a workshop on Carbon Capture Utilisation and Storage (CCUS) and engineered Greenhouse Gas Removal (eGGR) technologies

- 37 attendees from across public sector, industry and academics.
- Two 1hr sessions – first covering core themes and a second focussing on cross-cutting themes

Its purpose

- **Support DESNZ** in identifying the existing technical evidence and pinpoint the gaps for the deployment of CCUS and eGGRs.
- **Engage with interested** and **active organisations** in sharing the current barriers and challenges to the deployment of CCUS and eGGRs
- Understand what **technical evidence** needs to be gathered to resolve barriers and challenges for CCUS/eGGRs and how
- **Knowledge exchange** with subject matter specialists.

Facilitated breakout sessions

This workshop explored four core themes and a further five cross-cutting themes, through a series of facilitated sessions in breakout rooms.

In each breakout group, there were four key questions:

1. Defining the problem – what is the evidence gap or challenge that is facing your specific theme?
2. Describing the evidence need – what would be required to fill this gap or address this challenge?
3. Weight the impact and consider interactions – how important is this gap, what else does it affect?
4. What else exists – outline any research that might already exist, or that could be built on

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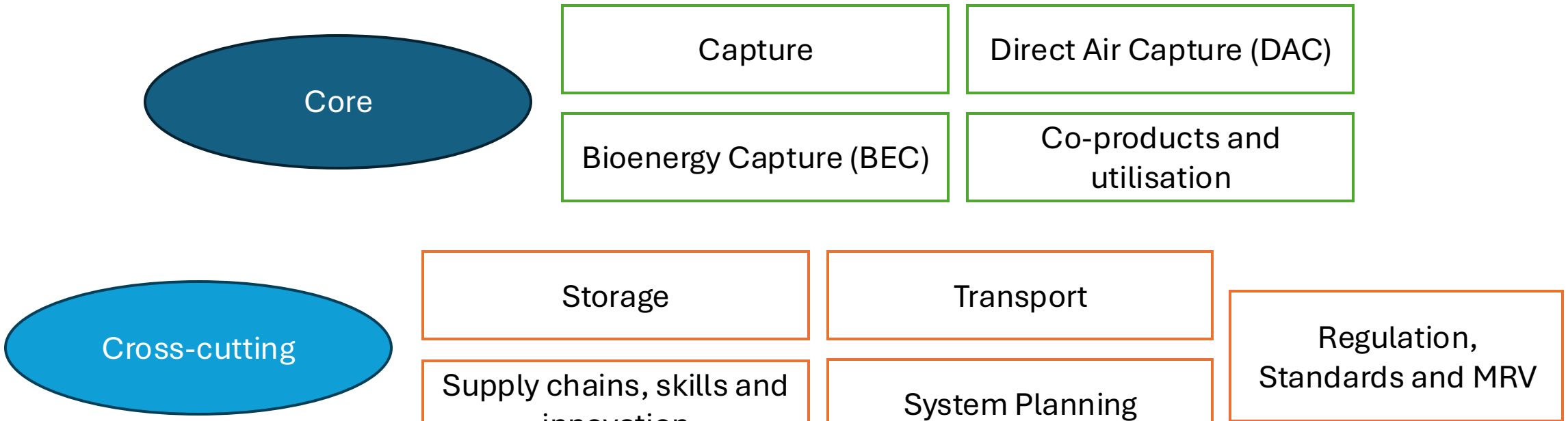
Themes discussed



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Details of core themes

Capture	DAC	BEC	Co-product and utilisation
This theme focused on the current and future role of capture technologies used to capture carbon and transport it into the CO2 network. The theme only focused on the capture process and did not consider the whole process (transport and storage). Capture here considers point source CO2 capture.	This theme focused on the current and future role of Direct Air Capture in generating negative emissions, along with the barriers to its deployment and uptake. The theme only focused on the process for direct air capture and did not consider the whole process (transport and storage). DAC considers CO2 captured directly from ambient air.	This theme focused on the technical challenges attaching CCS to bioenergy plants, and understanding the technical potential for Bioenergy with Carbon Capture and Storage in negative emissions, along with the barriers to BECCS deployment and uptake. The theme only focused on the process for bioenergy with carbon capture and did not consider the whole process (transport and storage). BEC considers CO2 generated from bioenergy production.	This theme focused on 1. current and future utilisation for CO2 captured, that may or may not result in long-lived storage 2. the impact of co-products (other than CO2 e.g. biochar) generated through industrial processing that can play a role in negative emissions or parts of the CCUS value chain.

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Details of cross-cutting themes

Transport	Storage	System Planning	Supply chains, skills and innovation	Regulation, Standards and MRV
This theme focused on the immediate to long-term transport needs considering both clusters and dispersed sites.	This theme focused on current and future storage options including the barriers and challenges to usage and uptake.	This theme focused on the CCUS/eGGR network, including emitter locations, storage, capture vs. eGGR, transport, and resource prioritization.	This theme focused on the technical evidence needed to facilitate supply chains, the skill gaps for deployment of CCUS/eGGRS and where innovation is needed for CCUS/eGGRs.	This theme focused on the technical evidence needed for monitoring, reporting, and verification of CCUS/eGGRs in industry, and the evidence required to support regulations and standards.

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Workshop Outputs

The following slides summarise the key points raised in discussion. We have presented:

- The overarching problems / challenges / barriers identified
- The policy, research and innovation insights interpreted based upon the evidence gap or solution for these problems / challenges / barriers

These slides do not represent all discussions from the workshop but a summarised output with a focus on policy, research and innovation insights gained. The insights gained are an interpretation from discussions and not restricted to the ones given.

Furthermore, **they do not represent current or future DESNZ policy.**

Overarching research themes identified

CCUS and eGGRs are expensive and actions could be taken to bring down the cost

- Using waste heat, integrated renewable energy and curtailed power, slipstreaming DAC with CCUS
- Pipeline transport is well researched and established, but further understanding of the costs and use cases for non pipeline transport (NPT) could drive research/innovation into reducing the cost of NPT.
- Offshore storage has been a focal point in research for storage of CO2. Understanding the long-term permanence of this storage as it is utilised is crucial, this will impact the costs associated with monitoring and licencing of further storage sites to meet demand.
- Finding uses for the CO2 captured rather than transporting it - potentially based on the co-benefits of clustered technologies
- Modularised technologies for CCUS should be explored.

There is an interdependence between transport and storage and capture technologies

Overarching themes identified

Utilisation could resolve a number of challenges, but still has an unclear role

- Need for an emissions accounting methodology for CCU and carbon recycling pathways
- Competition for biogenic matter between power and utilisation
- An understanding of the potential offtake pathways for CO2 and what is best for the UK – e.g. cement, e-fuels, high value chemicals

Groups repeatedly stated that good quality, long term publicly available reference plant data was essential to learning and improved systems

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Key Takeaways

- **Knowledge sharing** and where possible **data sharing** between projects, government and subject matter experts.
- **Future proofing** for CCUS / eGGRs, ensuring current deployment is optimised or flexible to future needs. Considerations for the future network and planning infrastructure with this in mind.
- **Innovation** not just for technology level, but for methods (e.g. new approaches to solving barriers), social (e.g. community involved projects) and considering environment impacts (e.g not only considering the carbon abatement but the wider impacts of e.g. CCS vs CCU in different locations).
- **Considerations beyond capex costs** need to be included into the deployment of CCUS. The most optimised solution may not be the lowest cost option.

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Capture

Challenge / Barrier / Problem

- Capture has high associated costs – energy demand from capture and compression, reaching 100% capture rates, geological stores differ regionally affecting the price
- Capture methods are not always suited to the emitter type
- No blueprint for a zero-carbon power station (only retrofit current plants)
- Gas+CCS balancing the grid in future – what are the implications on CCS ramp up/down as dispatchable power, how much CCS down time is expected (ie without abatement), feasibility of 100% capture rates?
- Limited solutions for distributed/small emitters

Research recommendations

- Assess the feasibility of atmospheric CO2 emissions monitoring near capture sites to check/validate emissions reduction has taken place. Measurement of fugitive and intentional emissions of capture and transport – explore ways to manage them.
- Understand the availability of waste heat sources – in terms of supply, suitability to specific industries and capture technologies based on availability
- Identification of optimal locations for transport and CO2-carriers based on the type of technology/source – can help develop CO2 business models for specific emitters
- Assessment of overseas supply chain (upstream emissions) not considered in net-negativity assessment of gas-CCS

Policy recommendations

Innovation recommendations

- Development of alternative transport and storage options for dispersed emitters
- Availability of reference plant data – pilot plants, operating at 10-100tCO2/day for 12 months, with an open access MEA solvent. Includes realistic flue gas emissions and full solvent (and non-CO2) management
- Pilot/reference plants for non-amine solvent capture methods – e.g. Allam cycle

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DAC

Challenge / Barrier / Problem

- DAC technologies have relatively high costs, energy and resource consumption
- DAC technologies must overcome the 'Valley of Death'
- DAC, like other CCS enabled eGGR technologies, requires access to the transport and storage networks, where there is a lack of certainty around transport, storage sites and role of offtake
- DAC has a manufacturing and embodied carbon footprint
- UK overseas territories have underexplored DAC potential
- Regulatory and innovation challenges to Direct Ocean Capture

Research recommendations

- Understand and model the role waste heat, water, variable and curtailed renewable power, co-location with CCS infrastructure can play in reducing the price of DAC deployment
- Role of slipstreaming to capture remaining (5-10%) carbon from point source capture
- Full systems life costs in terms of £, CO2 capture, land, energy – specific to long term UK energy prices
- Potential off-take that carbon from eGGRs can play – cement, e-fuels, high value chemicals
- A systems-based appraisal of UK potential for integrated set of GGR and CCS technologies
- Whole systems planning for energy parks – how to integrate mid-scale DAC, T&S and VRE
- Modelling the capture potential of UK overseas territories

Policy recommendations

- Greater certainty on the scale of negative emissions + DACs in carbon budgets – based on likely locations for deployment, storage capacity and technology selection
- Analysis of legacy regulatory regimes relevant to DAC and their interoperability
- Greater work between technical teams and regulators to co-design regulatory, compliance and potential funding regimes (including competition law, carbon market design)
- Taking a radical approach, the requirements for grids to be green could be relaxed as a way of rapidly accelerating DAC development and deployment

Innovation recommendations

- Demonstration/reference plants that describe DAC performance specific to the UK
- Integrated systems of waste heat, water and VRE to improve DAC cost-effectiveness
- DAC with improved capture rates (potentially modular) rather than building larger plants
- Low-cost (potentially modular) DAC systems with sustainable materials for deployment
- Alternatively, using scale to overcome CAPEX and non-energy OPEX challenges

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Co-products and utilisation

Challenge / Barrier / Problem

- Unclear availability of CO2 as a resource in sufficient quality (and of biogenic/atmospheric origin)
- No specification of CO2 for utilisation inputs
- Uncertainty / information gap about the commercial markets for co-products. Limited data sharing between producers.
- Limited compatibility of co-products/ alternative fuels with existing devices
- Unclear which processes to integrate co-product technologies into, and which groups/sites could work together
- Lack of formal / regulated certification for sustainable products, including CCU
- Limited knowledge of the fundamental science of alkaline co-products with CO2
- No established price for co-products

Research recommendations

- More rigorous understanding of the CO2 conversion mechanisms and which routes to accelerate, e.g., more advanced catalysts, process efficiency optimisation
- Techno-economic analysis of the pathway / end-products after final use to gauge whether they are carbon 'neutral', 'negative', etc.
- Production of LCA and TEA that goes beyond carbon/GWP
- A methodology that can assess the life cycle emissions and benefits of co-products, set system boundaries, and inventory of pilot project data for both LCA and TEA
- Tests machinery converting to alternative fuels and wider assessment of demand from industries that will need to switch to e-fuels
- Assessment of prospective CO2 utilisation pathways to 2050, and their uncertainty
- Estimated £ value of CO2 – which sets breakeven point for co-products

Policy recommendations

- Development of emissions and sustainability accounting methodology for co-products and carbon recycling – especially boundaries
- Support for R&D based on which technologies could support clusters of emitters

Innovation recommendations

- Assessment of the scalability of co-production processes based on clustering and output, that can prioritise between bench level R&D
- Innovation support directed at parts of the supply chain that can convert to e-fuels
- Reference projects, testing different capture technologies, to accelerate CCU learning

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BEC

Challenge / Barrier / Problem

- No operational BECCS project in the UK
- Distinct heterogenous inputs (burned individually, or as mixed waste streams) may have capture related issues specific to the fuel type
- Some small BECCS operators may not be connected to T&S network – non pipeline transport
- Unknown role of BECCS (power vs fuels/SAF) in net zero scenarios
- Unclear net benefit of CCU v CCS – emissions might still occur but displace the use of new/virgin fossil material
- There is no baseline case for waste – therefore additionality of EfW in terms of removals can't be compared to landfill
- No global definition of sustainable biomass

Research recommendations

- CO2 utilisation (e.g. SAF, greenhouses, e-Fuels, etc.) emissions accounting to compare the net environmental benefit for different BECCU value chains.
- Analysis of technical options for waste management and understand in which scenarios is combustion + CCS the most sustainable route for biogenic waste.
- Understand uncertainty in future biomass pathways - both magnitude but also interdependencies (between other use of biomass and nature based GGR approaches)
- Interaction and integration of land use change and peat land restoration on sustainable biomass production and end use
- Understand the trace flue components in BEC and its impact on producing a standard transport standard, capture technologies and downstream utilisation

Policy recommendations

- Introduction of comprehensive MRV regime for removals and reductions through BEC(CS).
- Collaboration between DEFRA and DESNZ on decarbonisation, waste and EfW
- Consider inclusion of EfW in voluntary carbon market

Innovation recommendations

- BEC specific capture technology demonstrators

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Transport and Storage (T+S)

Challenge / Barrier / Problem

- Exporting and importing of CO2 – uncertainty around capacity, infrastructure need and international agreements.
- Uncertainty past the T1 clusters for both storage and transport needs
- Understanding the long-term performance of CO2 T+S.
- The need to unbundle T+S within allocation and within business models.
- The role and feasibility of intermediate storage across the network (e.g. dispersed sites, variable demand, NPT)

Research recommendations

- Understanding of existing infrastructure, modifications needed and associated costs for exporting and importing e.g. port infrastructure.
- Further storage capacity appraisal to meet international demands and associated infrastructure for importing / exporting.
- Analysis of long-term performance of T+S infrastructure for CO2, to evaluate the current planned infrastructure and understand its resilience to future changes (e.g. changes in demand, importing / exporting CO2).
- Building on work done on specific case studies for intermediate storage and expanding this to other areas of the CCUS / eGGR network and determining the need and feasibility.

Policy recommendations

- Exploring the inclusion of imports and export estimates within the CCUS roadmap and understanding these in the context of the current targets.
- Looking at the potential options to facilitate exporting and importing of CO2
- Exploring producing a roadmap of CCUS / eGGRs for stakeholders and outlining potential mechanisms to achieve this.
- Looking at options and understanding the impacts of unbundling of T+S

Innovation recommendations

- Technology development for importing and storing of CO2 from other countries (e.g. floating and direct CO2 injection into offshore storage)

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Transport

Challenge / Barrier / Problem

- Lack of understanding of the role and economic feasibility Non-pipeline Transport (NPT) will have in a future CCUS network.
- Lack of understanding of the implications and what needs to be done to repurpose existing infrastructure (e.g. environmental impacts of gas pipelines, ports are they fit for purpose, rail and trucks).

Research recommendations

- Strategic analysis and mapping of pipeline transportation vs NPT including costs, technical feasibility (location, capacity required) and wider system impacts (e.g. environmental and social). Comparative analysis with other decarbonising options to determine if transport and storage of CO2 is the most viable option.
- Identifying the evidence gaps that still exist for repurposing of infrastructure (e.g. a lot of work has been done on pipelines, some on port infrastructure). A comprehensive feasibility study to fill these remaining gaps.

Policy recommendations

- Develop a strategy for the role of NPT
- Guidance / standards on repurposing of existing infrastructure for CCUS / eGGR s.

Innovation recommendations

- There are innovation opportunities for NPT first of a kind demonstrator projects which could reduce costs for commercialisation of NPT. Potential innovation in smaller or modular methods.

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Storage

Challenge / Barrier / Problem

- Onshore CO2 storage options and feasibility (e.g. storing locally, onshore aquifer storage, CO2 plume geothermal)
- Understanding of the scaling up of storage – what is the capacity needed, can we meet this, how do we speed up the process and what are the technical challenges
- Storage sites are currently treated in isolation hindering long term investment and development
- Understanding the behaviour of permanently stored CO2

Research recommendations

- Onshore storage appraisal (long and short-term) across the UK and the challenges, barriers and recommendations associated with onshore storage
- Development of new passive continuous monitoring of CO2 storage
- Understanding the permanence of CO2 storage as part of other processes e.g. CO2 plume geothermal
- Understanding the behaviour of permanently stored CO2 in geological storage
- Review of the technical risks of CO2 storage as we scale up to meet demand and what is needed to mitigate these (and ensure resilience)
- Understanding the pathway options and what is needed for interconnected storage sites

Policy recommendations

- Exploring options to optimise the appraisal and licensing process for storage sites
- Exploring the different strategies that could facilitates and encourages interconnected storage sites
- Looking at the longer-term strategies for the planning of CO2 storage to account for future UK and imported needs

Innovation recommendations

- Demonstrator projects for onshore storage options particular integration with other systems (e.g. temporary storage / short-term storage and CO2 plume geothermal)

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System Planning

Challenge / Barrier / Problem

- Understanding of the national scale infrastructure need across the UK for CCUS / eGGR and future proofing the current network deployments.
- How do we optimise capacity across the network (e.g. do we oversize pipeline for future demand, or do we implement other measures)?
- Decarbonising options for dispersed sites.
- Investment is needed across the entire supply chain.

Research recommendations

- System planning piece – which considers testing various future pathway e.g. oversizing pipelines, increasing demand scenarios, network capacity variations across the supply chain, importing and exporting of CO2, where different deployment may be located. Spatial and timeframe element. Building on existing work.
- Site specific work for dispersed sites which considers multiple decarbonising options not limited to just CCUS.
- Identification of where in UK steady flow of CO2 are and will be located.

Policy recommendations

- Investigating frameworks which could allow more flexible participation of different aspects of the supply chain.
- Exploring strategies for the current planned CCUS network and in how these could potentially apply to the future network.

Innovation recommendations

- A need for innovation to make the process of capture, transport, and storage more modular and cost-effective.

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Supply Chains, Innovation and Skills

Challenge / Barrier / Problem

- How do we manage cross-chain risks and identify cross-chain opportunities?
- Uncertainty in carbon emissions and accounting across supply chain.
- Large companies do not innovate and small companies who innovate cannot scale.
- Current Business models do not consider CCU, just CCS.
- Lack of innovation in the business, social and acceptance space for CCUS.
- Lack numbers of skilled professions in CCUS – possible shortages in specialist roles.

Research recommendations

- Analysis of the whole life carbon emissions across the CCUS supply chain (could be done as typical case studies / scenarios).
- Risk mapping across the supply chain and recommendations on how to manage these risks and suggested frameworks in place across the supply chain.

Policy recommendations

- Exploring frameworks that could manage cross-chain risk.
- Exploring business models which could consider CCU.
- Looking at strategies that could facilitate training courses and upskilling of other sectors for CCUS / eGGRs.
- Exploring funding options for smaller companies that could support commercialisation.

Innovation recommendations

- Foster partnerships of larger companies with smaller start-ups. Continue supporting small companies with innovation.
- Innovation within the business, social and acceptance space.

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Regulations, Standards and MRV

Challenge / Barrier / Problem

- Needs to be alignment on MRV and expansion to the current MRV system
- Definitions and terminology needs to be consistent across industry / government, and Internationally.
- Lack of defined and tested standards (e.g. purity conditions for CO2, pipeline/NPT, the time CO2 can be “stored” for different utilisation processes).
- Ensure consistency of industry metrics to government standards and regulations.
- Aligned emissions accounting standards.
- No CO2 specifications required to access T&S infrastructure

Research recommendations

- Quantify the permanence of long-term geological storage and identify the risks that influence the permanence of this storage and implications for MRV and governance.
- Quantify the permanence of utilisation (for different utilisation options) and implications for MRV and governance
- Research on broader sustainability issues and implications for MRV and governance.

Policy recommendations

- Continued development on codes and standards across the CCUS supply chain. Ensuring codes and standards used are backed up with evidence.
- Ensuring definitions and terminology are consistent and applicable or flexible for future changes in the network. If difference occurs defining those differences to ensure transparency.
- Ensuring data is shared where commercially possible.

Innovation recommendations

- Development of centralized facilities for testing CCS infrastructure.

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Next steps

- The workshop has helped to understand the technical evidence gaps for eGGRs and CCUS.
- This outputs from the workshop will be shared across policy, research and innovation teams, for consideration in design of future work.
- This output can be used by academics, industry and public bodies to identify areas of work that still exist as evidence gaps for CCUS and eGGRs.

Acknowledgements

We would like to thank all attendees of the workshop for their valuable contribution in the sessions, and through our follow up surveys. This will help improve how we run future workshops.

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