UK Carbon Dioxide Removals Ecosystem 2026+: Collective insight as to the needs of the UK Sector to 2035

Business model archetype – deliberative session 28th January 2025

58 Princes Gate, South Kensington, SW7

By Astha Wagle, Marsaili Van Looy, Philippa Westbury, David Contreras Diaz and Mark Workman

Summary and key messages

The UK has targets to deploy >100MtCO_2 of Carbon Dioxide Removal (CDR) by 2050 with interim technical targets of 5 MtCO_2 and 23 MtCO_2 by 2030 and 2035, respectively. In 2019, a number of policy initiatives were announced that have kick-started a nascent UK CDR ecosystem.[1]

To build on these foundations, it is recognized that there is a need for a shift in UK CDR institutional, governance and policy development commensurate with a pathway to realise the 2035 and 2050 targets. Working off previous CO_2RE road mapping which has generated *`outside looking in'* insight – this next exercise sought to identify market actors' needs for the UK CDR sector in 2026-35. Using the 8 Business Model Archetypes (BMA) from across BECCS, DAC, ERW, Biochar, NBS and mCDR technologies - market actors, enablers and policy makers explored the BMA needs through the following lines of inquiry: (i) Demand/Offtake Mechanisms; (ii) Regulation and Markets; (iii) Technological requirements; (iv) Resources and Capital Finance; (v) Social Acceptance and Trust building; and (vi) free form section. This took an *`inside looking out'* perspective of the specific needs of business models to maintain their development and growth trajectory to attain scale commensurate with the negative emissions required for the UK to realise net zero by 2050.

The systemic insight that came from the sessions include but were not limited to:

- Implicit throughout the workshop is that though the integration of CDR with compliance markets is a significant market signal in that it provides legitimacy for those negative emissions value chains that are incorporated *i.e.,* "*this is what good looks like and this is what we want*". The introduction of CDR into the UK Emissions Trading Scheme and the establishment of a carbon Contract for Difference is considered to be ***insufficient*** on their own to allow the nascent UK CDR sector to make the transition from establishment from the last 5 years, though to development and scaling from 2026 onwards. One of the global market leaders, which has a technology that can sequester CO_2 at substantive scale expressed concerns regarding the lack of demand for high quality, permanent removal allowances which is materially impacting the ability to get their pipeline of plants past Final Investment Decision. This is likely representative of a material systemic risk across the CDR sector.
- As a function of this, there were consistent requests for demand and offtake to be underpinned with deliberate and strategically significant long-term regulatory support by government. Though it was recognized that the government was providing forward guidance, e.g., the minimum quality threshold as to what needs to be included in LCA for BECCS and DACs, this was also considered insufficient.
    - The types of interventions aired ranged from the UK government directly purchasing negative emissions credits; the introduction of floor prices; stepping in as a buyer of last resort; explicitly integrating negative emissions into mandates, obligations, public procurement standards etc.; providing technical risk backstop - in light of new scientific insight which might result in baseline re-calibration; public-private collaborations - to - mandating private sector companies to purchase negative emissions allowances backed with clear legal definitions and to encouraging in setting.
    - Only then can the suite of market making mechanisms e.g., forward price curves, valuation models, insurance etc., allow CDR assets and products to be treated as a conventional asset class facilitating the drawing in of institutional investment. The needs of each BMA as to the types of government intervention started to be unpacked in the sessions on a CDR value chain basis. Further work is likely required to develop higher fidelity insights.
    - The ability to have revenue visibility for carbon and co-products over 12–15 years for the majority of BMA and 20 years for biochar and ERW was considered a minimum requirement to allow the finance community to even consider allocating risk adjusted capital to the sector.
- Leading on from the last point, there was a systemic call for the need to address capital raising gap sitting in the commercial *`valley of death'* whereby pre-commercial ventures require raises of multiples of £10M. In this valley, CDR technology is out of the Venture Capital raise bracket but too new, high risk and too small for big institutional money.

- A systemic call was also made by market actors that there was a need for a reduction in transaction costs by bringing convergence on MRV standards. This might be partially addressed by the government's integration of some CDR via the compliance markets. Academics considered that this might be too soon for some CDR technologies. It was also emphasized that some aspects of value chain carbon and co-benefit integrity might likely be better regulated than managed by the market e.g., land management.

Salient insight specific to the individual BMA stress tested included:

- For BECCS, the need for full Life Cycle Assessment (LCA) - cradle-to-grave - and land use implications as to whether true negative emissions were being generated. It was noted that this was problematical for long value chain CDR propositions like BECCS but was also especially so for CCUS products which going through multiple custodians.
- There were substantive concerns expressed regarding the BECCS Hydrogen BMA being able to attract any form of private sector investment as a function of the extent of uncertainty to which it was exposed.
- The need to accommodate DAC project lead times including the integration into the UK electricity T&D network and CCS networks was also highlighted which is also relevant for other CCS enabled CDR technology value chains.
- The Biochar and ERW BMA need sector standards to address confidence and trustworthiness of their generated credits. There is a need for the sector to have clearly stated *"how much and many years' worth of data is required to make establish trustworthy biochar CDR start up credible?".* A proposal was made as to how to address this capability gap through a government-academic and private sector collaboration.
- The mCDR BMA should be integrated into the Climate Change Committee's carbon budgets to provide the relevant signal that it was a recognized CDR within the UK Net Zero portfolio. The ability to do this would likely come down to the maturity of the air-sea gas exchange models which is a pressing critical path issue for the sector to generate the credibility needed i.e., that it was genuinely generating negative emissions.

Finally, the urgency with which the government needs to act was emphasised by participants as was brought out in the final exercise as to what interventions that participants sought to be introduced in 2026. These were posited on the need for guaranteed demand/offtake generation mandates and/or policies, reducing transaction costs though the convergence in MRV standards, developing a long-term vision and trajectory of signed posted policies/interventions for the UK CDR sector, establishment of FOAK large scale CDR plants to allow investor confidence to therefore attract private capital and learning by doing mechanisms to be realised.

Not all these dynamics are unique to the CDR sector and so they need to be considered in the context of broader UK net zero policy. However, it was broadly considered that risks of not acting on these insights are as real as the risks of action.

Further fidelity as to how these proposed UK interventions might be operationalized along with international CDR sector sentiment will be deliberated in subsequent engagements with US, EU and UK actors in further exercises throughout 2025.

1. Context: Why Carbon Dioxide Removal Ecosystem 2026+

Carbon Dioxide Removals (CDR) will be needed at scale in all scenarios that achieve the goal of the Paris agreement to limit warming to 1.5°C by 2050. The UK's CDR ambition has been clearly stated. The UK needs to develop a CDR sector of at least 100 $MtCO_2$ per year by 2050, split between technical removals at 60 $MtCO_2$ and nature-based removals (NBS) at 40 $MtCO_2$.[2] The technical removal target is on a par with the present size of the UK water sector and requires infrastructure, business model, and a regulatory framework development to incentivise investment in 25 years from virtually a standing start.

In 2019, the UK established a number of foundational initiatives and policies to kick-start a UK CDR sector and its associated ecosystem[1]. These have generated outcomes on a nascent pathway to realizing net zero which will struggle to advance further along a development and scaling pathway trajectory within the existing policy and institutional framework. There is a need for a new set of policy and institutional requirements in the period 2026-35 responsive to the new circumstances that the sector faces in order to build on the hard-fought outcomes realised over the past 5 years. This will be essential to avoid locking out the ability for the UK to meet its medium and long-term domestic negative emissions targets. The US has also announced a number of potentially game changing policies that stand to generate spillovers which will reduce the cost of scaling the sector if they can be captured by the UK depending on how the new administration addresses these in its American First agenda.[3,4] Therefore, the UK will have to balance the need to address its short-term net zero national targets with the opportunities of cost reduction that might materialise in the US in the medium term. The corollary of this being that the UK needs to make a number of decisions as to which aspects of the CDR sector it wants to play a global leadership role in and the economic benefits that might come with that in order to address the policy, institutional and governance requirements in the 2026-35 period. The UK must also be responsive to the significant broader shift in circumstances within the fragmented and market led CDR sector[5] - see Annex 1.

It is in this context that CO_2RE has convened a number of workshops which involved engagement with CDR sector actors. This workshop report represents the third phase of a 7-stage global CDR market engagement exercise - see Annex 2. Twenty-four UK policy makers, market actors and stakeholders took part in a Business Model Archetype (BMA) - deliberative participatory exercise to generate collective[6] insight as to what interventions need to be realised for the 2026+ UK CDR ecosystem from the perspective of the role of a firm. The business models that were analysed where BECCS (Electricity and Hydrogen Play); Direct Air Capture (Pure play and Utilisation - Enhanced Oil Recovery and Concrete CO_2 enrichment); Nature Based Solution and marine CDR - Biochar play; a land-based Biochar play and Enhanced Rock Weathering. The objectives of the workshop exercise were to address the following questions:

- What are the challenges and priority needs for market actors in the UK CDR sector post 2026 to 2050?
- What might the 2026 - 2035 technical, institutional, governance, organizational, policy and enabling ecosystem look like to address these needs?

The outputs were analysed by applying an evolutionary and institutional economic theoretical lens within a socio-technical transitions framing as justified in Annex 1. This avoids the distortive effects of the neo-classic economics orthodoxy on interpretation and policy design that is implicit in least cost whole system decision support.

Section 2 provides a summary of the analytical framework and shaping of the workshop `decision space' along with its theoretical underpinnings and observations regarding the participants insights within this framework. Interventions for each of the business model archetypes are summarized in section 3. Additional participant insights specific to each business model is captured in raw format in Annex 3. Finally, participants disclosed their personal assessment as to what needs to happen in 2026 in the UK and/or more broadly within the CDR sector in order to realise collective success in the UK CDR sector in section 4. Section 5 summarises next steps.

2. Analytical framework – interventions 2026–35: the business model *'inside-looking-out'* perspective.

The analytical framework for the workshop on 12th June 2024 which fed into this study can be found in the relevant workshop report.[1] To understand analytical framework for the shaping of the 'decision space' for this workshop and how this relates to the previous activities – the figures below display the theoretical framework and schema that has been applied to the Ecosystem 26+ workshop series. It builds on Geels Socio-technical Transitions framework (STS)[7] – figure 1 – within which Foxon's co-evolutionary[8] framework has been applied – figure 2 and figure 3 shows the systemic drivers of that each component of the STS framework operates.

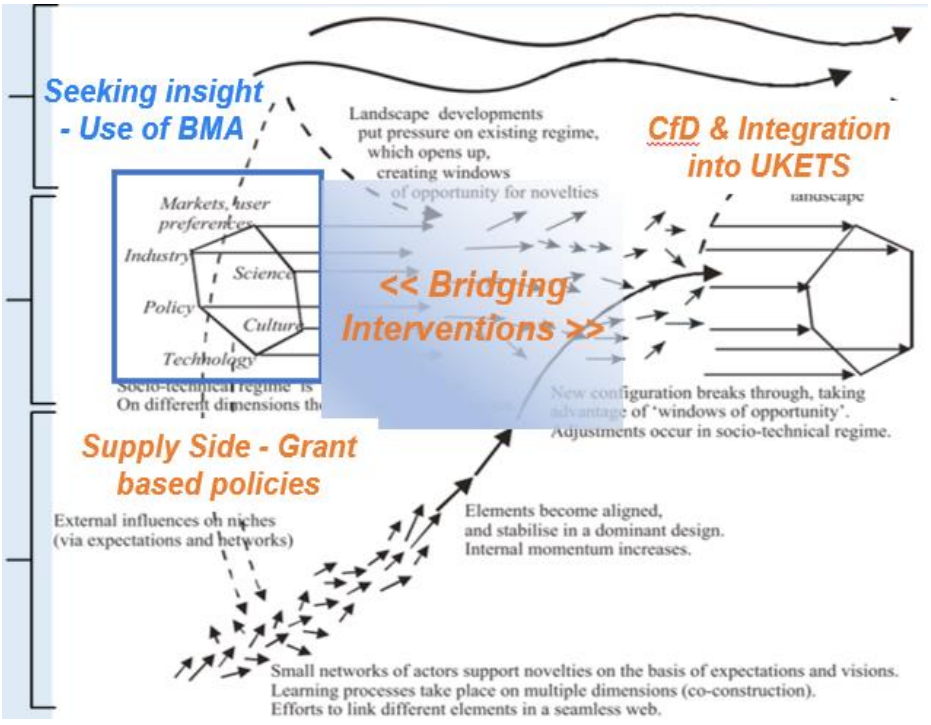
The workshop sought insight to be generated at the Regime level and the needs of market actors to address the path dependent trajectory to manage risk and uncertainty from the grant based, supply side government interventions of 2019 to present and the anticipated introduction of a carbon Contract for Difference (CfD) and the integration of negative emissions credits into the UK Emissions Trading Scheme by the end of the decade i.e., ***the Bridging Interventions*** articulated in figure 1, below – see also Annex 1. This specific 'window' is justified in that it will stand to have long term implications on the trajectory of CDR deployment in the UK and more than likely globally. The ability for the co-evolution of robust CDR business models and their concomitant value chains within the appropriate market strategies and policy ecosystem frameworks will in all likelihood allow costs in the sector to fall, the attraction of risk adjusted capital to get a pipeline of projects through final investment decision (FID) and facilitate sector scaling in line with net zero targets. The inability for the sector to realise such a co-evolutionary construct will likely result in the CDR sector drifting, whereby costs will struggle to fall and private capital flight meaning not only will scaling fall short of net zero targets but also the cost of realising net zero will be more expensive. A loss in sector confidence which will be hard to regain and the socialization of costs at a time when national debt levels across OECD countries are reaching record post-WW2 levels.

Figure 1: *Geel's socio-technical framework which emphasises a multidisciplinary approach by identifying multiple drivers transitions and the levels that they operate resulting in an emergent and path dependent co-evolutionary outcome.*

The socio-technical **landscape** provides the exogenous environment for regime change and is a source of major selection pressures on prevailing which in turn provide opportunities for niche innovations."

Regimes and niches develop in the context of a socio-technical landscape, which consists of both hard-geographical features, such as resource availability and infrastructure, and "soft" elements, such as political conditions, societal trends, and economic fluctuations.

A **niche** is a network of similar projects carried out by innovating actors who seek to challenge the



[1] Calverley, J. et al., 2024 UK Carbon Dioxide Removals Ecosystem 2026+: Collective Insight as to the needs of the UK Sector to 2035. A CO_2RE Workshop publication dated 4th November 2024.

incumbent and dominant socio-technical practice (regime).

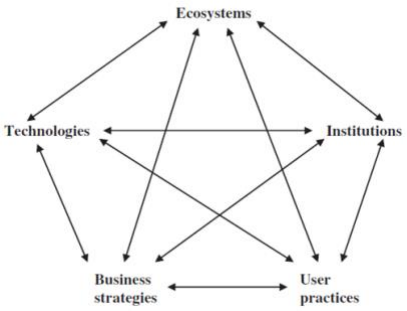


Figure 2: *Foxon's Co-evolutionary framework*

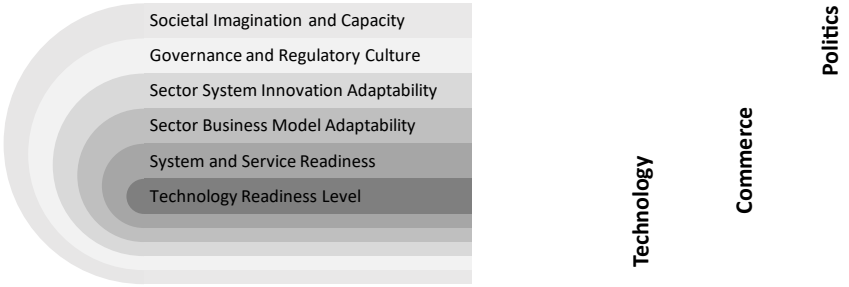


Figure 3: *Nested hierarchy of likely systemic needs to address CDR deployment and the likely drivers of transformational change*

The previous two activities in this series generated a market actor 'outside-looking-in' perspective as to what is needed for the UK CDR sector to build on the previous 5 years of CDR development. The decision space for this workshop was structured around the following aspects of subsequent research undertaken within the CO_2RE programme:

- Firstly, a working assumption for the establishment, development and scaling of the UK CDR sector is that it will be undertaken within a liberalised market framework. This is based on the Vision for CCUS[9] which anticipates 3 phases for a number of components of the CCUS sector development in the UK: a market creation phase from present to 2030 which involves developing CCUS out of 4 x clusters; a market transition phase (2030 to 2035) which anticipates market actor gaining confidence in the sector; followed by a self-sustaining market phase from 2035+ which is a fully fledged competitive market. Implicitly, the CDR market is anticipated to co-evolve within this vision narrative.
- Secondly, a socio-demographically representative survey of 2,110 UK Adults in Q4, 2024 undertaken within the CO_2RE Societal Engagement Workstream sought to understand the willingness of UK publics to accept mechanisms by which a large-scale UK CDR sector might be funded. This has implicit insight as to the political appetite for net zero and therefore CDR policy design in the UK – as a function of mandates for policy regimes in effect being granted by the electorate in liberal democracies. The salient insights from this survey, relevant to the decision structuring of this workshop, are as follows:[10]
    - The majority of publics at 68% want policy action, they also had a low favouring for existing policy instruments such as grants paid through general taxation, moderate appetite for compliance market mechanisms such as introduction of CDR emissions allowances into the UK Emissions Trading Scheme (ETS) and high appetite for regulatory policy intervention.
    - 70% of publics considered that fossil fuel producers and users should pay for UK CDR development; and
    - That publics were also aware of the `pass-through' implications of such organisations being imposed with an additional financial burden on the cost of products that they purchased.
- The final strand of insight that sought to shape the workshop decision space is an exploratory modelling exercise undertaken with 5 of the 8 business models stress tested in the workshop. In this study,[11] business model resilience was measured by their ability to generate an internal rate of return (IRR) which would appeal to strategic investors (<12%); infrastructure funds (12 to 15%) and private equity (>20%) – in different policy ecologies. The following was found:
    - In policy ecologies which included the two mechanisms that are being considered by the UK government (i.e., introduction of CDR emissions allowances into the UK ETS and a carbon contract for difference) – very few of the business models managed to generate an IRR based on a 15-year discounted cashflow model that fell within the risk appetite of these private capital funds.

- However, with a storage tax credit and public-private collaboration – e.g., joint venture, build-operate-transfer and private finance initiative – the attractiveness on an IRR basis improved substantially. Furthermore, different collaborations worked better for different business models in their ability to manage risk.

Within this *'decision space'* the workshop therefore sought to generate systemic Insight around the following dynamics around the following business models: BECCS (electricity and hydrogen play); direct air capture (pure play and utilisation – enhanced oil recovery and concrete CO_2 enrichment); nature-based solutions and marine CDR – biochar play; a land-based biochar play and enhanced rock weathering:

- Policies or issues of commonality cutting across all business models – i.e. no-regret interventions.
- What are the non-financial risks that new policy instruments can address directly?
- What are those that will be down to the private actors which new policy can address indirectly?

Discussion and generation of insights was primarily completed in four breakout groups of 6-8 participants – split by technology focus: (1) BECCS; (2) DACS; (3) non-CCS enabled CDR (biochar and enhanced rock weathering); and (4) nature-based solutions including marine CDR. The following exercises undertaken:

- Business model insight development, Session 1. In individual groups followed by a plenary briefing and cross workshop Input. i.e., each group spent time assessing a BMA within their group specialisation across a number of lines of inquiry relevant to BMA establishment, development and scaling.
- Business model insight development, Session 2. In individual groups followed by a plenary briefing and cross workshop Input. As per session 1, above.
- A reflection session on new insight generated by the session a 'What needs to happen in 2026 for the collective success of the UK CDR sector – why and how'.
- A final session closed-out and sketched next steps for the Ecosystem 26+ workshop series.

Discussions were conducted under the Chatham House Rule to ensure an open discussion was had as was reasonably practicable by participants.

3. Carbon dioxide removal: business model interrogation

The first and second round of workshops involved the four groups exploring the implications of two of eight proposed carbon dioxide removal (CDR) business model archetypes (BMA). The proposed archetypes were derived from the anticipated BMA required to address the Committee on Climate Changes 7th Carbon Budget (bioenergy with carbon capture and storage, or BECCS) – electricity and hydrogen; direct air capture – pure play and carbon capture and utilisation (CCUS) – enhanced oil recovery and cement plays; biochar and enhanced rock weathering as well as nature based solution business model archetype (BMA). A Marine CDR BMA was also interrogated. The latter two BMAs were generated by Kana[2] and Seafields,[3] as a function of their expertise and experience in these respective fields. Groups were asked to consider the implications of their ascribed archetypes on six elements of the anticipated future CDR system. Groups were considering implications of each archetype becoming a substantial system player in the **2026–2035** timeframe. The six implication categories were:

1. **Demand/offtake mechanisms:** How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth?

[2] https://www.kana.earth/about/
[3] https://www.seafields.eco/

What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?

2. **Regulation and markets:** Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing: How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?
3. **Technological requirements:** What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?
4. **Resources and capital finance:** is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs?
5. **Social acceptance and trust-building:** How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations?
6. **Freeform section.** Any other points that the participants would like to raise?

The exercises specifically sought to address the requirements of establishing these eight BMAs within the UK. Though all workshop participants acknowledged that constructs of resource and competitive advantage means that the UK is unlikely to be a sector leader across of all the BMA tested. Indeed, some would argue that the UK is already at a competitive disadvantage for some, however, with the nascent state of CDR development and the UK's legally established net zero targets the need to consider all was deemed appropriate in order to assess the risks, uncertainties and opportunities in as holistic manner as pragmatically possible.

Each archetype was represented by a diagram showing flows of energy, payments, services and carbon – see figure 4, below; and was accompanied by circa 200 words of explanatory text. Each group was given a copy of portfolio of eight BMA in advance of the meeting which included an implication feedback sheet for each archetype.

During the workshop groups were asked to structure responses around the six categories with space allowing for 'free responses' which did not fall into one of prescribed categories. All comments and free form discussions were collated by a dedicated table facilitator who also captured associated side discussions deemed relevant. At the end of each group session, there was a plenary session whereby a group representative provided feedback the salient findings from the session for their group. This allowed other groups to augment and/or comment on the findings for that BMA stress testing exercise. The plenary feedback was captured in the relevant section of the data capture categories.

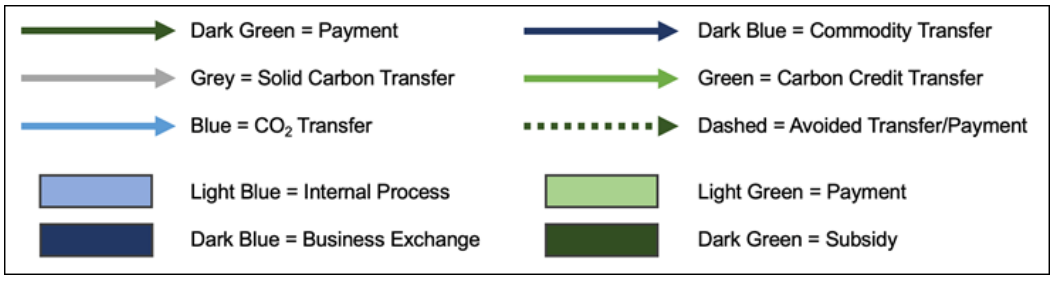
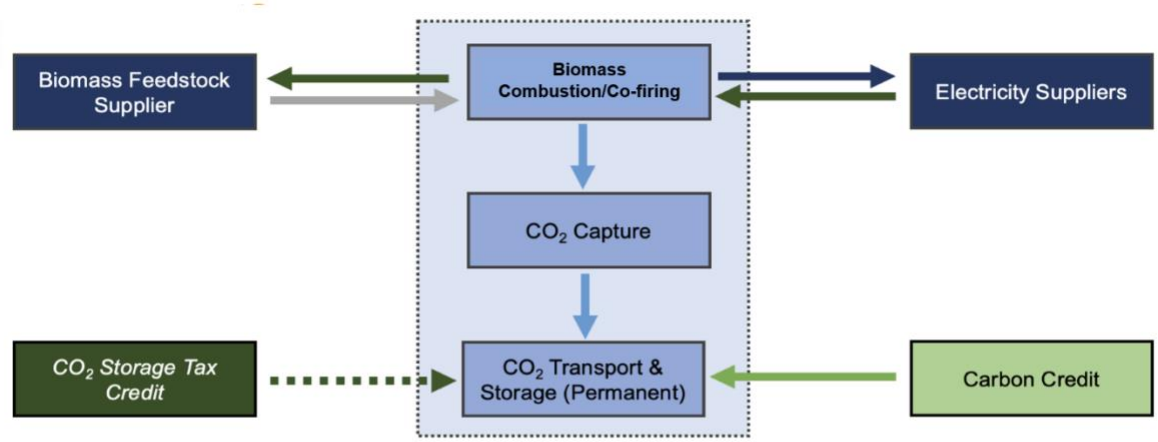


Figure 4: *Key for each business model showing flow of energy, carbon, payments and services for each archetype – see figures 3.1 to 3.8, below.*

The following sections are implication responses which are direct transcriptions from group facilitators and might often not be full sentences. This data will be used to: (1) Unpack policies or issues of commonality cutting across all BMA which might

form no-regret interventions by CDR sector actors; (2) identify what the non-financial risks are there that any potential new policy instruments can address directly – such as the introduction of the carbon contract for difference (CfD) and/or the introduction of negative emissions allowances into the UK Emissions Trading Scheme; and (3) identify those risks that will be down to the private actors to manage. Should the time and resources be available, (4) an exploratory exercise might be undertaken to quantify the possible revenues that each BMA might realise whereby these responses will allow the generation metrics for stress testing the different archetypes against system scenarios such as the National Grid Future Energy Scenarios (FES) or other such policy relevant pathways.

3.1. Bioenergy with carbon capture and storage – electricity



Key inputs: Biomass; energy for combustion

Internal processes: Biomass combustion/co-firing; CO_2 capture, transportation and storage

Key outputs: Electricity and CO_2 sequestered in geological sites

BECCS power business model: Carbon is removed through photosynthesis which occurs during biomass growth. The biomass is combusted to produce energy and CO_2 from the exhaust gas is captured and stored in geological formations

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Implications

1. *Demand/offtake mechanisms:* *How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- There are several business models being generated within UK government – two are relevant to BECCS. There needs to be a distinction between requirements for those BECCS plants above/below 100 MW threshold. There are distinctions for these requirements. These are outlined in the relevant business model consultations for both GGR and Power BECCS business models. In general, the dual CfD in the Power BECCS business model recognises the role of large-scale power BECCS facilities as both negative emissions generating facilities and electricity generating facilities.
    - BECCS larger (>100MW) will allow grid balancing services, the leveraging of existing infrastructure and economies of scale to be realised. We also have the geology for storage in the North Sea.
    - The <100MW would allow more environmental co-benefits to be realised -– fewer large-scale land-use trade-offs e.g. energy from waste. What makes most sense to farmers, land-managers, etc.?
    - Therefore, policy objectives will be an important dimension of developing the BECCS BMA.
- Demand: integration with compliance markets is holy grail because of legitimacy – "*This is what good looks like and this is what we want*". This would eliminate counterparty risk and provide investor confidence.

- There is a need for the right standards to activate both the Emissions Trading Schemes ***and*** Article 6. But this will only happens if there is high integrity and fidelity data across the whole chain. It's all about building the trust layer.
- BECCS will find it challenging to scale to $GtCO_2$. Full LCA – cradle-to-grave assessment of true negative emissions – so we know whether there is a negative emissions credit or not. Transparency with regard to MRV and LCA are paramount, particularly with political sensitivities around biomass supply chain/feedstock and when importing from other countries e.g., Canada, Finland. From the investment perspective – how does the establishment of BECCS fit into the energy transition, and how do you address whether it is truly net negative at a number of scales. Any question markets over validity, net negative – ruins credibility of carbon credit.
- The ability for revenue visibility for electricity and carbon over 12–15 years would provide confidence for investors.
- The government could provide forward guidance to the market by:
    - E.g., policy statements, considerations about "*how* [organisations] *should be thinking about portfolio*", guidance as to how to interact with the market etc. Government can do pilot purchases to lead by example with X and Y. CDR project previously vetted.
    - Providing soft support to certain portfolio of options/methods that align with scientific evidence, and that can encourage activity and trust in the sector.

2. *Regulation and markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing: How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?*

- Emerging theme is that land use is really important: government should make a priority to deliver a land use framework – though the land-use framework would need to be specified, because it's crucial that BECCS does not compete with peatland restoration? What is the government perspective/need/priority? Carbon/biodiversity/ monoculture?
- This could be a bespoke model for GW scale retrofitted plants "*no one else in the world will be importing that much wood pallets*".
- Land-use framework could benefit BECCS as well as NBS – we also came up with not separating NBS and technology.
- Puro and Isometric, etc. are verifying that some of these credits are actually carbon negative, and they're in fact acting as "market makers" by removing risk in terms of credit integrity.
- Government has an important role in terms of defining the taxonomy (as it was done with Carbon Removals and Carbon Farming in Europe). The UK is bringing in the Minimum Quality Threshold (MQT), which will define what needs to be included in the LCA, what emissions, it will be published with more detailed information about BECCS and DACs in the coming year or so. The MQT will act as a bridging mechanism for the eventual roll-out of a full set of standards.
- Waste to Energy: what does this have the capacity to scale to? It could work at the municipal level (Infinium).
- Establishment of standards of what a credible CDR portfolio might look like within a net zero strategy – such guidelines are anticipated to be forthcoming from the SBTi in 2025.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?*

– Nil entries

4. *Resources and capital finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs?*

- BECCS is more of a project finance pure play. Banks should back this BMA as it represents a potentially huge opportunity. You need visibility on the revenues over a 15-20-year time horizon.
- Dispatchable power agreement (DPA) establishment which can be assisted by the banking sector. A DPA carried non-trivial liability for government as it is taking a lot of debt in their balance sheet, and also liability on CO2 storage.[4]
- Without a substantial proportion forward sold to an offtaker, none of the business model happens from a bank perspective. You need that offtake visibility, you'll also need a good deal in terms of electricity purchase to get project finance.
- There is no price discovery within existing carbon removal market mechanisms.
- In a revenue support model, if you're only dependent on the subsidies, the venture/startup becomes less investable in the eyes of investors.
- Chicken and egg – counterparty risk throughout project cycle and operations.

5. *Social acceptance and trust-building.* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

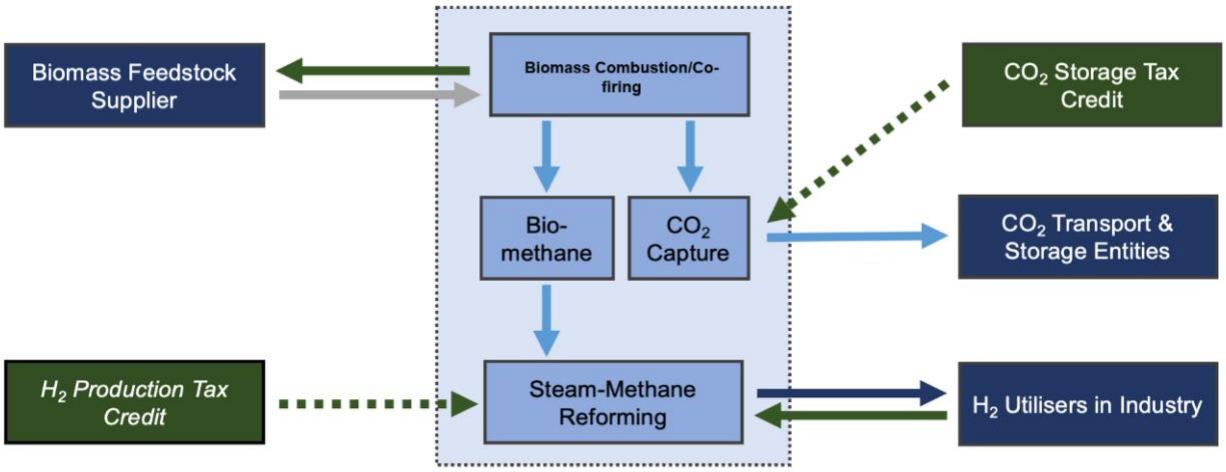
- More transparency and engagement is necessary to get more social acceptance

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes.*

– Nil entries

[4] DESNZ, 2022. Carbon Capture, Usage and Storage Dispatchable Power Agreement business model summary. November 2022 p.53

3.2 Bioenergy with carbon capture and storage – hydrogen



Key inputs: Biomass; energy for combustion

Internal processes: Biomass combustion/co-firing; CO_2 transportation and storage; steam-methane reforming

Key outputs: Hydrogen and CO_2 sequestered in geological sites

BECCS hydrogen business model: Carbon is removed through photosynthesis during biomass growth. Biomass is combusted to produce biomethane, which is used to produce hydrogen, and CO_2 from the exhaust gas is captured and stored in geological formations.

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Implications

1. *Demand/offtake mechanisms:* *How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- There was a general lack of belief by the participants as to whether this BMA was viable as a commercial going concern on a number of levels: (1) The hydrogen sector has not developed as anticipated and therefore the offtake risk is substantial; (2) the products had questionable value relative to the cost of producing it – there are potentially cheaper ways to make LCHS-compliant H_2, but do you get any additional points for carbon-negative H_2 from the H_2 market? (3) Process efficiency is questionable to generate products and negative emissions – whereby the challenge of MRV (there is general anxiety about the LCA of conventional methane) will increase transaction costs. The energy balance for Synthetic fuel production (eSAFs) are notoriously inefficient. Are there susbtantive cadre of hard-to-abate industries that could potentially benefit from the BMA: Heat, power, mobility – sectors all have cheaper alternatives possible fertilizers, chemicals, high-heat requirements might make the BMA viable – but subject to substantial uncertainty. (4) Scability is dubious, given the availability of sustainable biomass. Is it necessary to go through the whole biomethane and CCS component of the value chain when biomass for electricity production is much more efficient. All these issues questioned the ability for the business model to attract investment funding. ***Note:*** Hard-to-decarbonise sectors cannot reach net zero through electrification alone.

2. *Regulation and markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing: How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?*

- Is there a policy in the UK equivalent to the EU for the use of biomethane?
- The use of more renewables, or long-term storage, will kill hydrogen use, in particular without government subsidies.

- It's crucial to understand and draft the regulation to what the feedback can be, and how much carbon is locking up.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?*

– Nil entries

4. *Resources and capital finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs?*

In terms of business model though, the feedstock might be a benefit for the project developer, so it offers optionality in terms of different revenue models. But it needs to stands alone by itself, in order to unhook from the government subsidies.

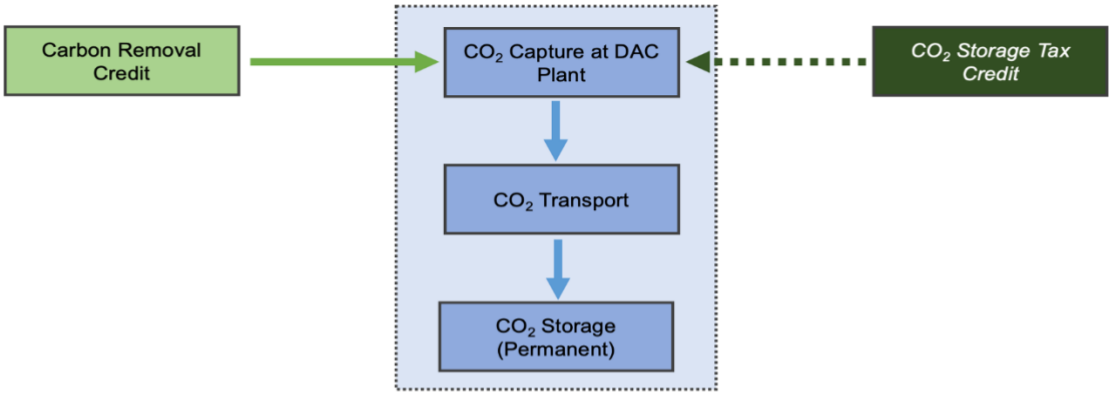
5. *Social acceptance and trust-building:* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

– Nil entries

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes.*

– Nil entries

3.3 Direct air capture and storage – pure play



Key inputs: Energy; air (source of CO_2)

Internal processes: Chemical binding of CO_2; CO_2 capture, transportation and storage

Key outputs: CO_2 sequestered in geological sites

DACCS business model: Uses chemical processes to directly separate CO_2 from the atmosphere and store it in geological formations. Requires renewable energy, sorbents, and infrastructure for capture, compression, transport, and storage, generating revenue through carbon credits and offsets

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Implications

1. *Demand/offtake mechanisms:* *How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- Only two DACC companies are left in the UK. Mission Zero and Airhive. Everyone else has moved to the US.
- A fundamental aspect of the BMA viability if that DAC plants will set up where capex and opex (electricity) is cheapest and then sell credits internationally. It is important to note this is not the only consideration. International credit trading is not market standard at the moment. DAC companies will have to balance between where costs are cheapest vs where they can get most value from credits vs other strategic benefits like access to T&S and subsidy regimes.
- Demand and offtake require significant regulatory support – in UK and elsewhere. Demand only happens when there is regulatory support. Regulation could increase demand in the UK: Could be a mandate – if that is politically acceptable. There is a need to minimize taxpayer burden to make policy survivable across electoral cycles. There needs to be in-demand stimulation and emphasis on the consumer e.g., aviation levy which places burden on those who are flying. There may be subsets where it's part of taxpayer responsibility to stimulate economy. Suggestion that there is a mandated proportion of CDRs in levies now at a low level that is bearable, that doesn't make huge impact on the consumer and that gradually gets built up over the next 20 years or so.
- DAC is expensive but is also highly durable and the MRV is conceptually simple to trust which should be priced in. Costs are going to come down so targeting highly profitable businesses that can absorb the costs as a function of their high profit margins should be considered, i.e. there is a need to initially focus on industries that can support the initially high costs initially,[12] e.g. tech/data centres. These might be mandated to address net zero and/or purchase durable CDR. There is also the potential to put CDR alongside SAF as a mandate. SAF already has CDR in the chain, so can further lower the carbon intensity of SAF by applying CDR as well. Without these measures the burden on taxation to support the CDR sector will be substantial.
- Price differential of different CDR technologies be solved through contract for difference (CfD) with different strike prices for different technologies.
- Difference between ETS and mandates – ETS picks industries but not the technologies they can use, and mandates picks the technologies vs the government directly buying. That's the difference between mandate and ETS.
- Kickstarter: it was postulated, hypothetically, can Great British Removals buy portfolio of removals?

2. *Regulation and markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing? How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?*

- Planning processes to gain connection to electritcity and price/source of electricity are fundimental barriers to DAC development and deployment. There is a skew for using fossil fuels and against renewables. Need to be able to offset. It is noteworthy that data centres have access to grid connection and there are places in the world with an excess of renewables.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?*

- Geological storage access take many years to get up and running and viable. 10–20 years from inception through FIDs for those as well. So there is big interdependency which means that there is a need to start early on storage – as you can't capture without storage.
- UK government is doing good job on this, for example, the CCS Track 1 clusters will allow huge amounts of storage. If government can incentivise cheaper renewables i..e, the cost of electricity is a major barrier, the storage problem will eventually solve itself.
- There is a timescale and co-ordination issue though which gives an easy reason for industry not to act.

4. *Resources and capital finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs*.

– Addressed in sub-section 1, above.

5. *Social acceptance and trust-building:* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

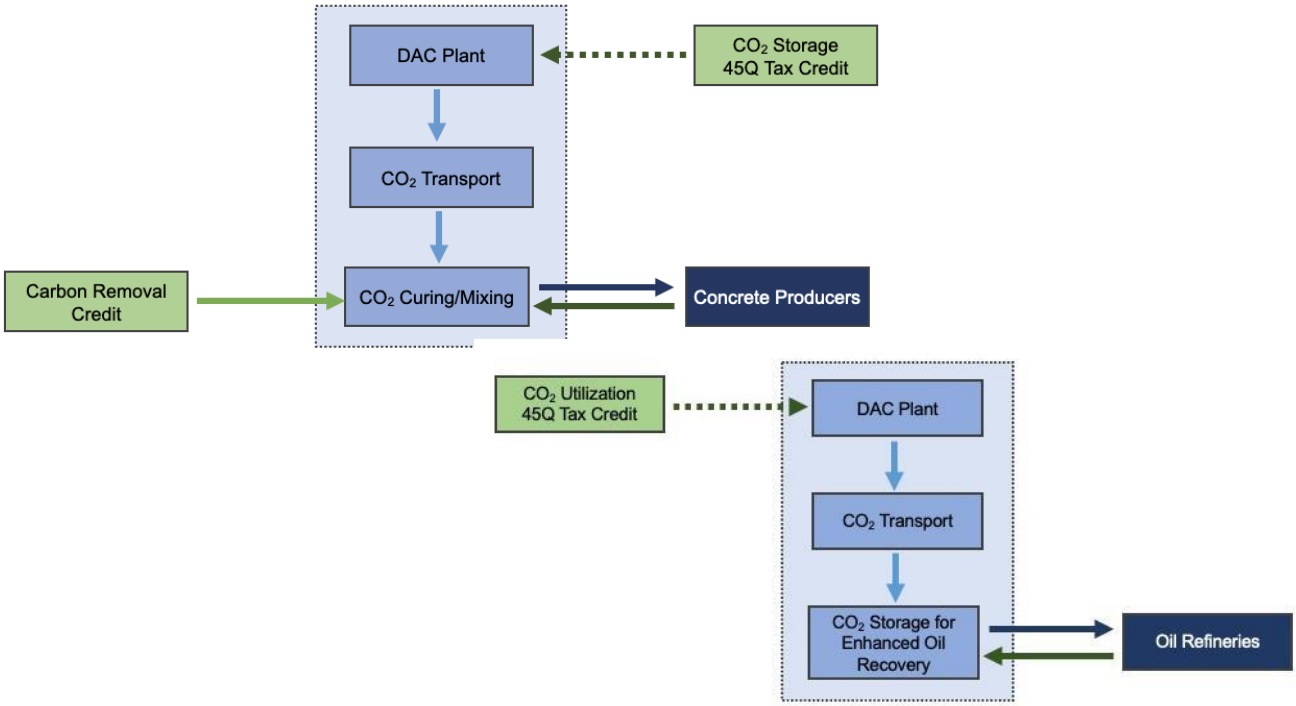
- Pipelines will always be difficult to get access to and set up as they don't benefit communities that they run through. Get different levels of acceptance based on geography – e.g., very different attitude in Teesside vs Poole. Public push back has used quotes such *as "it's another Chernobyl".*
- Relative locational flexibility for DAC so can situate close to storage point - you don't need huge infrastructure
- DAC projects in US e.g., Permian Basin have had an extensive community engagement Programme. It's also a community that is used to having industrial scale movement of 'chemical fluids'. Jobs are created though this tends to be for onshore storage. The UK might be a different with offshore storage being accessed.
- Green Plains[5] is an example where public opposition prevented a pipeline network project collecting CO_2 from ethanol. The project stalled as a function of this.
- Financial due diligence for social acceptance is a relatively low priority relative to other aspects of financing considerations.

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes*.

– Nil entries.

[5] https://gpreinc.com/carbon-capture/

3.4 Direct air capture and storage and utilisation – enhanced oil recovery and cement



Implications

1. *Demand/offtake mechanisms:* *How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- Insurance: how does this work when you don't have control along the value chain and access to data for concrete? In EOR you have a lot of data.
- You might think about the final product on a scale for decarbonising carbon intensive products where you make your product less CO_2-intensive. Therefore, supporting an industry to abate with a removal to offset the inability to address embedded emissions. In these DAC BMA you are trying to reduce the CO_2 intensity of aviation fuels i.e., you are focusing on the product.
- Analogue between conctere CO2 enhancement and ERW**.** Have smilar challenges of an open system. It's still storage, but the MRV and the additionality questions are more complex too. BMA will inject in concrete if there is a green premium and/or reputational gain. However, WTP likley greater for geological storage vs concrete.
- Economics of the concrete process were questioned.
- Pre-final Investment decision costs are another factor for this question. Lots of uncertainty that dissuades investment. Want to understand developer's perspective on what can be done to support to reach FID? OnePointFive's first commercial scale plant was a bet. Will need offtake to get to FID for the next plant. That's why demand stimulation is so important. There needs to be level of offtake secured before you get FID on a plant. First plant is a huge undertaking. Technical risk is really low.

2. *Regulation and Markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing? How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?*

– Addressed in sub-section 1 to pure play DAC, above.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?*

Discussions covered the differences between EOR and concrete in the BMAs, and the permanence and MRV of these techniques including liability when the concrete passes through multiple stages of ownership after its creation – therefore relevant to sub-topic 3: technological requirements.

- Business models are very different from each other. EOR releases the CO_2 immediately and concrete is near-permanent as a difference. Fuel is high-value and cement is not.
- How much do we trust these storage techniques? How do we count if this is an emission reduction rather than offsetting, abating etc. Would this not be down to the measurement of CO_2 sequestration over time? Unlikely that there is lot of measurement happening.
- With EOR, it depends on which type of feature you're storing it in. There is already good understanding of liquid CO_2 behaviours in O&G sector. 50 years of data. Can measure pressure waves through a reservoir.
- Uncertainties about concrete. Much harder to become confident: how much CO_2 is going into the product, is it reversable – acid rain impacts, it's harder to track a product – where it's used, how it's used, ownership change. Concrete goes through lots of ownership changes, that's why there are more doubts about utilisation as a method of storage. Who takes the liabilities? OCO, a party in Mission Zero's consortium,[6] have an issue selling credits as there is no depth to the market. It becomes a carbon accounting problem. The MRV methodology doesn't accommodate for reversal, but such is the nature of it that there will be end of life, acid rain etc. so clearly MRV issues and that will need ironed out.
- From a government perspective, concrete is a saleable product, unlike storage. If someone says we need to store CO_2 that has no market value but has public good value, therefore we need another way to compensate like ETS. But if I'm selling concrete, even if produced expensively, to store CO_2, then it's got more of a private good economically. Note that if you put a boundary around concrete producing, the concrete producer is not getting any subsidy as it is in the concrete product.

4. ***Resources and capital finance:*** *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs.*

– Nil entries

5. *Social acceptance and trust-building.* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

- Oil refineries have big social acceptability issues.

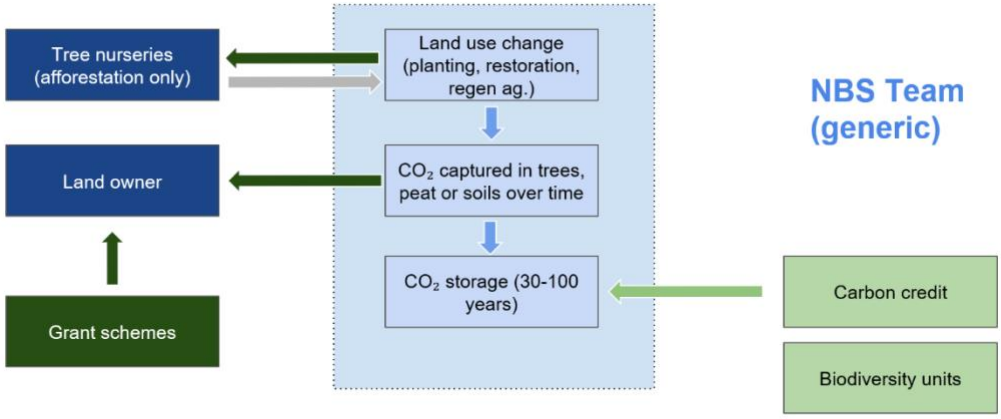
[6] https://oco.co.uk/o-c-o-technology-moves-to-pilot-plant-for-next-stage-of-dac-programme/

- There is a demand component related to social acceptability: when you mix EOR and deforestation, etc. all credibility is lost – it's hard to sell.
- Corporations that buy credits see reputational risk and regulatory risk. They map differently, but the reputational risk is there for *"low quality credits".* There is potential reputational benefit if you're buying best quality which can be DAC with storage. Then there's responding to future regulation. They may be able to get right of first refusal, trying to hedge against there being a regulation in future. As long as the regulation exists, they'll be fine. But the regulatory risk opportunity thing is important when buying credits. The more we can show that there will be a compliance scheme the more likely the sector will bring in buyers.
- How much learning is going from SAF development over the last 20 years into GGR scaling? Some SAF targets are very ambitious. EU has taken different approach, see how plays out with ETS and SAF allowances. There is the intention for market alignment with the UK and EU. The more global a policy is, the easier it is to cooperate between markets.

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes.*

– Nil entries

3.5 Nature-based solution – generic play



Key inputs: tree seeds/saplings, government grants for woodland creation or peatland restoration.

Internal processes: tree planting and monitoring, restoration or rewilding practices; CO_2 capture and storage in biomass

Key outputs: CO_2 sequestered in biomass, improved biodiversity, soil health, water and air quality, community benefits.

Land based carbon business model: carbon is removed from the atmosphere through photosynthesis and is stored in plants and soils. Additional benefits include improved biodiversity (including access to biodiversity markets), soil health, water and air quality, and community benefits.

Implications

Business model description submited by Kana: Carbon source grows over time (blue: trees, saplings – could also be regeneration, reforestation). Carbon captured over time and stored 30 to 100 years permanence. Money goes back to land-owner, e.g. via the land-owner giving consent to developer and then being paid by the developer. Landowner can do this themselves. There are grant schemes e.g. for peatland restoration. There is an interplay of ecosystem services and how they can be bundled and stacked with a CO_2 storage tax credit. There is an open question as to how to drive the sector with the need to balance taxes and grants for ecosystem services versus the ability to generate carbon credits.

1. *Demand/offtake mechanisms:* *How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- A stable demand curve is needed to drive investment into NBS CDR. In the UK VCM, corporates need clear and stable policy guidance on what constitutes a net zero claim, when they have to do it and what units could be used to offset residual emissions, rather than relying on various private/international standards. This policy needs to be legislated and stable across changing governments. This will formalise a voluntary demand curve and allow investors to create the business case to invest in projects. Alongside a valuation model, showing how different project types and their attributes (benefits, risk, location etc.), investors can have far greater certainty of ROI.
- To further a stable demand curve, the govt could introduce price floor mechanisms (like the Woodland Carbon Guarantee) to guarantee the business case of nature-based projects.
- A stable demand curve will draw in money from institutional investors with experience in medium term investments (£4bn of pension funds), who can be confident in an attractive risk adjusted return in a stable policy environment.
- MRV is constantly being adapted and improved as new technology becomes available, which should be an inherent goal of any code or standard. The question is what data needs to be available and accessible to make these projects investible? The development of a reliable project assessment framework, which breaks down project quality by those delivering the project, the location as associated risk factors, the credibility and rigour of the governance standard and chosen methodology, the project benefits and project risks, can offer a complete invest -ability picture for investors to guide decisions and increase project transparency.
- Regarding fungibility, it might need to be accepted that nature based and engineered CDR cannot be compared in a like for like manner. Durability considerations aside, inclusion of NBS into a compliance market where the unit is only valued for its carbon removal may reduce project developers and investors to focus on maximum sequestration and overlook the value in the other co-benefits NBS provide, reducing the units to the lowest common denominator (cheapest to produce with most carbon sequestered – i.e. monocultures of fast-growing species.
- There is a need to create a forward pricing curve based on a stable demand curve that will grow the value of NBS projects into the future. Combined with a price floor, the projects will be profitable and therefore become investible. The investors, who have experience in controlling well managed medium-long term fund structures, will engage in a market with clear regulation and policy guidance, that is insulated against major volatility.
- There is the potential to create a business case which generates predictable profits, making nature-based carbon an investable asset class.

2. *Regulation and markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing? How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?*

- How much is soil carbon addressed as this is taking place in other jurisdictions such as Philippines? Environmental Land Management has incentives for soil management via the encouragement of low-till and no-till practices. Need to pay from an initial baseline set at a specific depth within soil.
- Soil carbon measurement has substantial uncertainty and is resource intensive – uncertainty in soil measurements is an order of magnitude greater than trees. Need to rely on modelled estimates which requires a substantial set of assumptions to be made.
- Fungibility and additionality. Important with regards the introduction of NBS into the UK ETS. Additionality is critical for land, there will be permanence issues – pests, fire, disease, changing climate risks. There are ways of addressing

the shortcoming of biogenic stored credits when integrating credits into instruments which have geological stored credits e.g., insurance, discount factors. It is important that they are included in such mechanisms otherwise the sector will get left behind.

- Biologically stored carbon only fungible from farming emissions, geological storage for fossil emissions.[13]
- When people make a green claim, what does that mean in legal terms. No legal definition of a high integrity credit. How can the NBS credits be regulated across a credit lifecycle and/or within the business model?
- An example of where a confidence building measure has been established is in Australia – within an initiative called Climate Active,[7] which is a public-private collaboration between the Australian government and businesses.
- Convergence on the standardization of methodologies for verification being sought. There as a huge number of methodologies, people can't buy confidently. Corporates don't want to spend time defending their purchase.
- Co-benefits are being ignored and how these get rewarded?

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?*

- Technology on market-making side. Digitalise every step and set up data management systems. This will drive scaling, verification, speed and trust - *See market architecture needs above in subsection 1.*

4. *Resources and capital finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs.*

- Lack of scalable financing models: the NBS sector is too fragmented, projects have an unclear ROI due to uncertain carbon pricing trajectories which discourages large-scale project deployment.
- Is there a trade-off between regulated market versus encouraging voluntary action?
    - Grants to enable farmers to make long-term commitments to land-use. With soil, still need to incentivise the farmer as may be droughts – otherwise too risky for them, and too slow for them to realise benefits.
    - Part of the problem is the grant-based mechanism.
    - Would a guaranteed buyer and standards to generate a market allow the sector to be established? PIUs are not selling. There is a substantive trust issue with farmers with market based polices as a function of government policy flip-flopping in the past. Farmers tend to be more comfortable with grants.
    - How do value other aspects of the potential value stack. Biodiversity vs carbon sequestration or do carbon credits need to reflect biodiversity aims and can they be embedded it into the methodology?

5. *Social acceptance and trust-building.* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

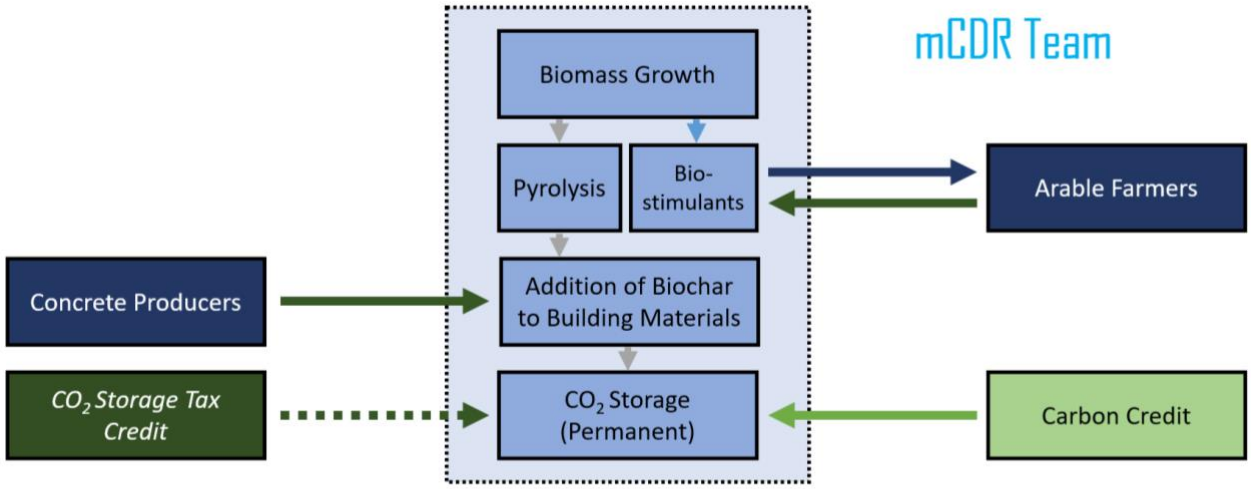
- There is a lack of trust. People need to be confident in long-term delivery.
- There is a need to scale high-integrity NBS markets, but this requires generating greater trust in ecosystem services.

[7] https://www.climateactive.org.au/

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes.*

- Many of the issues raised here are also relevant to BECCS and biochar.
- Land management, co-benefits and trade-offs beyond carbon, can result outside of the business model. These are better addressed through environmental regulation and nature credits though managing it will be a challenge due to siloed policy design process between Defra and DESNZ on all tables.

3.6 Marine CDR – macro-algae play



Key inputs: Nutrients for growth; marine space; energy for pyrolysis
Internal processes: Biomass growth; processing (mechanical, chemical); pyrolysis; addition of biochar to building materials
Key outputs: CO_2 sequestered in building materials; biostimulants

mCDR biochar business model: CO_2 removed through photosynthesis during biomass growth. Biomass processed to generate biostimulants, a saleable commodity, and a carbon-rich residual. Residual pyrolysed in the absence of oxygen to give biochar, which is then added to building materials for permanent storage of CO_2.

Implications

Business model description – submited by Seafields: Seafields business model is based on Sargassum, which is a macro-algae native to tropical waters. The above BMA is viable in UK waters with different species of macro-algae. Using marine biomass is not the only marine option. This BM just focuses on marine biomass. Micro-algae cultivation is also possible. Seagrass options, mirroring NBS in afforestation which includes protection of seabeds are also viable. Biomass growth is where Seafields BMA is focused, cultivating in an engineered fashion to produce commodities such as biological fertilizer and other sustainable commodities. Residual from production of such sustainable commodities are carbon rich and can be put through a biochar process – to embed in materials which forms a permanent store. In terms of financing flows, this results from the sale of commodity and the realization of a carbon credit. Grant funding for ecosystem services can also be captured; this is similar to regenerative farming.

1. *Demand/offtake mechanisms:* *How would B2B and B2C demand be generated for this archetype? Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- MRV is a substantive challenge. During macroalgae cultivation CO_2 is drawn from the water. There is a requirement to prove air-sea gas transfer flux, i.e. to verify that CO_2 is moved from atmosphere, to water, to biomass before the

establishment of carbon credits. This is technologically challenging and almost unscalable if this forms a component of the methodology for the BMA.

- There is a need to strike the balance between a robust methodology and it being impractical. Though the impact on economics is tricky to assess there is the possibility of managing uncertainty being built into the carbon credit by stating a fixed uncertainty. According to best practice, can only quantify CO_2 uptake experimentally in a closed chamber, then use those measurements to derive emissions factors.
- Japanese government will pay for carbon credits from kelp farming and other biodiversity benefits.
- CDR credits being generated for VCM, cement compliance through CBAM.
- Arable farmers pay for fertilizer from BMA, which replaces chemical fertilisers. Trials have validated efficacy in terms of increased yields and resilience. Additionality through reduced carbon in fertilizer manufacturing is not being realised.

2. *Regulation and markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing? How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-land-use master planning and co-ordination be facilitated?*

- Sargassum has a very fast growth cycle whereby the biomass can double in 14 days. How to turn the process into an operational system which is economic is still an open question. Biodiversity has a qualitative co-benefit but have not yet managed to generate credits. Could be used for biodiversity net gain as legislation is coming in for offshore wind whereby this this will be important in the planning process.
- Previously looking at a pure CDR play by transferring the biomass into the slow carbon cycle, i.e. when cultivated biomass dies off, or acerating this by harvesting, baling and sinking and therefore physically transferring it to the oceanic slow carbon cycle. There is substantive interest in this as a long-term direction for the BMA as there is substantive opportunities to scale. There remain regulatory barriers to enabling this.
- People are getting carbon credits for mangroves. The BMA solution above is about cultivating and harvesting for the commodity of biochar.
- If you want to grow/cultivate macro-algae, need nutrients. Coastal waters abound with nutrients because of run-off. Further offshore, more depleted and less biodiversity – though there are ways that you can add nutrients with regulatory constraints. Proposals for dumping 'pollutants' into open water as being prohibited, i.e. as would happen in ocean alkalinity enhancement, requires clarification. If you site a project in international waters, who gets the NDCs, how is this regulated? Publics tend to have stronger emotional reaction to perceptions of dumping.
- There is a need to allocated space to enable these projects – ideally coastal zones. Ideally, that would be the near shore but that is where the highest competition is for space tourism, fishing, offshore wind etc. This forces mCDR projects to look further offshore which is nutrient depleted.
- Under the London Protocol there has been hesitancy from party members as to the impact of mCDR projects as a function of transboundary impacts of unintended consequences for mCDR projects. Likely will take many years to get a convention locked down. There are analogues with the peatland fires in Indonesia caused by legal entities based in Malaysia causing smog plumes in Singapore. Who is responsible and how is responsibility absorbed becomes very messy to address.
- Marine CDR is not recognized in the Committee on Climate Change Carbon Budgets. An opinion was expressed remotely following the workshop that they could be integrated into carbon budgets by mid- to late 2026. The dependency would be down to the maturity of the air-sea gas exchange models. The ability for the CO_2 flux to be measured at this interface is anticipated to be the tipping point for commercial and public sector acceptance of

carbon mCDR credits and the ability for the business models to function. This also provides the time needed for technologies to develop to the necessary scale.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like transport and storage or slow pyrolysis plants that need to be upgraded?*

– Nil entries: see MRV in sub-section 1, above.

4. *Resources and capital finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this? Pension funds? Wealth funds? Citizen finance? Crowd funding? Would it require public-private collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs.*

- Suffers from the same financing barriers as across all GGR projects.
- Scepticism as to whether venture capital being able to get the mCDR BMA to be established and scale. Developers may move away from CDR if something doesn't change. Need to look at the quickest pathway to make a return on.
- Question of what happens to the biomass as well as the addition of biochar to building materials. IPCC would expect emissions factors rather than direct measurement.
- Reputational damage to the mCDR sector due to Planetary's St Ives project and the demise of Running Tide.

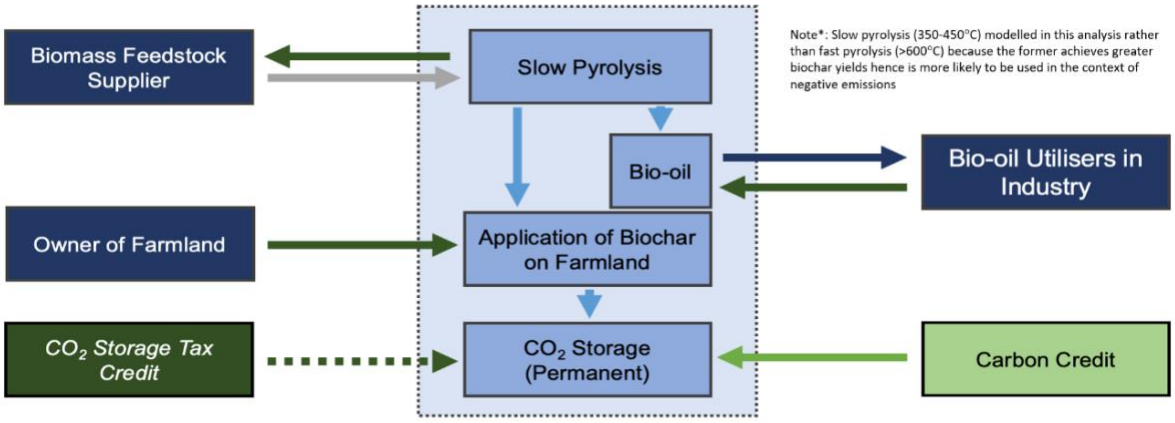
5. *Social acceptance and trust-building.* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

– Nil entries

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes.*

– Nil entries

3.7 Biochar



Key inputs: Biomass; energy for slow pyrolysis*

Internal processes: Slow pyrolysis; application of biochar on farmland

Key outputs: Biochar within which carbon is sequestered; bio-oil; syngas

Biochar business model: A carbon rich material created by pyrolysing biomass in the absence of oxygen. When applied to soil, it sequesters carbon and enhances soil health. By-products of the pyrolysis process include bio-oil and syngas, the former of which can be sold as a commodity.

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Implications

1. *Demand/Offtake Mechanisms:* *How would B2B and B2C demand be generated for this this archetype: Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would Quality Assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- Market transition - long term demand is needed: private sector - Microsoft: direct procurement interesting analogy, commitment for offtake, hence sets incentives for projects to be developed, government can do something similar via public procurement.
- Development of the market: look at players interested in carbon neutrality and set standards to allow engagement by corporates and therefore stimulate demand for deep decarbonisation and CDR projects/initiatives.
- Can generate a `Green Premium' for farmers in that they benefit from the credits. Develop In-setting mechanisms and accounting mechanisms: partnering with food producers (labels) looking for net zero or carbon neutrality: But need to Develop Carbon accounting methods so that both farmers and food producer (labels) don't get removal credits.
- MRV methods are available. Technology and digital MRV platforms are being set-up. The biochar sector is more developed relative to other GGR, but UK government endorsement, recognition and fungibility guidance is required.
- Still need to settle concerns regarding trustworthiness of biochar generated credits; the benchmarking risk is high. To address this there is a need to know *"how much and many years' worth of data is required to make establish trustworthy biochar CDR start up credible?".* The devil is likely in the detail: so methodology is the key accommodating the different phases of biochar production - pyrolysis, feedstock biomass, temperature.
- The GGR Business model is working but there is the need for additional support to make it viable.

2. *Regulation and Markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing: How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-Land-Use Master Planning and Co-ordination be facilitated?*

- Government should clarify biochar sector standards - as VCM goalpost keeps changing. What are the thresholds for inclusion as high integrity? Addressing the definition of waste vs utilization clarification needed as EA regulations prohibit the spreading of waste in the countryside even pyrolyzed waste.
- A demand signal could be provided by embedding a mandated e.g., the Renewable Transport Fuel Obligation. Need for sub-mandates to balance the markets desire to seek out cheapest options.
- Certainty in demand will be "game changing" for the sector in the short term. Even a small mandate such as inclusion into the ETS.
- Government should aim for *"Progress over perfection"* in in terms of incentives or policies for the GGR sector.
- Lack of incentives for small farmers to adopt Biochar and the need to incentivise farmers to collect long run data will be needed. The way that academia is funded questions the suitability to collate data on long term trends e.g., PhD student can only work for 3-4 years, but the time scale for soil study is 20 years. What comfort on level of extrapolation from datasets?
- Its going to take years to build the evidence which will make scaling the sector problematical. Government partnership overseeing GGR related activity was proposed: (1) Data collection/ facilitation for private actors; (2) GGR related investment, analysis; (3) Academia can create the framework to enable; (4) government to commission studies and data collections; and (5) Academia: studying and validation without compromising commercial sensitivity. **This would solve the Solving data problem and use this to design methodologies for MRV and govt has the ability to merge the gap.** Government can also subsidise companies to share data pool to converge methodologies. This is what happened in the fuel 5 sector. Can be done by 2030: 3 to 5 years trails for certainty to decades. Still tensions to resolve in that academics' incentive to publish paper vs commercial sensitivity of private information. Anticipated investment from govt £1.5 million over 3 years.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like Transport and Storage or Slow Pyrolysis plants that need to be upgraded?*

- Everyone is rushing to DACCS and BECCS as it is perceived that govt supports them. There is a lack of dialogue around the contribution that Biochar and ERW can make to UK CDR net zero portfolio.
- Considered that there is more activity in biochar relative to other GGR and that the technology is relatively mature.
- Biochar has MRV methodology - primary form academia.

4. *Resources and Capital Finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this: Pensions funds? Wealth funds? Citizen finance? Crowd funding? Would it require Public Private Collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs?*

– Nil Entries

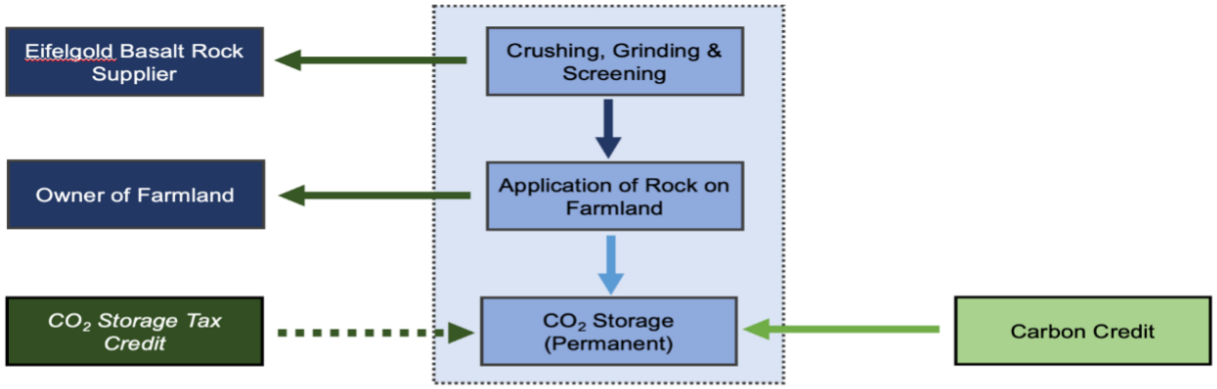
5. *Social Acceptance and Trust building* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

- Depending on feedstock that is used in biochar production social acceptance is fairly good. Perhaps biochar classification of feedstock should be put in place to allow for transparency.

6. *Freeform section.* *Any other points that the participants would like to raise? Plenary session notes.*

- There are differences between ERW and biochar: (1) Carbon credits are issued in tranches but volumes trend in opposite direction with biochar higher to start with and decaying and ERW low and then growing; though (2) co-benefits are aligned with an increase in pasture yield.
- The government needs to set minimum price for credits and act as a buyer of last resort as well as create a standard methodology. Then market will crowd in. You are never going to get the fungibility for different CDR credits with the voluntary market.
- The need to deal with downstream reversals as a threshold for inclusion, what level of certainty is required?
- You would need to be operating in high density e.g., in one river catchment to see significant change.
- Biochar is not incorporated into GGR BM funding in current Track 1 - can it be included in future rounds?
- There is increasing alignment on the permanence of biochar: It depends on feedstock and pyrolysis undertaken. What is the level about what proportion of biochar can be counted a carbon sequestered – also have to include environmental issues impacting sequestration efficacy.

3.8 Enhanced Rock Weathering



Key inputs: Basalt rock; arable land

Internal processes: Spreading rock; storage of CO_2 in stable mineral forms

Key outputs: Co-benefits (improved soil quality and crop yields) and CO_2 sequestered in soil

ERW business model: Accelerates the natural process of mineral carbonisation whereby CO_2 is removed from the atmosphere through the weathering of silicate and carbonate rocks broken into small particles and applied on soils, coasts or oceans.

Implications

1. *Demand/Offtake Mechanisms:* *How would B2B and B2C demand be generated for this this archetype: Who would pay, how and why? (1) What would the political acceptability of this be? (2) How would it impact competitiveness and economic growth? What kinds of counterparty would benefit from this archetype? How would Quality Assurance around negative emissions generation be realized (MRV) and the need for fungibility to be facilitated? What are the barriers to making the offtake for this to work?*

- Price! That's the biggest blocker to project finance across all CDR types. It's unclear what the incentive system for companies in the UK is going to be to buy carbon credits, without a mandated Net Zero timeline. At the moment, drivers are generally intrinsic *e.g.,* Microsoft's commitments, driven by the knowledge that the company's energy requirements are ballooning and could impact their social license. Extrinsic drivers linked to ESG reporting are less powerful and emissions are only a small part of that reporting.

- Who would pay is also important. The ultimate cost of CDR to bring companies to Net Zero will be borne by the customer and the implications that has at a micro and macro-economic level. Possible emphasis to importance of in-chain removals/insetting: for example, where a concrete producer is able to incorporate CO_2 storage into a product or a farmer conducts ERW for a carbon neutral crop. Today, there is no mechanism for this to be accounted for.
- The political acceptability of any measure will be directly linked to the micro and macro-economic impacts of additional costs. For ERW, any incentives for landowners to adopt the practice must stand up in the context of recent changes to farm subsidies; not all farms will be able to access the right rock due to costs of haulage, those in the NE UK and Scotland may be seen to benefit unfairly. That will also be true for biochar - feedstock will be more available in some regions than others.
- Finally, none of this makes any sense in an international context. It's not credible that there will be a flight to quality in the carbon markets, somehow elevating the UK as a preferred supplier because of incredibly stringent MRV requirements. There is no evidence of this to date in the market - so alignment with the EU ETS, at the very least, looks essential.
- MRV for ERW is anticipated to align in the next 2 3 years but this will require future demand commitment aligned with government standards.
- Biochar and ERW demand in developed market is geographically segmented: with increasing demand of biochar/ ERW being restricted to that produced in a certain geography.
- Government to take technical risk. Technical risk is defined as being a situation that if suddenly new research shows new timeframe, new absorption capacity, once govt backed methodology is in place and the credits are sold, govt takes this risk as to implications on baseline on project viability. Is there a role for insurance here?

2. *Regulation and Markets:* *Are there policies, regulations and standards acting as barriers? What policies, regulations and standards need changing: How would that impact current policies and market design? What incentives are needed? How are counterparties/consumers protected? What are the institutional systems that need to be put in place? How would infrastructure-Land-Use Master Planning and Co-ordination be facilitated?*

- Possibility of ex-post financing, therefore developing future reliable markets is important to allow this opportunity to be realised.
- The establishment of a Two-way Contract for Difference (CfD) whereby: there is a different reference price for different technology credits; 20 years for CfD instead of maximum 15 years - the duration of CfD is very important for ERW, as the sequestration takes longer, and credits generation will be more likely ex-post and/or in phases.
- On the ERW methodology required to be developed – this is similar to the situation as biochar: (1) can the government step in to increase the amount as per the Carbon Removals and Carbon Farming in the EU; (2) procure in volume across a range of ERW value chains; and (3) Start to define the high integrity ERW portfolios.
- Other possible govt signal/ mechanism to increase trust for the market: (1) Government as a backstop purchaser: small amount for signal to derisk projects; (2) Establish public sector UK specific SBTi type organization where large UK economic sector are required to report their Net Zero commitment and role of GGR and CDR within that similar to EU initiatives; and (3) Public Private Collaborations between government and private sector to derisk projects and crowd in private investment. Items 2 and 3 generated broad consensus in the group.
- “Subsequent demand waves will not happen unless companies are made to buy” and Transition from voluntary to compliance is tricky.
- It was emphasized that UK Government role is considered to be that of a market facilitator rather than driver. Any direct demand signal could be perceived as picking winners which falls short of the liberal market approach that the UK has to Net Zero. It will be problematic for the government to commit to owning parts of a GGR project.

- Not enough incentives for farmers to adopt and/or participate in ERW projects - even though there are substantive co-benefits for the farming sector.
- Corporate demand for the UK removals is soft. British Airways is the biggest purchaser. There is the need for greater incentives for corporates to buy GGR.
- Issues relevant to data collection are similar to those for biochar – see above.
- Environmental regulations aren't sufficiently up to date to cope with either ERW or biochar deployments. Likely also true of planning consents and environmental monitoring for other engineered removals. Recognition that there is likely good reason for this. What isn't fit for purpose is the speed at which the regulator (EA) is able to engage on the issue. It took Undo a year to agree that crushed rock fines are not a waste whereas SEPA took a month.

3. *Technological requirements:* *What technology needs to change, develop, or get cheaper? Which existing development may render this irrelevant? Are there enabling technologies like Transport and Storage or Slow Pyrolysis plants that need to be upgraded?*

- Removal timeline for ERW is long. MRV protocols are still at an early phase of development.
- On the ERW developer side, there is a need to prove a route to high quality, verified credits through the VCM in a financially viable manner. Then...we need policy which accepts the standard on the VCM is high enough for the compliance market.

4. *Resources and Capital Finance:* *Is this archetype capital-intensive? Does it need lots of small investments or very few big ones? Who is likely to finance this: Pensions funds? Wealth funds? Citizen finance? Crowd funding? Would it require Public Private Collaboration to crowd in private funds? What would allow the archetype to be self-sustaining (CCUS Vision) by 2030? Consider natural resources, water needs, fuel import needs?*

- ERW projects fall into the commercial valley of death in terms of capital scale needed of £10M. The technology is out of the VC bracket but too new and too small for big institutional money.
- Upfront investment in feedstock with (in the UK) up to 20 years return means that the capital needs to be patient.

5. *Social Acceptance and Trust building* *How socially acceptable is this CDR value chain? What would be needed to make it acceptable to local communities and for trust to be generated by from fenceline communities, local communities and regional and national advocacy organizations.*

- ERW is considered to have low barriers to social acceptance.

6. Freeform section. *Any other points that the participants would like to raise? Plenary session notes.*

- Defining threshold of inclusion in ERW projects and their inclusion in compliance markets: if the UK government establishes precedent perhaps other countries would follow.
- Just standards not enough, demand stimulus needed e.g., UK Government defining corporate in setting standards and carbon neutrality beyond UK ETS
- Market signal outside of procurement as an option: on top of standards
- The ERW sector has yet to have a complete understanding of systemic implications of ERW projects and their trade-offs e.g., downstream, ocean, river effects etc. Innovation processes needs to also be encouraged to explore these uncertainties - Cascade protocols.
- Debate between innovation and certainty.
- Mechanisms to lower cost of capital.

4. Collective success: the single most important intervention that needs to take place in 2026

The final exercise that participants undertook was to consider the characteristics of the nascent CDR sector – as outlined in Annex 1. The following question was then posed: That if there was a drive for collective success within the UK CDR sector: (1) **WHAT** do you, as a representative from the CDR sector that you operate in, consider to be the single most important thing that needs to happen in 2026? (2) Consider **WHY** is it so time critical? And (3) And as relevant **HOW** might that `important thing' be addressed?

The feedback is summarized as follows for respective tables:

DACC cohort
• ***WHAT*** - There is a need to demonstrate the ability to geologically sequester 350 $ktCO_2$ in 2026 from an operational DAC facility at an economic price point. ***WHY*** - This will allow a clear demonstration that DAC can work effectively at scale. This is important to generate confidence for investors. Our organization has sufficient capital for the first and second large scale DAC facility with co-investors such as Blackrock - but there is a need to shore up investors willingness to allocate sufficient capital to allow a pipeline of projects getting past FID in turn allowing a pipeline of projects and learning by doing effects to be realised and the technology to go down the cost curve.
• ***WHAT*** - The introduction of CDR offtake policy/regulatory mechanism by a major economy. ***WHY*** - there is a need for a clear mechanism that will act as a demand signal to the sector to address offtake risk. This is important to generate confidence for investors and allow the pricing of project finance capital and therefore the learning effects to take place as per above. These issues will have implications as to the ability for the sector to develop momentum commensurate with the global scale that the CDR sector needs to realise.
• ***WHAT*** **-** Generating a globally accepted MRV standard. ***WHY*** - it would reduce transaction costs (up to 50% of credit generation[8]). Uncertainty about future government regulation and a lack of protocol standardisation are major barriers to assessing and reducing the cost of MRV. Lower costs would also allow greater access by actors from the global south to establish a more liquid and broader based market.
• ***WHAT*** - a clear demand signal underpinned by policy/regulation. ***WHY*** - lots of start-ups coming through the technology push phase of CDR policy interventions in 2024-25. There will not be progression of these technologies if there is a constant shift in demand curve further into the future. It is starting to `spook' people and undermine confidence in the sector as a viable investment proposition. This is already happening with the Venture Capital markets. The CDR project development sector cannot get to off-balance sheet finance into project finance until a clear demand curve is established.
• ***WHAT*** – a clear roadmap on how the CDR sector is going to be established, develop and scale – which will compel market actors to engage. WHY – in the absence of clear signal a behavioral psych of *`why would we invest this year if a project is 6 years out or the need to engage is as yet unclear.'*
BECCS Cohort *(Note. that at this stage of the workshop only a handful of the table members were left)*
• ***WHAT*** **-** A robust, transparent MRV process which can be applied internationally. ***WHY*** - reducing transaction costs and improving fungibility for removal approaches.
Biochar and Enhanced Rock Weathering Cohort
• ***WHAT*** - Mechanisms by which long term off-take contracts for projects that generate verified carbon credits are realised. ***WHY*** - to allow the project finance to be developed within the market.
• ***WHAT*** - a large-scale demand signal to be established. ***WHY*** – The Advanced Market Commitments are no longer enough to pull projects through and introduction to Emissions Trading Schemes is insufficient and will be introduced too late.
• ***WHAT*** - a roadmap of demand side policies that encourage high integrity credits to be generated. ***WHY*** - Investors will be able to price capital risk in CDR projects and buyers will be aware of high integrity CDR standards.
Nature-based solutions and marine CDR cohort
• ***WHAT*** - rationalization of MRV standards/methodologies. ***WHY*** - results in high transaction costs in market and reduced potential for project developers to invest profits into future project development
• ***WHAT*** - Have the government step in as a buyer of last resort. ***WHY*** **-** to ensure that offtake risk is addressed on CDR projects and therefore the pricing of risk capital for supply side projects.
• ***WHAT*** **-** Community acceptance. ***WHY*** - address reputational damage caused by previous projects which might have spillovers on the sector.

[8] Leo Mercer et al Oct 2024. Towards improved cost estimates for monitoring, reporting and verification of carbon dioxide removal. Grantham Institute for Climate Change and the Environment London School of Economics

- ***WHAT –*** certainty of high-quality demand to introduced by mandating companies rather than their ESG claims. ***WHY*** - to ensure that offtake risk is addressed on CDR projects and therefore the pricing of risk capital for supply side projects.
- ***WHAT -*** mandated transparency and data sharing of carbon and environmental monitoring of whole lifecycle. ***WHY*** - Build trust, credibility in sector and allow market architecture to be established and function.

An additional question was posed in a similar vein to that for the above exercise by a workshop attendee: **'What can government do to provide market signal beyond setting methodologies - i.e., to increase the level of purchasing, improve the diversity of those procuring credits':**

- Set a minimum price for a credit within which a standard methodology will become the *de facto* market standard. Government role at the beginning would be procuring, and then private market will be crowded in. The present reliance on good actors is not enough to price capital and mobilise project finance.
- Stop focus on VCM and focus on compliance markets.
- Long-term CDR value chain monitoring which takes years. Trialling has taken place in labs and fields, not robust enough. Tension with need to establish a market whilst research is being undertaken.
- There is a need to balance between quality and volume. Setting different carbon prices depending on certainty, permanence, co-benefits – or deal with co-benefits separately through regulation or value stacking.
- Understand baseline requirements. Large scale ERW projects will result in 10s of 1,000 tonnes of rock spread over river catchments effects. It is problematical to untangle carbon sink signal from ERW from other agricultural practices and environmental processes.
- Government to act as a backstop for technical risk and setting *de facto* standards to reduce the diversification of standards.
- Corporates looking to claim neutrality. Government needs to set carbon neutrality standards to give corporates the confidence to invest in neutrality initiatives which will generate CDR demand. It might also lower WACCs for projects and the government might encourage capital provision by, for example, lowering capital requirements for banks if they are financing decarbonisation projects/initiatives.

5. Next steps: how this intersects with other Ecosystem 26+ workshops and GGR-D Programme insights

The structure and the analysis of the UK Ecosystem 26+ workshop series has generated much insight and allowed further fidelity as to what the UK CDR actors are seeking to transition to the next stage of UK CDR sector establishment, development and scaling. It is clear that this requires an urgent, deliberate and strategic shaping set of government interventions which will be problematical for the UK to undertake in the face of fiscal constraints and the liberalised market approach which requires the need to address market failures whilst not be seen to overly intervene in the market.

It is likely that It will allow prioritization and coverage of the most salient issues from the GGR-D programme to be brought into the identified needs of the UK CDR sector which will also be problematical to shape with the end of the programme scheduled in 2026.

The CO_2RE Business Model WS will seek to conduct the US and EU round of workshops. Following these insights there will be the possibility of yet greater fidelity to be realised with regards to each BMA needs in further workshops with market participants, policy makers and the finance sector on a CDR value chain by value chain basis. This would be augmented with an exploratory exercise to quantify the possible revenues that each BMA might realise whereby the interventions from these exercises will allow the generation metrics for stress testing the different archetypes against system scenarios such as the National Grid Future Energy Scenario or other such policy relevant pathways.[14]

Annexes:

1: Characteristics of the CDR sector – implications on the framing of the workshop, theoretical underpinnings and subsequent analysis.

2: Workshop process.

3: Participant annotated business model canvases.

4: References.

Annex 1: Characteristics of the carbon dioxide removal sector – implications for the framing of the workshop, theoretical underpinnings and subsequent analysis

The nascent CDR sector is characterised by several factors which has material implications for its development by policy makers, market participants and stakeholders alike: (1) First, the political economy being manifest from the retrofitting of CDR value chains throughout the fabric of capital-intensive economies as well as culturally sensitive and historic landscapes for which public acceptance is largely untested;[15] (2) second, the space is market-led - the market is running head of the ability for regulation, policy and market frameworks to be emplaced by governments and for academia to assess what is best practice and compliant with a long-term sustainable and equitable net zero trajectory;[16] (3) there is also lack of analysis as to role of strategic investment on first movers and incumbents to allocate endogenous resources and invest in CDR value chain development ;[17] (4) the CDR sector is technologically highly heterogeneous, fragmented and fraught with information asymmetries[18] and deep uncertainty[19] as to how the CDR technology portfolio will develop and what factors will be significant in driving the sectors establishment, development and scaling; (5) Academia, funders and participants have little systemic visibility of research, project activities and investment programmes to enable whole of system insights required to design systemic interventions.[20]

Traditional whole systems cost optimised policy decision support tools are unable to manage the extent of complexity inherent to the nascent CDR sector nor the impact of policy interventions.[21] This makes policy design and targeting specific interventions to generate an economically functioning and self-realising CDR sector highly problematical. Even more so within liberalised markets such as those that characterise the nations pioneering CDR sector development - the US, UK and EU – whereby policy is reluctant to be seen to be '*picking winners'*. The workshop approach in the Ecosystem 26+ workshop series sought to bridge this capability gap. It addresses deep uncertainty, the fact market actors lead innovation in the sector and the lack of systemic perspective by the co-production of challenges and opportunities through engagement with market actors. These in turn will be used to understand and identify the appropriate targeted innovation policy instruments such as fiscal, regulatory, or statutory interventions required to incentivise actors along the value chains to realise economically functioning UK CDR value chains. Especially relevant will be targeting interventions to motivate first mover and incumbent market actors who through their financial, physical, human, organisational, informational, and relational resources can be a barrier to systems change; this is all the more important with a sector which seeks to retrofit value chains within existing economic sectors.

As a function of the CDR sector characteristics we avoid neo-classical economic assumptions that the resources of actors/firms are mobile, that their foresight is perfect and that they are utility maximisers. Rather we will take insights from both evolutionary and institutional economics which contest these assumptions. Using a broad Multi Level Perspective, ***we will classify CDR UK first movers as part of the 'Regime' of energy transitions - see figure 1 in main text***. A more or less stable set of institutions, technologies, user practices and business models exist as a legacy of the existing system state.[22] The CDR market actors will have to accommodate the existing system state whilst seeking to realise the net zero transition. Regimes can be disrupted from within, from below by niches, or from above by landscape factors beyond the system. The CDR market actors are always under change pressures within liberal democratic capitalism, where the forces of competition are designed into markets for energy and other pipe and cable utilities. Thus, we can expect CDR first movers to be under constant pressure; both to adapt to societal demands for market transitions, and to survive under the market's own internal dynamics. This is particularly salient to a sector seeking to establish itself such as a CDR sector with the characteristics articulated in the opening paragraph[Error! Bookmark not defined.].

The socio-technical transitions (STS) field broadly recognises "markets" as a key element in socio-technical regimes. The other elements are industrial networks, techno-scientific knowledge, user practices, technology,

infrastructure and cultural or symbolic meaning - see Figure 1. These system elements have been simplified by Foxon,23 who argued each element co-evolves with the others, iteratively shaping different transition pathways in a manner which will lock in and lock-out other potential pathways. The following is relevant to the analysis conducted on the workshop series outputs:

- For the first workshop on 12th June 2024, the co-evolutionary approach applied an analytical framework with five discrete elements: ecosystems, institutions, technologies, user practices and business strategies. Using this co-evolutionary framework discrete elements of the system can be isolated and assessed in depth without losing a broader systems perspective e.g., those exploring the role of institutions have shown how institutional traditions and systems of finance affect pathways for energy transitions.[24] In the case of the work on CDR, user practices were substituted with demand creation and ecosystem has been augmented with policy ecosystem.
- This framing is especially important for a nascent sector, such as the UK CDR sector with the characteristics cited above. Landscape actors, such as policy makers, will have to accommodate the pressures that they apply and how they shape path dependence and potentially lock out optionality for potential alternative CDR pathway development. Regime and niche actors will then have to prioritise their limited resources and capacity to respond to these pressures and seek to reshape within their levels - taking advantage of opportunities provided – whilst also anticipating the implications of future pressures and dynamics created by the emergent pathway trajectory. These generated an outside looking in perspective from the first two exercises in the Ecosystem 26+ series.
- The third workshop then used the kernel of insight as to different business models operating within the present regime level from and inside looking in perspective. Thereby allowing the contextualisation of the forces that market actors and participants identified in the first two exercises.
- These will be built on in the subsequent Ecosystem 26+ engagements in the US and Europe – see Annex 2, below.

Annex 2: Workshop series and process

The aim of the Ecosystem 26+ workshop series has been to explore what is next for the CDR within the 2026+ UK CDR ecosystem via participatory stakeholder mapping exercise. The objectives of the series are to address the following questions:

- What are the challenges and priority needs for market actors in the UK GR sector post 2026 to 2050?
- What might the 2026 - 2035 institutional, organisational and policy ecosystem look like to address these needs?
- How can better systemic visibility be provided for actors in the UK GR ecosystem post 2026?

The last objective has been removed as though insight as to how this might be undertaken was alluded to in the first workshop on 12th June, this has indicated that this topic warrants a strand of workshops in itself.

The different phases of the workshop series include, at the time of writing, the following stages:

1. 19 market actors to participate in a participatory exercise to generate insight as to what interventions need to be realised for the 2026+ UK CDR ecosystem on 12th June 2024.
2. 5 policymakers, ENGOs and standard setters reviewing and commenting on the outputs of the first workshop.
3. This deliberative workshop as held on 28th January 2025;
4. A CDR open data workshop to be held in Stanford on 13th March 2025 led by David Hayes;9
5. A workshop to be held in Stanford on 18th and/or 19th March 2025 with US start-ups and market actors;
6. A Californian government roundtable to be held in Sacramento on 21st March 2025; and
7. An EU workshop to be held in Brussels/Berlin in May 2025 with EU start-ups and market actors exploring the implications of national agendas on EU CDR policy.

The deliberative workshop on the 28th January convened 24 market participants, policymakers and stakeholders across the UK CDR sector, including:

- Bethany Garry, DfT
- Duncan Preston, Mission Zero
- Teresa Geruson, AirHive
- Jess Poole, Equinor
- Kate Ronayne, BGF
- Diwita Mosali, GFI
- Sophia Lewis, Defra
- Tom Watson, Kana
- Tom Newton, Seafields
- Jo House, LCA – Bristol
- Justin Reynolds, Intl Investment Assets
- Chris Walters, CIP - Biochar
- Sam Karslake, Committee on Climate Change
- Steve Kelly, 1PointFive
- Bryony Livesey, Industrial Decarbonisation Challenge
- Jessica Mackenzie, DESNZ
- Natasha Martirosian, Bristol
- Louis Hennequin, Bellona
- Kash Burchett, HSBC
- Lewis Rodger, Drax
- Cameron Henderson, DESNZ
- Matt Isaacs, Counteract
- James Townsend, Carbon Gap
- Ben Westcott, Undo

[9] https://law.stanford.edu/david-j-hayes/

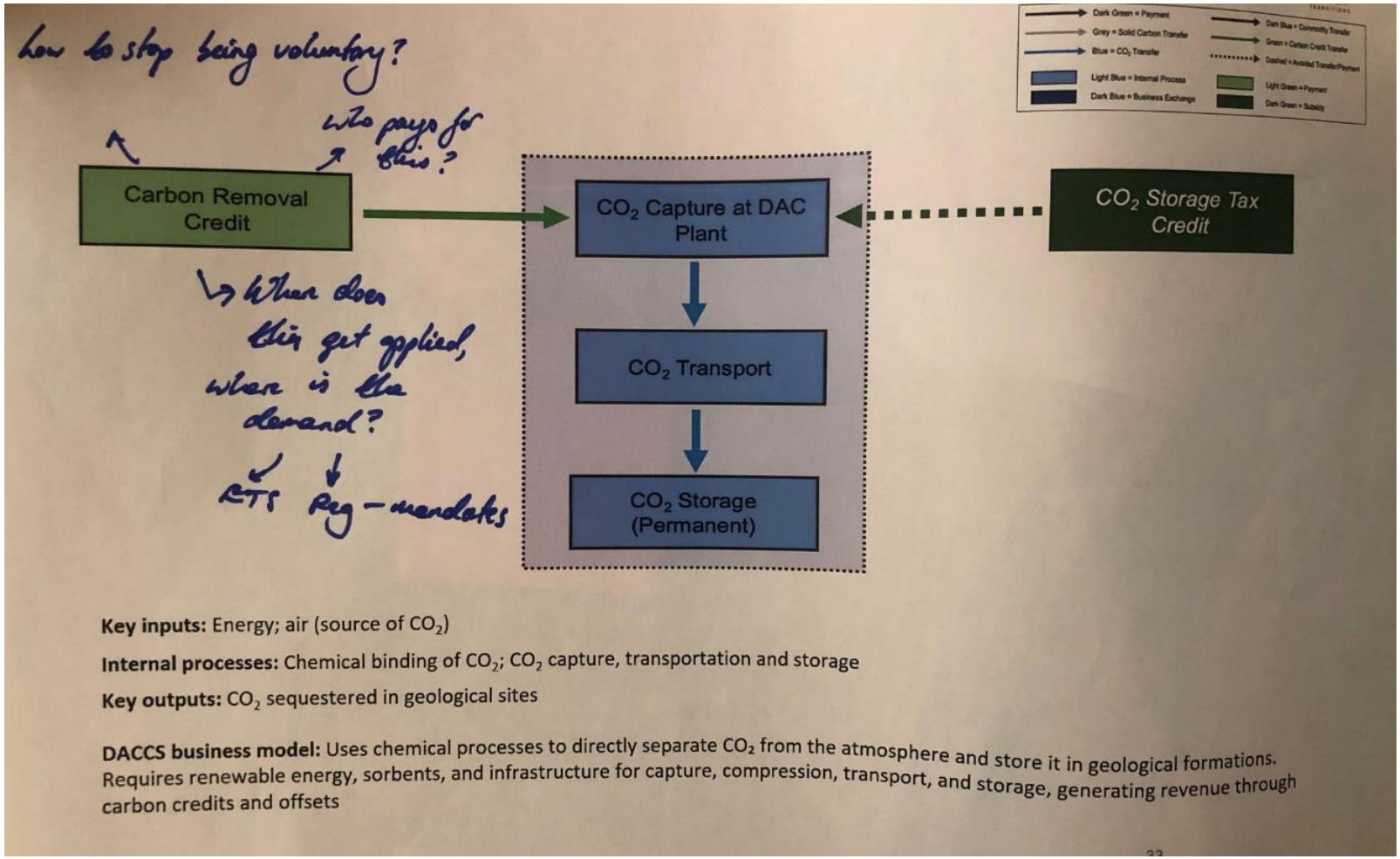
Discussion and generation of insights was primarily completed in breakout groups of 6-8 participants, initially split by technology focus: BECCS, DACS, Non-CCS enabled CDR (Biochar and Enhanced Rock Weathering) and Nature based solutions including marine CDR.

The exercises undertaken were as follows:

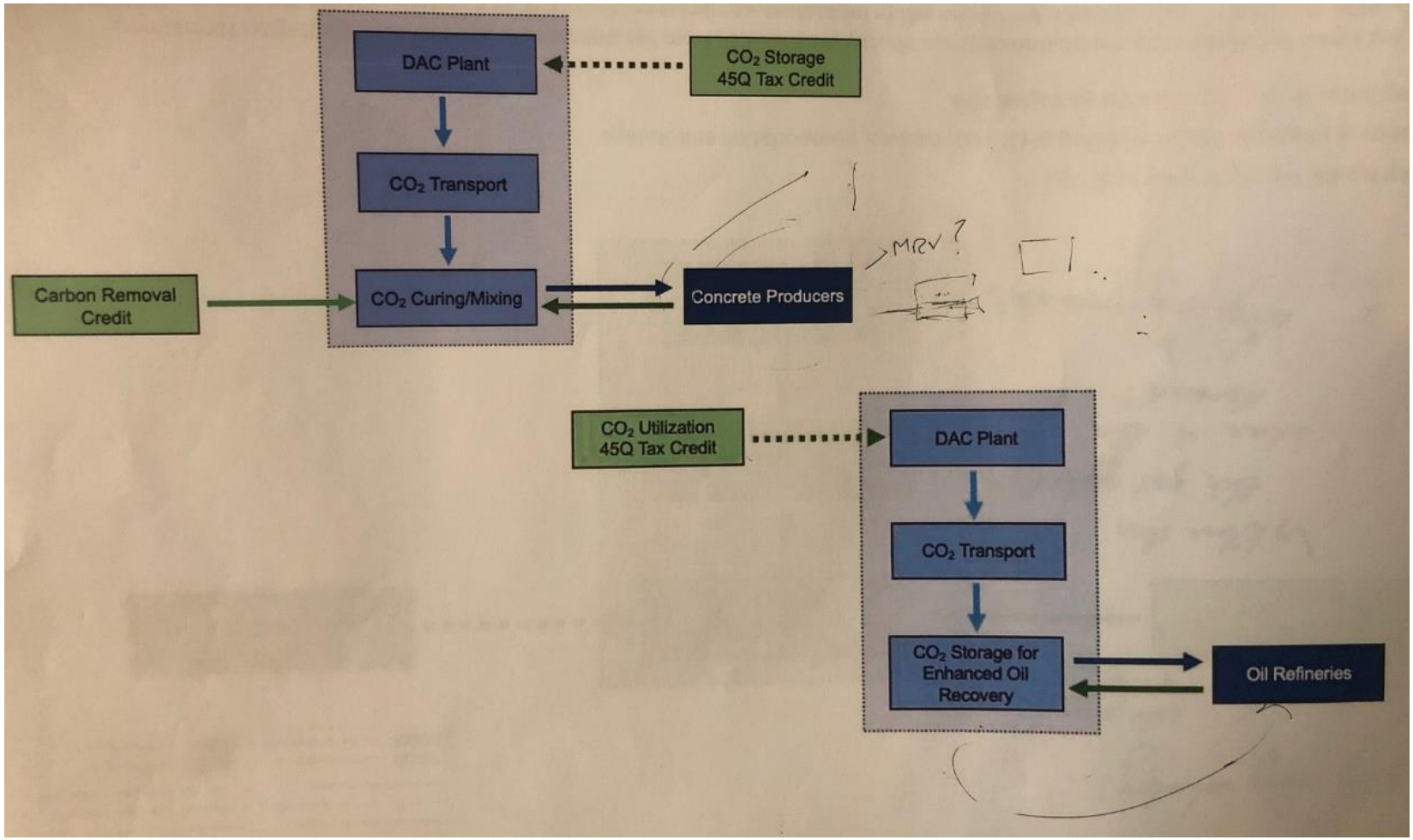
- Business model insight development Session 1 – In individual groups followed by a plenary briefing and cross workshop Input.
- Business model insight development Session 2 – In individual groups followed by a plenary briefing and cross workshop Input.
- A reflection session on new insight generated by the session a 'what needs to happen in 2026 for the collective success of the UK CDR sector with close-out and next steps

Annex 3: Participant annotated business model canvases

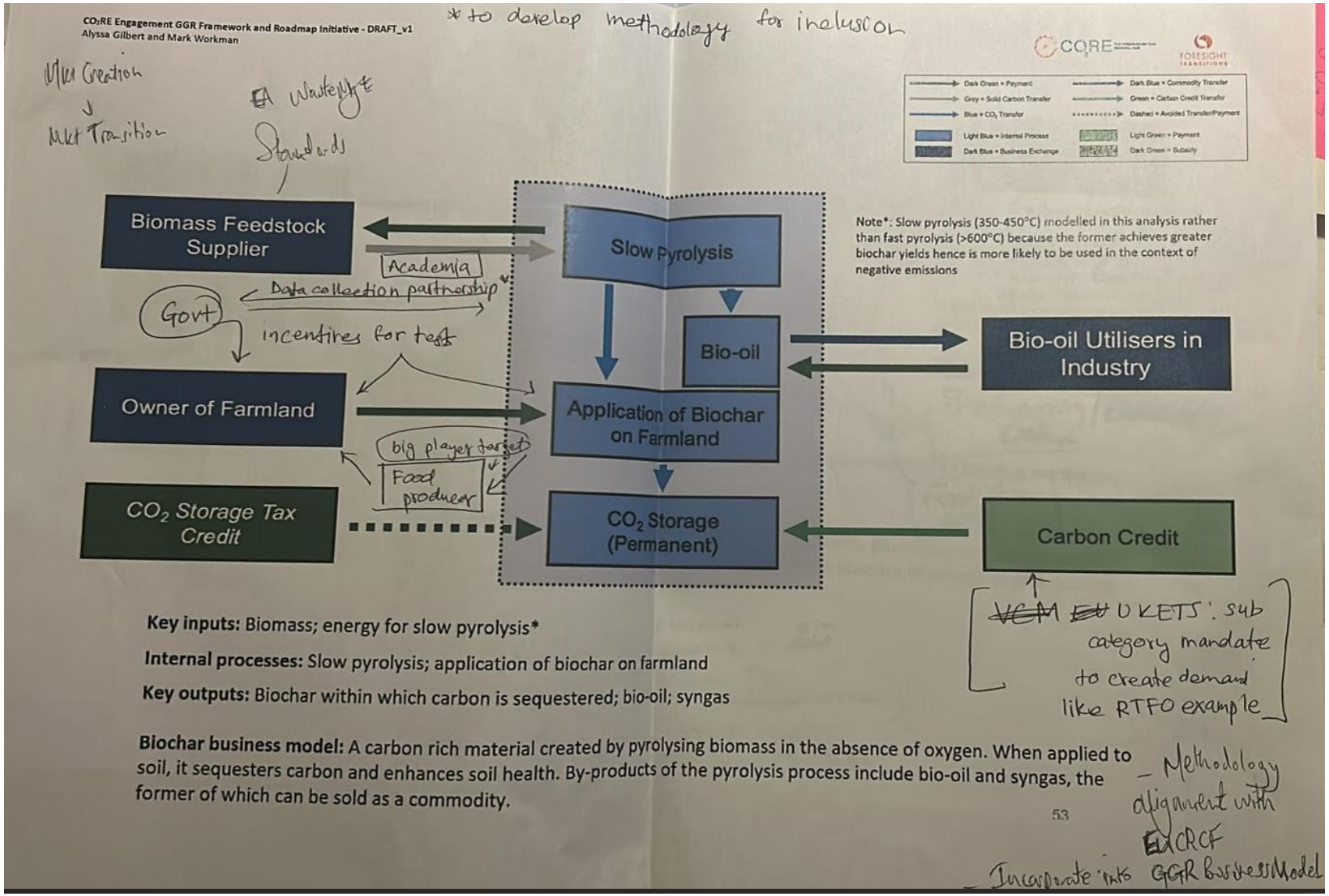
As part of the business model canvas interrogation workshop participants were able to write directly into the canvases that they were presented to work on in respective groups. Below are those BMA which participants placed notes. No notes were made for the BECCS business models.



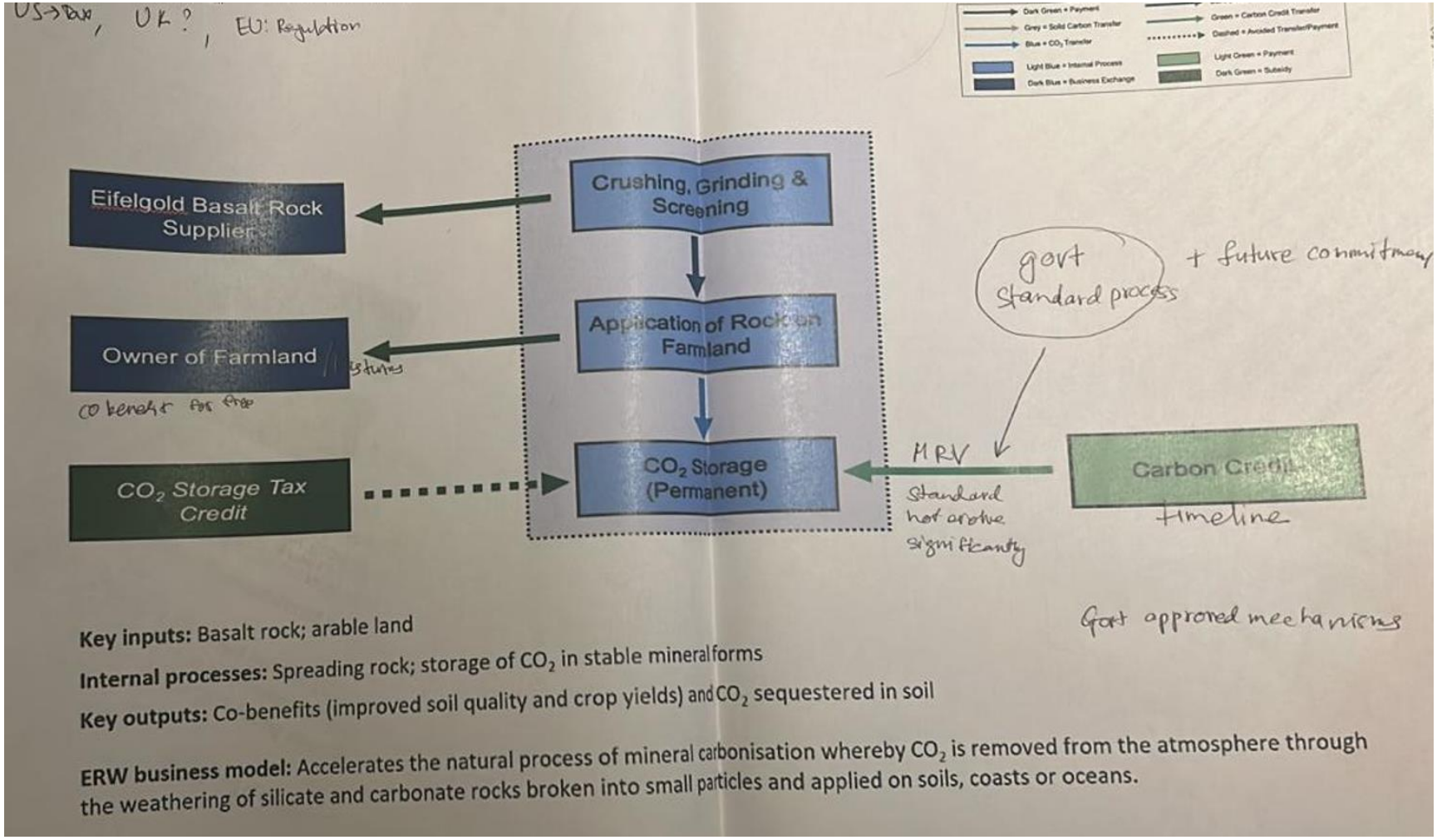
DACC - Pure play



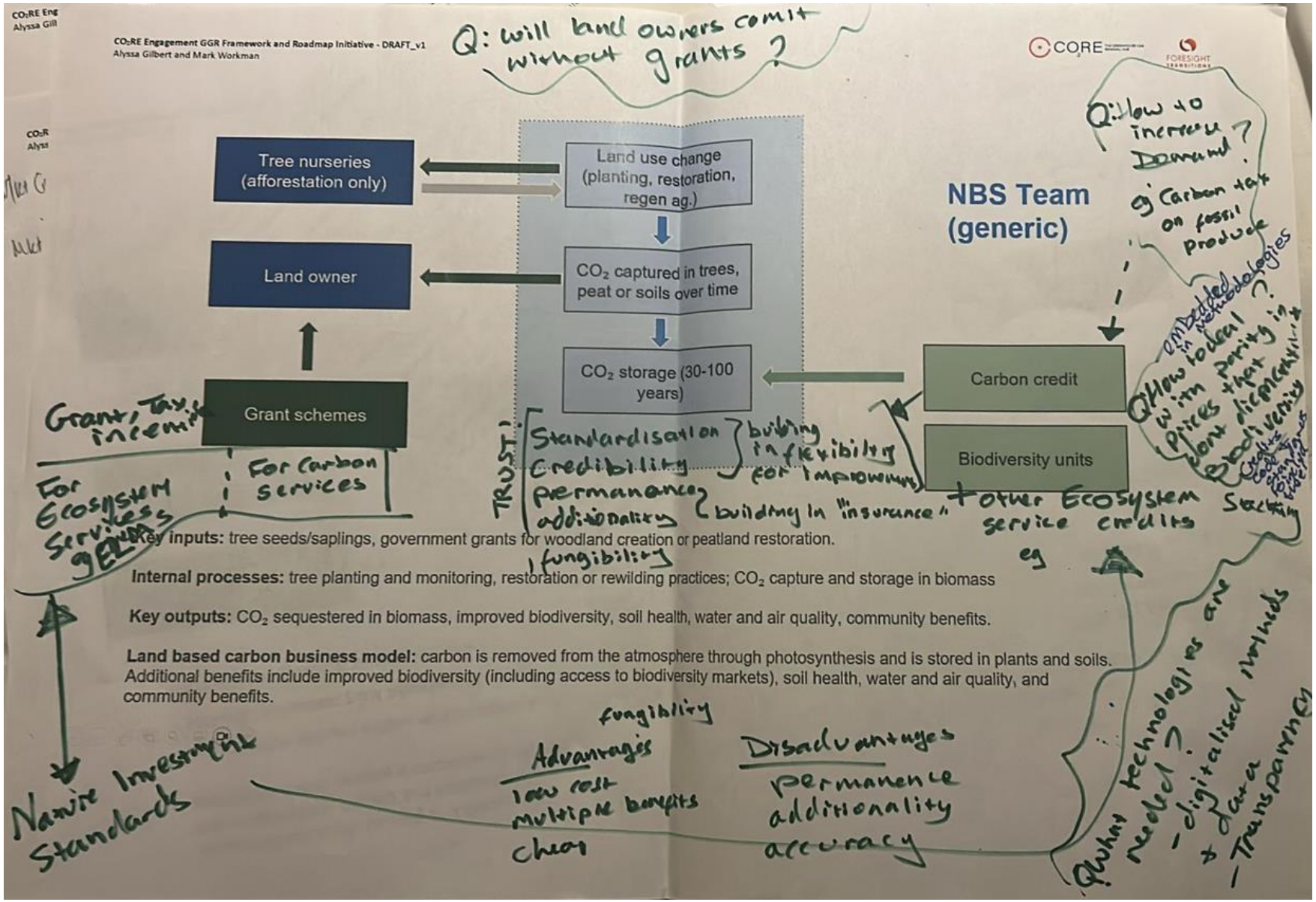
DACC – CCUS: enhanced oil recovery and CO_2 enriched concrete


CO2RE Engagement GGR Framework and Roadmap Initiative - DRAFT_v1
Alyssa Gilbert and Mark Workman
* to develop methodology for inclusion
Mkt Creation
Mkt Transition
Standards
Biomass Feedstock Supplier
Academia
Data collection partnership
Govt
incentives for test
Owner of Farmland
big player target
Food producer
CO2 Storage Tax Credit
Slow Pyrolysis
Bio-oil
Application of Biochar on Farmland
CO2 Storage (Permanent)
Bio-oil Utilisers in Industry
Carbon Credit
Note*: Slow pyrolysis (350-450°C) modelled in this analysis rather than fast pyrolysis (>600°C) because the former achieves greater biochar yields hence is more likely to be used in the context of negative emissions
Key inputs: Biomass; energy for slow pyrolysis*
Internal processes: Slow pyrolysis; application of biochar on farmland
Key outputs: Biochar within which carbon is sequestered; bio-oil; syngas
Biochar business model: A carbon rich material created by pyrolysing biomass in the absence of oxygen. When applied to soil, it sequesters carbon and enhances soil health. By-products of the pyrolysis process include bio-oil and syngas, the former of which can be sold as a commodity.
53
UKETS: sub category mandate to create demand like RTFO example
Methodology alignment with EU CRCF
Incorporate into GGR Business Model

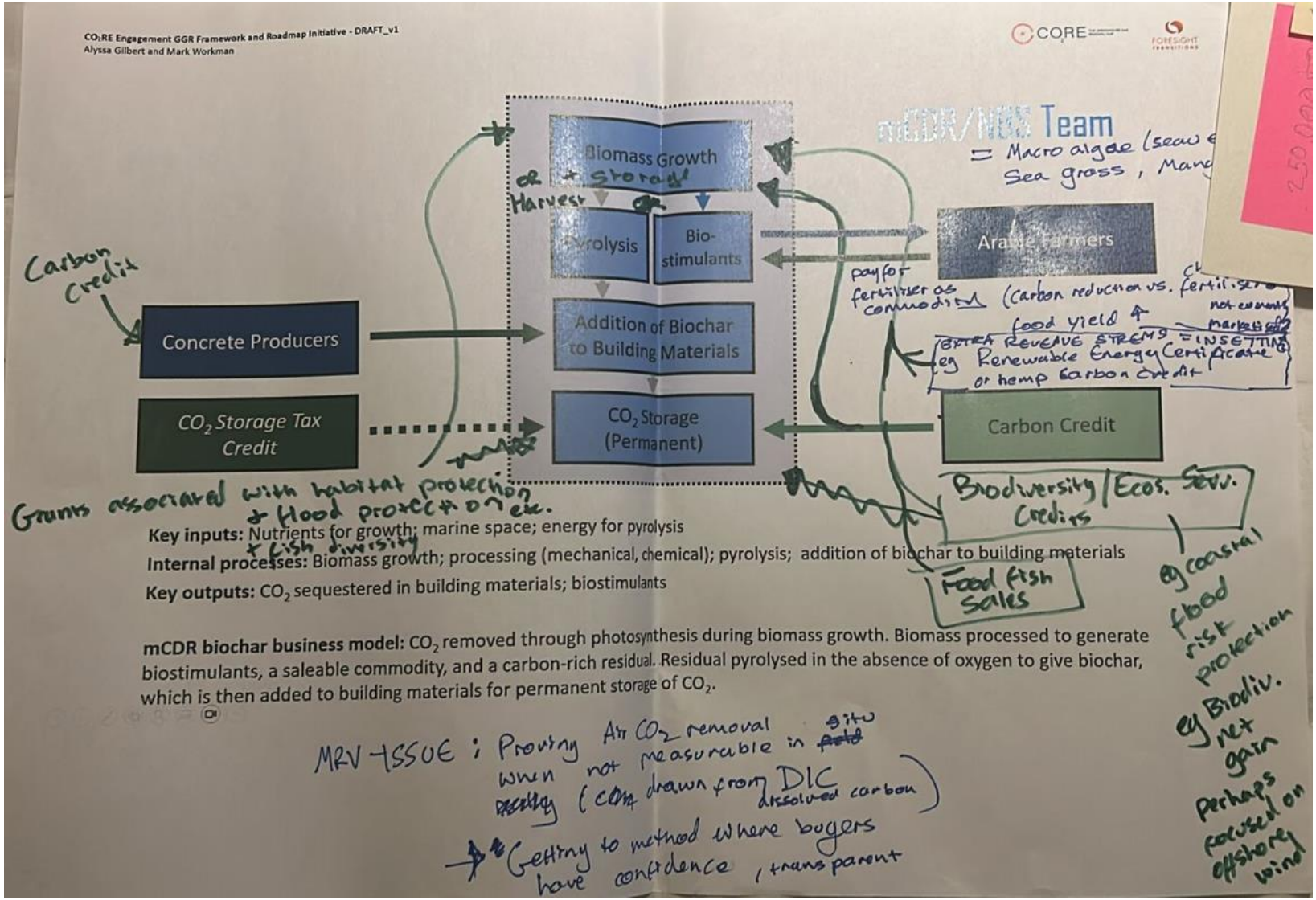
Biochar



Enhanced rock weathering



Nature-based solutions play



Marine CDR biochar play

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