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

Business model archetype needs mapping 13th to 21st March 2025

Report summarising engagement activities undertaken under the auspices of CO2RE for the following: (i) 'Building An Accessible and Robust Greenhouse Gas Data System to Inform and Drive Decarbonization' on the Stanford University Campus on 13th March; (ii) Stanford Sustainability Accelerator Showcase finalist interviews on the Stanford University Campus, 18th and 19th March; and (iii) Californian, Canadian and UK CDR Collaboration Opportunities Mapping Roundtable in Sacramento on 21st March 2025.

By Natasha Martirosian, Miriam Aczel and Mark Workman*

*Corresponding Author mark.workman07@imperial.ac.uk

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 recognised 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.

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. The question for UK policy-makers is therefore how to capture these spill-over effects when they materialise and how to collaborate with US market makers to track developments so as to design timely and effective policy when they are opportune to capture from the US.[i] As a function of this, the CO$_2$RE Ecosystem 26+ project sought to explore how the proposed US interventions were being operationalised. This would then allow analysis as to how they might relate to and interact with other international CDR sector initiatives – specifically those taking place in the UK and EU.

This report summarises the insights that have been developed over a trio of engagements with US CDR based initiatives as follows: (1) data accessibility to establish market frameworks for greenhouse gases; (2) CDR start-ups from the Stanford Greenhouse Gas Accelerator, developers and finance specialists; and (3) a roundtable held at Sacramento with Californian government, ENGOs, Canadian think tanks, UK developers etc. The high-level findings from respective engagements were as follows:

1. 'Building an Accessible and Robust Greenhouse Gas Data System to Inform and Drive Decarbonization' sought to building investor-grade climate data systems rooted in transparency and open standards. The following is relevant:

- The US has substantive experience, capacity and legacy datasets/experience to develop a systemic GHG data infrastructure in order to build transparent investor-grade climate data systems. However, US initiatives to drive the agenda forwards do not account for that substantive and material activities that are taking place outside of US including in Europe and UK both at a policy, investor and private sector level. There are initiatives in the UK that are working with investors rather than project developers to work backwards to what data is needed to get investors into natural capital assets, CDR and GHG emissions management which would be invaluable to US initiatives. The UK/EU would also learn from the US.
- There are huge data gaps across jurisdictions for different components of GHG data infrastructure development as well as asymmetries as to visibility. Some of this data is context-specific but needs to be aggregated to allow insight as to CDR technology value chain efficiency. Other data is essential to allow market infrastructure to be realised e.g., to raise, deploy and manage a portfolio of CDR projects. This latter data will be fundamental as to the ability for an efficient international market to function. Furthermore, this latter data, in tandem with the context- and project-specific data, will be fundamental to allow international and national policies to be enacted to facilitate market interventions by policy-makers. A three data-layer perspective is developed as a heuristic to shape the development of transparent investor-grade climate data systems and realising a multi-trillion-dollar sector.
- There would be substantial benefits from working across geographical jurisdictions on data-sharing initiatives across all three data layers – i.e., a project-level life cycle assessment (LCA) data layer; at the intermediate market infrastructure structuring layer; and at the highest level: the international and national policy market.

2. Stanford Sustainability Accelerator Showcase finalists CDR business model insight. CO$_2$RE researchers interviewed 7 of the 18 greenhouse gas removal (GHG-R) Stanford finalists. Though another 4 were approached their technology had not advanced sufficiently *'out of the lab'* to even start to consider their business model design and commercial aspects to make their technology a viable commercial going concern. A Goldman Sachs ESG specialist was also interviewed.

The following is salient regarding the insights generated with those GHG-R finalists interviewed:

- Substantial resource in time and effort has been invested in developing technologies most of which are still *'in the lab'.* Those ventures whereby there has been focus on how the technologies will be integrated into business

[i] The Economist dated 23rd March 2023. How should the EU respond to American subsidies? Instead of imitating them, it should play to its strengths (accessed 22nd October 2023).

models and interact with market realisation were in the minority. The majority of technologies were too immature to consider downstream aspects such as business models.

- There were propositions that generated technologies to allow markets around CDR value chains to function. These were hindered by the lack of data – see above.
- Building on the techno-economics focus of the initiatives interviewed, there was a clear push by Stanford and the individuals to develop demonstrations of technology performance making real world impact by, where possible, establishing beyond-lab-scale experiments as soon as technically feasible.

It is clear that without focus on market dimensions and limited consideration of business model design to realise commercial opportunities these ventures will struggle to scale. The ESG specialist emphasised that the Trump administration would likely add to the uncertainty and therefore inhibit the ability to scale. The lack of focus on commercial and market making aspects is also likely why the traditional Californian Venture Capital model for scaling is not working as effectively as in other tech-plays which are attracting orders of magnitude more funding. Those interviewed were keen to learn from initiatives in Europe and UK. The positing of the interviews on Stanford finalists means that a representative insight has not been developed as to CDR business model development in the US. However, when cross-referenced with the fact that the Inflation Reduction Act flagship Direct Air Capture Hubs are technology focused as well and that tax credits incentivise incumbent actors such as Oil and Gas actors due to their post-commercial qualification and the insights from the roundtable – see below – it does suggest that this is likely to be a systemic issue across the US geography.

3. CO_2RE Californian, Canadian and UK CDR collaboration opportunities mapping exercise. Carbon dioxide removal (CDR) actors from California, Canada and the UK met for half a day in Sacramento to explore possible areas for collaboration in the next 4 years in order to build on the hard-fought successes of the last 5 years.

There was clear appetite to share lessons. This would be important to ensure that institutional knowledge was built upon and spillovers realised. Four areas of collaboration (AOC) were identified: (1) place-based lessons sharing; (2) business model-centric support in order to crowd in private capital for market creation; (3) rapid evidence generation and translation to policy; and (4) cross-cutting opportunities. An enabling framework and a clear 'give-get' to attract other actors needs to be established. The Californian Centre for Science and Technology has offered to develop a conference.

The need for US state-level outreach with other CDR pioneer regions will be all the more important, with federal engagement on international initiatives such as UNFCCC COP process following the US withdrawal from the Paris Agreement and their reduced commitment to Misson Innovation.

It was also clear that the needs of each jurisdiction and the members that made up each region sought very different interactions with counterparties. The heterogeneity of the needs being a manifestation of the technologies that make up the CDR sector and the very different way that CDR policy initiatives and start-ups have been established and scaled in the UK, California and Canada. This suggests a bottom-up approach to institutional systems to share success and disseminate best practice.

4. Next steps: a bottom-up approach to the establishment of institutional systems to share success and disseminate best practice – a "Carbon Dioxide Removal Knowledge Exchange Hub" to a Global Centre of CDR Excellence. The biggest take-away from the US engagement is that there are substantial opportunities for learning to take place across UK and Californian CDR initiatives on data, market infrastructure, technology, commercial and business model dimensions, etc.

It is likely that a bottom-up approach would allow a number of polycentric initiatives that are being established which are tailored to specific partners' needs, e.g. the FCDO-Abu Dabi-Bridge Institute Centre of Excellence, the State of CDR Head of Partnerships, the National Advance Market Commitment Initiative, etc.

Rather than working in competition with other initiatives, a co-ordinated approach should be undertaken by first building on those initiated should partners be willing to engage. Timing is as important as opportunity.

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 MtCO2 per year by 2050, split between technical removals of at least 40 MtCO2 and nature-based removals (NBS) on a similar scale.[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.[3] These have generated outcomes on a nascent pathway to realising net zero which will struggle to advance further along a development and scaling pathway trajectory within the existing policy and institutional framework beyond 2025. 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.

In parallel, under the Biden Administration, the US developed a multi-billion-dollar subsidy regime with the Bipartisan Infrastructure Law and Inflation Reduction Act, which led to the establishment of a number of ground-breaking CDR initiatives – most salient being the $3.5B commitment to establish four direct air capture Hubs. Some have framed these initiatives as a threat to UK CDR sector development implying the need to compete with the US on a subsidy basis. Competitive advantage[ii] strongly suggests that this would be wrong-headed for a number of reasons:

1. The US is the world's second-largest economic bloc and is therefore an ideal place for technology innovation, as it can sell into a largely homogenous market ($33 trillion in size compared to the UK's $3.8 trillion), so it can therefore realise economies of scale with fewer transaction costs.
2. The billion-dollar scale of the public investment will also allow capital critical mass to be developed, allowing learning effects to be better realised if targeted appropriately.[iii]
3. Expenditure on domestic innovation does not lock in benefits to the subsidising nation.[iv] In a globalised world, 'global innovation leads to national growth, and national innovation leads to global growth' – i.e., CDR innovation will lead to spill-over and network effects.
4. Therefore, the consideration for the UK is not how to compete on a subsidy basis, but rather to consider how to work in tandem with the US multi-billion-dollar investment as an opportunity – in that the US subsidies will enable CDR technologies to go down the cost curve, potentially substantially.

Subsequent to the launch of the Biden initiatives, the 2024 US Presidential election resulted in the return of the Trump administration. How the new administration addresses these climate initiatives within its America First agenda is currently playing out.[4,5] 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 along with the political uncertainty that comes with the new administration regarding climate policies and subsidies.[v] 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 geo-political circumstances within the fragmented and market led CDR sector.[6]

It is in this context that CO2RE has convened a number of workshops which involved engagement with CDR sector actors. This workshop report represents the 2nd phase of a 3-stage global CDR market engagement exercise. In the first phase, 43 UK policy-makers, market actors and stakeholders took part in a 'business model archetype (BMA)' – a deliberative participatory exercise to generate collective[7] 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 were

[ii] Bernhofen, Daniel M., and John C. Brown. 2018. "Retrospectives: On the Genius Behind David Ricardo's 1817 Formulation of Comparative Advantage." Journal of Economic Perspectives 32 (4): 227–40.
[iii] V. Dodge, R., 'Critical Mass and Tipping', *Schelling's Game Theory: How to Make Decisions* (New York, 2012; online edn, Oxford Academic, 24 May 2012), https://doi.org/10.1093/acprof:oso/9780199857203.003.0018, accessed 8 July 2025.
[iv] The Economist dated 16th January 2021. Molecules, Missions and Money. The case for more state spending on R&D. Economists are convinced that governments can increase economic growth by spending more on research and development. Are they right? (Accessed 22nd October 2023).
[v] Cuthbertson, M., Workman, M. and Brophy, A. 2024. Without mandated demand for Carbon Dioxide Removal – High integrity GtCO2-scale global deployment will be jeopardized: Insight from US economic policy 2020–23. Applied Energy 372 (2024) 123806.

bioenergy with carbon capture and storage (BECCS) (electricity and hydrogen play); direct air capture (pure play and utilisation – enhanced oil recovery and concrete CO2 enrichment); nature-based solutions 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, organisational, 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. This avoids the distortive effects of the neo-classical economic orthodoxy on interpretation and policy design that is implicit in least-cost whole-system decision support.

With frontier CDR innovation and development taking place by actors within the present proto-CDR market.[vi,vii] Any process which does not accommodate insight harvesting and knowledge generation from participating market actors will result in substantive gaps in insight. Furthermore, to understand market sentiment and political dynamics it was considered that the most appropriate form of approach for this research was via ethnographic processes.[viii] The US engagement was undertaken via a number of ethnographic approaches and represented a second phase; the third phase will involve a trio of engagement activities with European policy-makers, market actors and stakeholders.

Section 2 provides a summary of the engagement framework that shaped the research, interview and roundtable sessions in the US which took place between 13th to 21st March 2025. The insights from the session regarding developing open data architectures for the management of greenhouse gas within which data to allow the development of a functioning market in the CDR sector will be fundamental is covered in Section 3. Section 4 covers the interviews and insights from start-ups participating in the Stanford Sustainability Accelerator.[8] Section 5 then summarises a roundtable session that was held between UK, Californian and Canadian policy-makers, market actors and stakeholders to explore what are the opportunities to collaborate and share insights over the last 5 years of activity. How a bottom-up knowledge exchange mechanism might be co-evolved with market participants to culminate in the establishment of an institutional mechanism to share best practice is then articulated in Section 6. A summary of insights and suggested next steps is covered in Section 7 for those organisations that will remain once the CO2RE consortium has completed its term is then made – namely the State of the CDR sector Head of Partnerships – which seeks to establish the equivalent of IRENA for the CDR sector – and Carbon Gap, who generate a more pluralistic engagement approach to CDR sector development.

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

The US CDR sector is market-led, albeit the US has established a larger tranche of federal support in the form of DAC hubs, with over $3.5 billion of funding, which will potentially lead to a concentration of activity across 4 localities in the US. CO2RE sought to conduct an impartial participatory stakeholder mapping exercise to generate insight as to market actors' needs. The agenda is based on structuring insight around the following areas:

- What are the challenges and priority needs for market actors in the US CDR sector post 2026 to 2050?
- What might the 2026–2035 institutional, organisational and policy ecosystem look like to address these needs?
- What are the areas of potential collaboration between the UK and US in sharing best practice around CDR sector development?

The primary audience for the outputs is UK government policy-makers. This will contribute to a top-down initiative being led by other workstreams within CO_2RE working on what a UK CDR framework might look like being fed in at a ministerial level and therefore with a more political audience. It will also provide international context to elements of the somewhat UK-centric CDR Review.[ix]

[vi] Workman, M., and Hall, S. 2022 Carbon dioxide removal (CDR) market transition risk – see Illuminem Blog dated 6th June 2022.
[vii] Battersby, F., Workman, M., et al., 2022. The Role of Corporates in Governing Carbon Dioxide Removal: Outlining a Research Agenda. Frontiers Volume 4 – 2022. https://doi.org/10.3389/fclim.2022.686762
[viii] See footnote v.
[ix] See footnote x.

2.2 Schema for CO2RE visit to California between 13th to 21st March 2025

The US sessions are phase 2 of this collective intelligence insight generation exercise. The US exercises were based on the following engagements:

- **Open data exercise – *'Building an Accessible and Robust Greenhouse Gas Data System to Inform and Drive Decarbonization'***, Paul Brest Hall on the Stanford University Campus, 555 Salvatierra Walk, Stanford, CA 94305 to be run by David Hayes on 13th March 2025 at Stanford.
    - It involved bringing in the collaborations that have taken place within CO_2RE across: (i) the UK GGR-D programme;[x] (ii) the Data Gap Analysis that has been led by Isabela Butnar within the Evaluation Framework (P4CCDR); and (iii) Kana on their market Infrastructure development activities.
- **Stanford Sustainability Accelerator Showcase: A Year of Impact.** This featured 18 Innovations in Carbon Dioxide Removal Open Day on 18th and 19th March 2025 at David and Joan Traitel Building 435 Lasuen Mall and Yang and Yamazaki Environment and Energy (Y2E2) Building, Stanford. A trio of the CO_2RE team attended the open day for Stanford-funded start-ups to interview start-ups and market actors as to what the needs are for the US CDR sector. These will be an extension to the insights regarding market actors' needs generated from the workshops that have been held in UK in June 2024 and January 2025 and in the EU in June 2025.
- **A CO_2RE-sponsored Californian-Canadian and UK CDR collaboration opportunities mapping roundtable** held on 21st March 2025 in Carmel AB, Hyatt Regency Sacramento, which was co-organised with Roger Aines (Chief Scientist of the Energy Program at the Lawrence Livermore National Laboratory, Berkeley) Miriam Aczel (Researcher, Sustainability Transition and Justice at the United Nations University) and Mark Workman (CO_2RE) to understand what opportunities there are for sharing success over the last 5 years of CDR innovation development in respective geographical jurisdictions.

Details and insights from each of these engagements is summarised in section 3, 4 and 5, respectively.

3. Open data exercise: 'Building an Accessible and Robust Greenhouse Gas Data System to Inform and Drive Decarbonization'

The workshop was sponsored by Stanford Law School's Environmental & Natural Resources Law and CodeX programmes; Stanford's Doerr School of Sustainability's Woods Institute for the Environment & Sustainability Accelerator; and the Data Foundation. Mark Workman attended as a representative of CO_2RE. A PDF of the full report is here, and a PDF of the highlights summary is available here. Both documents also can be accessed through this link.[9]

An overview from these documents is as follows:

U.S. companies, financiers, and entrepreneurs are continuing to make substantial investments in reducing emissions of carbon, methane, and other greenhouse gases (GHGs) and, in a growing trend, in direct removals of carbon dioxide from the atmosphere.

While many clean energy investments will continue to scale, a single market failure- the lack of investor-grade performance metrics—threatens to hold back investments in three of the most promising opportunity areas for GHG emissions reductions and removals: methane emissions reductions; hybrid (or engineered) CDR solutions; and forest carbon interventions.

A synopsis is made as to how poor performance accounting standards is a major structural gap that is undermining each of these sectors' ability to scale. In all three cases, there is no general agreement on protocols that should be used to measure and confirm GHG reductions and removals, nor is there a system for transparently sharing performance results that allows market structuring and therefore investment propositions to be made.

This lack of GHG performance accounting can and must be fixed. The report reviews how leaders in other fields have come together to identify and incentivize the use of modern data management tools to pool together shared, trusted performance information that data users of all types can rely upon. The report provides recommendations for how key stakeholders in each of the three sectors highlighted in the report can—with the assistance of expert convenors and

[x] https://www.ggrprogramme.org.uk/

university consortia—leverage and expand nascent standard-setting and data collection and sharing initiatives to generate accessible, trusted GHG performance data, triggering increased investment in activities that will reduce methane emissions, scale CDR solutions, and increase carbon uptake in forests and other nature-based solutions. [It is suggested that]….Building trusted data systems and data dissemination networks will involve at least three phases.

- First, framework development will include crafting interoperable standards, defining transparent governance protocols, and enabling privacy-preserving data sharing.
- Second, coalition-building will require establishing structures for participation and exploring data integration models – perhaps by assimilating learnings from other fields, such as the medical field.
- Finally, the implementation of data-sharing approaches may begin with targeted pilots and documenting lessons learned to inform future scaling efforts.
- Ultimately, building investor-grade climate data systems rooted in transparency and open standards will equip decision-makers with the necessary tools to pursue the most effective climate mitigation activities. Though improvements in data sharing are already being made across all three use cases, there remains significant potential to turn fragmented data landscapes into a foundation for shared progress – helping drive investment, improve accountability, and accelerate global mitigation efforts.

The report also highlights GHG performance data gains that can be made in the urban context, building on foundational work undertaken by Crosswalk Labs and the Data Foundation.

This Open ***Greenhouse Gas Data*** initiative has a number of crossovers with initiatives taking place in CO_2RE and its associated network. Below is an extraction from the CDR-D submission to the UK CDR Review on project-level CDR data availability:[xi]

- There remains an evidence gap around the wider positive or negative impacts of many CDR methods.[10] Improved data need to be tracked, including outside of the UK, if removals are contingent on important inputs (e.g. imported biomass for BECCS generating removals domestically).
- For ecological restoration, there are many habitats that are likely to provide carbon removal and storage, but with very large uncertainties over quite how much.[11] Overcoming some of these data gaps would enable better land-use prioritisation for removals, enhance the outcomes of interventions and also help develop modelling and mapping to support the inclusion of more land-based removals in the UK National Inventory Report (NIR). At present, there is not a clear pathway for some land-based removals to be included in the NIR (even if they are already happening), resulting in an additional barrier to their usage.
- Similar evidence gaps exist for other land-based removals (e.g. biochar, enhanced rock weathering), where extended research and monitoring is required to confirm whether and how removals continue over time, and the durability of carbon stored.[12] Here there is a crucial opportunity to extend the work being done at the field sites operated by the Demonstrator projects in the GGR-D Programme. A number of sites across the UK, covering different removal methods and different environmental conditions, have been created as part of the programme. But their funding comes to a close this year with no confirmed further funding from UKRI to continue. Extending their duration will be vital for improving understanding, while closing them now would be a major loss to UK and international CDR capabilities.
- There is an opportunity to create value through sharing data effectively if the appropriate incentives and mechanisms are in place, potentially benefiting all those involved in this nascent sector. Data on the environmental benefits and impacts (as outlined above), as well as quantification of removals and commercial data, for example, is particularly valuable, but much of it is currently proprietary and commercially sensitive. An independent intermediary would be needed to facilitate data sharing underpinned by the appropriate frameworks and infrastructure. The researchers have adopted a data framework and mapped data availability; this work has highlighted the need for continued data collection over the long-term.[13]

There are huge data gaps across jurisdictions for different components of GHG data infrastructure development as well as asymmetries as to visibility. Some of this data is context specific but needs to be aggregated to allow insight as to CDR technology value chain efficiency. Other data is essential to allow market infrastructure to be realised e.g., to raise, deploy and manage portfolio of CDR projects. This latter data will be fundamental as to the ability for an efficient international market to function. This latter data in tandem with the context and project specific data will be fundamental to allow International and National policies to be enacted to facilitate market interventions by policy-

[xi] https://www.gov.uk/government/publications/greenhouse-gas-removals-CDRs-independent-review

makers. Within the project-level data availability outlined above, based on other data that has been appropriated from other CO2RE partners, CDR data requirements can be arbitrarily structured at 3 data-layer levels (from lowest to highest):

- ***Project-level life cycle analysis data layer.*** Isabela Butnar[xii] has been mapping data relevant to life cycle analysis (LCA) both within the UK CDR-D demonstrators as well as across the 24 competition finalists in the DESNZ DAC and CDR competition – now whittled down to 14. This work includes other components of the CO2RE Principles for Credible CDR.[14] Isabela has also been working on UK Mission Innovation initiatives relevant to DACC as well as LCA best practice, as well as the DACC and BECCS UK ISO standards, which are interim and will form the blueprint for the full standards to be developed in the next few years. They will be used by DESNZ for appraising projects applying for innovation funding – see below.
- ***Market infrastructure structuring data layer.*** This is the data required to establish a market infrastructure so that CDR can be treated as a normal investment class/commodity – see figure 1, below. There are also initiatives within the UK on British Standards Institute work on LCA and MRVs for BECCS and DACC which were scheduled to be completed in June 2025. The EU is developing policy in this space, which will involve much in the way of data framework development – these include but are not limited to:
    1. The Carbon Removals and Carbon Farming Regulation, which seeks to establish definitions and codify what constitutes a negative emissions credit/process. It is anticipated that BECCs and Biochar will be defined in 2025 with other value chains to subsequently follow.
    2. Climate Law targets, which will explicitly commit member states to a 55% reduction in emissions on a 1990 baseline by 2030, including the differential role for CDR and mitigation.
    3. The Clean Industrial Deal, which seeks to address deep decarbonisation, a pivot to the clean tech economy and the stimulation of economic growth.
- There is also data required in order to generate high fidelity insight as to how to stimulate the market by generating targeted policy and/or regulatory interventions – one might call this the international/national ***policy-market interaction data layer.***

[xii] Isabela Butnar

Raise: Capture the interest and improve the confidence of asset owners, leading to large scale investment in the sector.

- Market overview
- Pricing
- Valuation
- Selling units
- Portfolio reporting.

Deploy: Assess investment opportunities within the scope of an investment mandate, using a combination of quantitative and qualitative methodologies; and effect investments.

- Project data
- Additional data sources
- Project ratings
- Internal project evaluation system

Manage: Effectively manage the portfolio of natural capital assets containing a large number of projects of different types, methodologies, and maturities in a consistent and cost-efficient and scalable manner.

- Project monitoring and reporting
- Insurance
- Accounting
- Legal framework

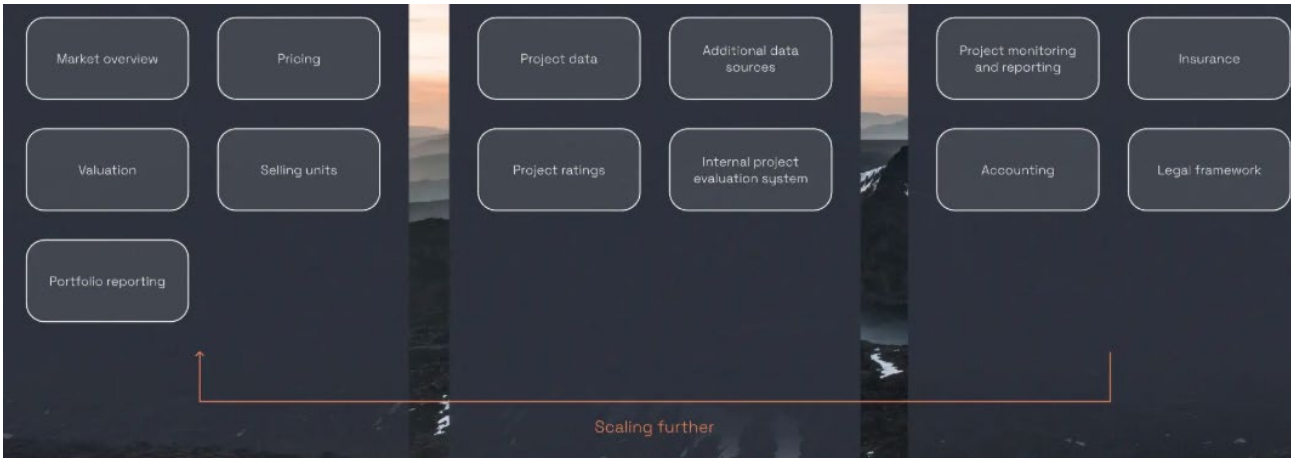

Figure 1: *Natural capital asset development. The thesis cuts along the following kernel of thinking: there are a number of first-mover institutional investors seeking to make large outlays into natural capital and nature-based CDR on that basis that those assets will accrue long term value. This will be subject to a number of market-based infrastructure needs being met – e.g., valuation models, forward pricing curves etc. as above. This links to the theory of change as to spillovers as to the ability to price tangibles (land, lumber, water etc.) based on established asset pricing mechanisms which then implicitly prices intangibles which can be transposed onto the engineered removals sector which is essentially made up of intangibles.[15] This intervention forms the foundational elements of a theory or change for the establishment and scaling the engineered sector.*

Work undertaken by Kana,[xiii] which has engaged with UK institutional investors with £billions under management, also through ethnographic methods to generate the Market Infrastructure Structuring Data Layer. On the basis of these engagements, it is considered that for the CDR sector to significantly scale it needs to make itself attractive to patient capital with investment structures that have the mandate undertake '100s of these CDR projects' with a view to making a risk adjusted return.

Their thesis as to how this will happen is as follows:[xiv]

- ***Business case***. There is a need for developers collaborating on projects at scale individually and numerically across projects. As there will be a number of different approaches built on firm competitive challenges identification of a core set of ingredients which have allowed the establishment of a demonstratable track record, cost of power, location to industry, cost of a plant, and so on. It is important for investors to be able to assess two financial metrics: (i) ability to make a return on an investment; and (ii) What he Risk Adjusted Return would be. The financial metrics for this will be predicated on the revenue that these plants can generate which in turn is dependent on the price and long run trend of negative emissions credits prices that are generated from these plants; this in turn is dependent on the demand for credits.
- ***Launch a $250m fund***. Once the business case and data model for key metrics for successful CDR plants has been established the next stage is to assess how easy would be to launch a $250M fund. The need to raising, deploying and then managing the fund will need to comply with conventional assets that investors manage. In this regard there are some big items in here such as the Cost of Deployment (e.g. due diligence), the role of insurance, how to value future units and so on. Kana have managed to get 7 of the asset managers that were launching funds in the Natural Capital sector to collaborate .[xv] Carbon Dioxide Removal would be a pure infrastructure play – so rather

[xiii] https://www.kana.earth/
[xiv] Kana 2025 – Blueprint for Natural Capital pp82
[xv] These included: Adrdn, Federated Hermes, Gresham House, Octopus Real Estate, Oxygen Conservation, Respirea and River Global with enabling assistance by Kita, Treefera and Jams Rawson.

than Natural Capital Investors being involved you would seek the following - Global Infrastructure Partners (Blackrock), Brookfield, KKR, Macquarie, Blackstone etc. It would be hard to get competitors to collaborate, facilitate and create an output of value. From the case study of the Natural Capital sector is not only possible but also seen as a game changer.

- ***Creating the sector.*** If there is a business case and there are asset managers that see this as an attractive use of their time, you then need to target the investors. The investors that would be beneficial to target would be the Adu Dhabi investment Authority, Norges, Allianz and some of the Canadian and Australian pension plans. The role of sell side countries (Article 6.2 ITMOs) should not be underestimated .[xvi] Once the momentum is established, the parameters of locating some of these plants will be where there are cheaper land, labour and electricity. If this can be achieved it would create the pathway for CDR to be a $1trn sector.

The concern with the US, EU and UK data initiatives are that they are taking place in isolation with limited knowledge exchange or protocol sharing between jurisdictions. In the US initiatives the coalitions tend to only refer to US entities, in the UK investors tend to be UK based ones and CO2RE has limited visibility of EU based data initiatives. Based on the US and UK insight alone, this lack of co-ordination will reinforce the fragmentation and siloed nature that has stunted the ability for all GHG related initiatives to establish and scale. Most importantly the ability for the investor community to understand value opportunities and generate risk adjusted returns.

4. Stanford Sustainability Accelerator Showcase – Ecosystem 26+ Engagement

The Stanford Sustainability Accelerator has funded 18[16] participants from across the US CDR sector focused on developing technology; improving measurement, reporting, and verification; and creating new markets. The background to the accelerator can be found here on this link. The different levels of funding available from the accelerator from pilot (1 year); Scaling up (2 years); Pilot (3 years) – can be found here; start-ups can qualify at any level and progress from one to the next should they meet certain criteria. It is noteworthy that the accelerator funds scientists in Stanford who are primarily interested in advancing science for impact for which impact is spinning out a company. Grantees and funders had been invited to attend a showcase to be held on the Stanford Campus between 1200 to 1800+ on 18th March 2025. Teams reported advances in atmospheric, forestry and soil, terrestrial and oceanic removals within a broader agenda setting framework of talks[xvii] and panel sessions.[xviii]

CO_2RE team members of Natasha Martirosian, Miriam Aczel and Mark Workman attended with a view to recruiting finalists for interviews on 19th March 2025 to be undertaken at Yang and Yamazaki Environment and Energy (Y2E2) Building. The Sustainability Accelerator finalists were allocated a designated CO_2RE team member so that recruiting could be as systematic as possible - see table 1, below. The finalists were interviewed based on the same questions as those asked to groups in UK workshops: demand/offtake mechanisms; regulation and markets; technological requirements; resources and capital finance; social acceptance and trust building; and freeform section where possible. Where this was not possible interview transcripts have been presented to capture more generic answers and sentiment. An ethical process which required individuals to complete a Participant Information Sheet (PIS) and Consent Sheet was undertaken.

[xvi] Bfinance, 2024. Natural Capital Investing. An introduction to Forestry, Agriculture and Carbon Credits. January 2024 – pp16.
[xvii] Stanford Doerr School of Sustainability staff, April 14, 2025., Greenhouse gas removal, Events, Technology Accelerator Showcase: Greenhouse gas removal Stanford's Sustainability Accelerator convened more than 300 researchers, investors, entrepreneurs, and alumni on campus to learn about greenhouse gas removal and how 18 teams are seeking to enable it on a large scale. Explore highlights from the event.
[xviii] Tara Roberts, April 14, 2025., Energy and climate technologies as a 'foundation for human prosperity'. During a recent Sustainability Accelerator event, venture capitalists urged researchers working to scale greenhouse gas removal technologies to focus on cost and seek common ground with a wide range of prospective partners.

Table 1: Allocation of Stanford Sustainability Accelerator finalists between CO_2RE team members. Those highlighted in bold were interviewed.

Turquoise: Tech – BECCS, soils and DACC-CCUS	**Blue: Non-CCS enabled – NBS, Biochar & ERW**	**Green: Non-CCS enabled – mCDR/enabling**
Mark	Natasha	Miriam
1. Free Radical Breakthrough: Pioneering atmospheric methane removal	1. Growing a Better Future: Scaling agroforestry as a global CDR solution	1. A method to directly capture carbon dioxide in soils
2. Bringing Carbon to Market: A case study of enhanced weathering	2. Risk-Proofing Scale: New frameworks and technology for natural climate solutions	2. Making Zero-Carbon Cement at Scale
3. Supercharged Rock: CO_2 removal that adds value	3. Scaling low-cost measurements of soil CO_2 emissions	3. Sinking Carbon, Saving Seas: Marine CDR that's economical, ecological, and efficient
4. Breaking the Energy Barrier: The novel chemistry that could unlock DAC at scale	4. The Hidden Sink: Old-growth fungi as a carbon solution	**4. Farming for Blue Carbon: Modelling seaweed cultivation for marine CDR and ocean restoration**
5. Supercharging Separations: Reactive capture and conversion of nitrous oxide emissions	**5. Global Worming: The natural path to carbon dioxide removal**	5. Seeing the Light: Designing a new regime of MRV sensitivity
6. Insight at the Interface: A breakthrough in atmospheric methane removal	**6. Trait mapping: Coalescing feedstock, conversion technologies, and durability to spread biochar**	6. Comparative techno-economic analysis for emerging CDR technologies
7. Scaling low-cost measurements of soil carbon dioxide emissions	**7. Scaling Biochar: Converting agricultural waste into a gigaton-scale industry**	7. Piloting Partnerships: Uniting the world of ocean alkalinity enhancement

Of the accelerator projects, the following were willing to be interviewed:

- Free Radical Breakthrough: Pioneering atmospheric methane removal – Max Kessler.
- Supercharging Separations: Reactive capture and conversion of nitrous oxide emissions – Carlos.
- Scaling Biochar: Converting agricultural waste into a gigaton-scale industry (Divya Chalise).
- Global Worming: The natural path to carbon dioxide removal.
- Biochar feedstock data gap analysis.
- Farming for blue carbon.
- A Goldman ESG specialist was also interviewed who was not a part of the accelerator but recommended by one of the CO_2RE team.

Other accelerator projects that were willing to be interviewed but whereby projects were considered too early for commercial aspects of business model development:

- Breaking the Energy Barrier: The novel chemistry that could unlock DAC at scale.
- Bringing Carbon to Market: A case study of enhanced weathering (Kate and Marc).
- Supercharged Rock: CO2 removal that adds value (Jade).
- Insight at the Interface: A breakthrough in atmospheric methane removal.

4.2 Free Radical Breakthrough: Pioneering atmospheric methane removal.

Looking to get the accelerator to take the technology and process from out of the lab and to pilot (scaling by 10) – looking to attach the scaled technology to Stanford's wastewater treatment plant.

1. **Demand/offtake mechanisms:**
    - Removal from the air of CH4 is the holy grail but sceptical as to whether this will be possible – CH4 is a very hard chemical to bond to – and so focusing on concentrated sources e.g., wastewater plants, cattle sheds, gas pipelines, etc.

2. **Regulation and markets:**
    - CH4 was regulated in the Inflationar Reduction Act via the methane fee that was charged to oil and gas companies, but it was only in existence for 2 years before the latest administration repealed the fee. The effectiveness of the fee on emissions reductions is not known yet.
    - It is likely that CH4 would be better dealt with as an air quality issue rather than a climate issue. CH4 causes ground-level ozone which in turn causes health problems (asthma), impacts crop yields which would stimulate the farm lobby to act on CH4, i.e. it is bad for the economy. The Ammonia Bill or integrating with some form of cap-and-trade mechanism would be beneficial.
    - Who pays for CH4 removal will be problematical to develop at a federal level and would likely be voluntary. Possible state actions e.g., California and aspirations regarding being net zero by mid-century. The aspiration to hit this target is not on track so a review might result in CH4 livestock also being included and the coverage of waste streams CH4 as long as doesn't have an economic impact to 2030.

3. **Technological requirements:**
    - Experiment at scale with Stanford's wastewater treatment plant.
4. **Resources and capital finance:**
    - Too early to tell.
5. **Social acceptance and trust-building:**
    - There is a need for a narrative as to why CH4 is an important GHG that needs to be addressed and that when it is combusted to produce CO2 that is a better predicament than letting CH4 vent into the atmosphere.
    - There is a need for broader societal understanding of the extent of the problem and for that to translate into policy e.g., CH4 removal only accounted for 2% of all climate funding.
6. **Freeform section.** Any other points that the participants would like to raise?
    - NA.

4.3 Supercharging Separations: Reactive capture and conversion of nitrous oxide (N2O) emissions.

Carlos is one of 4 postdocs working on this project whereby they allocate 1.25 days per week. The team is based in the lab and all have the ambition to develop a start-up with a view to scaling. They are using the accelerator as a mechanism to develop their skills as entrepreneurs and are working across a number of projects. They all hope that one of them will allow them to scale even if it is not the N2O project.

Scale of clean tech funding in US small compared to AI by an order of magnitude ($10M for clean tech relative to $100M for AI). Carlos was keen to remain part of the CO2RE diaspora and be kept aware of developments in UK and Europe.

1. Demand/offtake mechanisms:
    - Dual and co-benefit systems so as to not rely on climate policy e.g., Ammonia production rather than N_2O.
    - Mechanism to get the proposition to market – options: (1) chemicals production; (2) sale of facilities e.g., electrolysers; or (3) sale/rent units to farmers to produce decentralised ammonia products.
    - Yet to work on customer discovery where other members of the team have been thinking more deeply about.

2. Regulation and markets:
    - Sceptical that there will be the policy put in place for N_2O to be removed on a regulated basis.

3. Technological requirements:

- Everything on electro-chemical processes is about the price of the energy to make it techno-economically feasible.
- N2O is too dilute and the mechanics of moving so much are to remove N2O will make this process prohibitively expensive but there might be some new scientific breakthroughs which results in new insights and commercial opportunities.
- The technology is 10 years away from being commercialised.

4. Resources and capital finance:

- Have had a lot of interest from VCs from the show case on 18th March 2025.

5. Social acceptance and trust-building:

- NA.

6. Freeform section. Any other points that the participants would like to raise?

- NA.

4.4 Scaling Biochar: Converting agricultural waste into a gigaton-scale industry – biochar as a coal replacement

Overall impressions

- The project has been designed from inception with a business model framework.
- Two different project end users: (1) oil and gas – replacement for coal; and (2) carbon removal at millennium scale burying waste biochar product in old mines. This latter application has had market receptivity. Project viability is being tested in real time and next phase is pilot (stage 2+3). The venture has already involved in conversation with oil and gas (Shell). There is a need for policy support to get the venture into US and EU markets.
- Open and willing to form international partnerships in the UK and EU.
- New patent (in progress) technology to reduce biochar energy and time by 90% – slightly secretive because it is not yet patented – believes biochar stability will be enhanced and is generally underestimated though the evidence for this is yet to be generated.

1. **Demand/offtake mechanisms:**
    - Competitiveness and economic growth are considered to be going in parallel directions.
    - Coal has a large demand in Asia. The venture is trying to work directly with businesses with coal to sign order agreement for replacement of coal with biochar.
    - In US, targeting the carbon removal market as there are fewer consumers of coal. Carbonising locally produced biochar and creating agreements with petrochemical petroleum producers (e.g., Shell, etc). The proposition is to offer cheap biochar as a carbon offset medium whereby prices are lower than current market but with long-term large volume contract.
    - The biochar will be stored in used and abandoned mines. Exploring idea of offtaker paying for biochar plus land-lease fee mine space fee i.e., akin to CCS.
    - Local storage and production, but working with global companies. It's a carbon balance of the planet.
    - Breweries as feedstock. End users (cement, steel, coal fire power plants) properties that can be provided are enough but not willing to sign because of supply chain. Scale limits of biochar because biomass is problematic to source.
    - Supply chain fragmentation is one of the biggest challenges.

2. **Regulation and markets:**
    - How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated?
        - Hydrogen to carbon ratio – up to 0.7 per carbon atom is acceptable and reflectivity test – lower reflective is more stable. These are corellations but no understanding of why.
        - Struggling with stability of biochar. Kate Myers – new methods of standardising. Lack of standardisation. Soil, carbon, etc.
    - What are the barriers to making the offtake for this to work?
        - Supply chain.
    - What incentives are needed?
        - Countries agreed to adhere to the Paris Agreement.
        - In South Aisa, learned that acceptance of climate change is much more than US. In india, they are open to reasonably good economic incentive.
        - Stanford – in vision, not US-centric. Stanford is trying to work with different buyers and countries. Asia sees the green revolution as not just an environmental incentive and see them as independent from fossil fuels.
        - Energy resilience and security.
        - Advantage of working with Arun – Head of Faculty.
    - What changes would you be keen to see?
        - Insentivising farmers – farmers are tired after harvest.
        - Need framework to collect biomass. Tax credits*?*
    - From your perspective looking at Europe – are you looking to us or are you leading the way?
        - Focused on US because it's easier to penetrate – Indonesia and Asia because it's got lots of coal-fired generation plants, etc.
        - If you could help us connect with in Europe – end users, etc. do you use sewage sludge?
        - Thinking of it as a different form of DAC.

3. **Technological requirements:**
    - What technology needs to change, develop, or get cheaper?
        - Tonne per day in the lab.
        - Need new biochar plants – process is completely different from traditional biochar reactor.
        - This process is simpler and energy consumption is order of magnitude lower. Only removing hydrogen and oxygen – no wasted energy. Carbon retention high.
        - No biochar producer has the reach. No drive to organise this supply chain at scale.

4. **Resources and capital finance:**
    - Creates a lot of employment.

5. **Social acceptance and trust-building:**
    - How socially acceptable is this CDR value chain?
        - Definitions of net zero, coal replacement, negative emissions – education is missing.
        - Burning coal and capturing it is the same as not burning it at all but finding it attractive to capture the carbon.
        - We don't see value in working with forestry wood – you need to cut billions of trees.

- 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 organisations.
    - Biggest thing is framing it. In Europe I could have this conversation easily, in Asia not as easy, in US not at all. How do we convey what is right and wrong to communities?
    - How do we convey the facts?
    - Activation barrier – supply chain. Who do you convince?

6. **Freeform section.** Any other points that the participants would like to raise?
    - Breweries operate at a decent scale – operating at 100 tonnes a day waste. Right now they dump landfill, 10–15% goes into insect protein. Circular economy.
    - No matter who you talk to, they realise the importance of change. They need viable solutions. No scientist disagrees.
    - Accelerator funding.
    - High-impact tech – from Stanford
    - Launch in mid-summer. Working on a pre-pilot in lab. Raising pre-seed money to build a pilot in Napa. After pilot is done and there are agreements with end users, fundraising in about a year. Two patents filed, 3rd coming.

4.5 Global Worming: The natural path to carbon dioxide removal

Overall impressions

- The project framed as a soil health solution, with a carbon byproduct to fit in with the US market.
- No business plan – *"too early"* – realistically, PI doesn't think in the way of business models, just wants to do research and is a faculty member. Not interested in making money. "*why do people think that business is about making money when we are clearly trying to improve society as the main motivator?"*
- Nate Looker joined the team 3 weeks ago – on record to say *"We know we don't operate in a vacuum and are open and looking for UK and European partners".* Wants to come to UK – who are the worm experts in the UK?

1. **Demand/offtake mechanisms:**
    - Could replace bait worm market – but that's in Canada.
    - Needs to be local to be viable.

2. **Regulation and markets:**
    - How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated?
        - Measuring invertebrates and biodiversity.
        - Worm effects over long timescales in natural gradients.
        - Need supply chain considerations – who grows the worms?
    - Are there policies, regulations and standards acting as barriers?
        - Livestock industry has a lot of power in terms of power in policy and laws. In California, worms are considered livestock so, e.g. compost facility needs licensing but worm compost doesn't. In this case, because of lobbying it's loosely regulated. Not the same as rock flour or biochar – not adding.
        - Vertebrates are regulated but invertebrates aren't.
        - Department of Agriculture regulates soils for invasive species but only at county level. If earthworm nursery and inoculation in same county it's fine.
        - Good for birds – but away from wind production and aviation to keep birds away from planes for accidents, etc.

- What policies, regulations and standards need changing: How would that impact current policies and market design?
    - Farm Bill isn't too effective in targeting soil health. Good at waterways but not on soil health. Helpful if the farm bill identified incentives to increase soil health or adding organic carbon to soils and helping people transition to no till.
    - Perennials – any policy that supports change in annual to perennial or pasture to orchard would support economics.

3. **Technological requirements:**
    - What technology needs to change, develop, or get cheaper?
        - Don't know yet.
        - Worms could take immature compost and applying – feedstock.
        - Don't know how they get into the field?
        - Raised beds with trenches – local materials, practice/techniques not technology.
4. **Resources and capital finance:**
    - Is this archetype capital-intensive?
        - Human capital-intensive.
        - Model of training, how much would be done.
5. **Social acceptance and trust-building:**
    - NA.
6. **Freeform section.** Any other points that the participants would like to raise?
    - Nate: There are great earthworm experts in the UK we'd like to partner with. We know we aren't in a vacuum and want to pursue partnerships: (1) Lancashire – Kevin Butt landfills in earthworms and (2) York University – Mark Hodson.

4.6 Biochar feedstock data gap analysis

Overall impressions/high level

- Project designed to fill data gaps to create a viable Biocahr market.
- Defining biochar for end use will help create the market and minimise greenwash and miscommunications within society/public perceptions.

1. **Demand/offtake mechanisms:**
    - ***How would it impact competitiveness and economic growth?*** This isn't necessarily a product – it's to map traits to understand what traits and metrics we need to account for variability and durability, surface area for soil remediation, etc.
    - Business school project was more business minded – what the market in the US looks like, what's holidng the industry back and what is on the horizon to make it possible.
    - Original vision was to design a machine learning model – match feedstock conditions to outcome requirements. There isn't enough data to undertake the project so instead we did this. We don't have a dataset for biochar deployments. Not enough info on type gradients, etc.
    - ***What kinds of counterpartry would benefit from this archetype?*** UC Davis database on biochar. Thousands of properties entered. No alignment on measuremet methods. No fungibility.
    - ***What are the barriers to making the offtake for this to work?*** Alex – physical product end-point. In the USA farmers are reluctant to pay for agro-amendment material, especially with small margins. They won't want to pay for it. Credit payment comes after application.

- We talked to a lot of people trying to change end-use. You could use char as a reducing agent in silicon, and it was used in steel already so it makes sense. However, scale is incompatible with industry. They don't scratch the surface of scale. Scale mismatch.
- Rian – for soil it's a huge problem. A way to get money – risk analysis for banks, they don't know how to give out loans for this. Access to funding is difficult. 2nd point – a producer said that there are people willing to sign big off-take agreements but they want such a large amount – if you're not able to scale, or have access to a lending scheme, then you can't get the bid to scale. It's a chicken and egg issue.
- Fertiliser – farmers? Crop yields won't show within a year and farmers are living check to check and they don't have time for an investment. The benefits aren't parameterised – need creative ways to show improvements of soil quality. But no solid evidence.
- What incentives are needed?
    - If one state does it and it works economically, then others will follow. Waste water in the US is funded well, and they pay to get rid of sludge – if you could make it a valuable resource it might help.
    - We've seen big change in the wine industry – they use biochar because their neighbors do it. They are a high-value crop and have a long-term view. And although the science and studies to prove benefits aren't robust, they still use it.
    - The co-benefit literature isn't a mechanism to map biochar to agro endpoint, there are meta analysis of positive impacts, but there's also negative impact literature – farmers don't necessariy know the co-benefits or trade-offs.
    - We need to know what biochar from what feedstock will have positive impact on specific soil types with particular pH and water content, etc. for soils. People are actively against climate action, so going in and reframing for soil health, etc.
    - Farmers don't see themselves aligned with scientists. Biochar needs marketing and reframing.

2. **Regulation and markets:**
    - Are there policies, regulations and standards acting as barriers?
        - Total lack thereof. Tech for agnostic – 45Q crediting system. C-BAM 2026 in EU – maybe the EU changing their policies will force US to do it. Need a carbon pricing instrument for border carbon pricing.
        - Long path for building materials policies.
    - **How would quality assurance around negative emissions generation be realised (MRV) and the need for fungibility to be facilitated?**
        - Rian: what is the feasible way of MRV for in field biochar? Now it's H to C ratio and assuming proportion of biochar is permanent for 100 years (standard) – working on a method that's low cost for global field trials and more accurate/confidence under certain circumstances. It's in testing. At least to get differentiation for regional deployments.
    - **What policies, regulations and standards need changing: How would that impact current policies and market design?**
        - Rian: I'm interested in sludge waste. Incinerating sludge is disincentivised in policy. Where you can put sludge as biochar is regulated. Could be landfill cover. Could be low-cost material and the bio-oil from sludge could be fertiliser.

3. **Technological requirements:**
    - **What technology needs to change, develop, or get cheaper?** Depends on the objective and how you'd like to move it forward as a solution. Applied carbon using in field analysis and deposition moving a few miles an hour.
        - There are many ways to skin the cat for biochar and it depends on the business

- Mobile pyrolisers for field use of biochar. LCA deteriorates with transport so this makes the most sense for end points that are field amendment. Small-scale is the right option. Low-tech modes produce crude and low-demand credits.
- When the product is sold with fertiliser in Brazil it's really successful.
- Bio-oil as fertiliser might be worth while
- Brazil is having a lot of buy-in due to marketing and mixing biochar with fertiliser.
- Sattelite imaging too.
- Which existing development may render this irrelevant?
- BiCRS, and BECCS render null some of the low-integrity biochar becaue there are better uses of biomass.
- It's all country-specific.

4. **Resources and capital finance:**
    - 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?
        - Compliance markets forcing companies to invest in materials.
        - The capital could come from impact investment, institutions, pensions, wealth, finance.
        - Having spoken with venture capital, it doesn't look like they are interested in this because this doesn't fit the venture model. They won't be happy with what you can get from biochar in near term – no confidence in VCM.
        - Venture capital has buying signal for scaling CDR.
        - Maybe it's government procurement.
5. **Social acceptance and trust-building:**
    - How socially acceptable is this CDR value chain?
        - It isn't yet, at least not in the US.
        - 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 organisations.
        - Reframing the relationship between scientists and farmers.
6. **Freeform section.** Any other points that the participants would like to raise?
    - Lexi – Josia Hunt Pacific Biochar – said that biochar is everything and nothing. It's a material that's an umbrella term for a line of products.
    - We talk about biochar for climate change – it's a material, whereas other technologies are processes. Separate activity from material and recognise that the single name conflates what it is. Calling it "Biochar carbon removal" (BCR), biochar for steel.
    - Nomenclature. Biochar is the cure for everything. Need to think about how it's presented, the activity, the outcome.

4.7 Farming for Blue Carbon

Farming for Blue Carbon: Modelling seaweed cultivation for marine CDR and ocean restoration

To start, what do you, as a representative from the CDR sector, consider the single most important thing that needs to happen in 2026?

Kristen Davis: "One of the most critical things that needs to happen in 2026 is advancing large-scale demonstrations of seaweed cultivation as a viable carbon dioxide removal (CDR) strategy. Right now, we're working with seaweed farmers

doing field-scale projects, measuring carbon fluxes in that system, and using that information in a dynamic background to grow the model, to really think about closing that carbon budget.

It's time-sensitive because ocean-based CDR solutions need to be rigorously tested before they can be widely deployed. Climate change impacts are accelerating, and if we don't establish seaweed cultivation as a scientifically sound and economically viable method for carbon sequestration, we risk losing valuable time in mitigating climate change. Additionally, regulatory frameworks need time to adapt to new technologies."

How might this be addressed?

Kristen Davis: "It requires coordinated efforts from policy-makers, researchers, industry leaders, and funding bodies. First, we need to secure stable funding for long-term experiments. Second, collaboration with seaweed farmers and ocean research institutions is crucial to refining cultivation techniques, measuring carbon fluxes, and ensuring sustainable practices."

Kristen Davis: "So right now, I think we've been working with some seaweed farmers who are interested in using that seaweed biomass as a bio-stimulant, actually for farming. And I know that some of the other seaweed farmers that we're working with are interested in using it for human food. So there's different pathways, different partners that we're working with are considering different pathways."

What about political acceptability? How might this impact competitiveness and economic growth?

Kristen Davis: "Seaweed cultivation aligns with multiple policy priorities, including decarbonization, food security, and ocean restoration. However, regulatory hurdles still exist, particularly concerning offshore farming permits."

What are the key barriers to making this offtake model work?

Kristen Davis: "regulatory uncertainty, lack of large-scale demonstration projects, and challenges in establishing carbon credit methodologies specific to seaweed. Additionally, ensuring MRV standards for carbon sequestration is complex, given the dynamic nature of ocean ecosystems."

Are there specific policies or regulations acting as barriers?

Kristen Davis: "Yes, in the U.S., permitting for offshore aquaculture is fragmented, with multiple agencies involved. Additionally, there is a lack of standardized MRV protocols for ocean-based CDR. Without these, it's difficult to integrate seaweed cultivation into carbon markets."

What policy changes would help facilitate growth?

Kristen Davis: "We need policies that recognize seaweed farming as a legitimate carbon sequestration strategy. Streamlining federal and state permitting processes and establishing guidelines for environmental impact assessments would also be beneficial."

What technological advancements are needed for seaweed cultivation to scale?

Kristen Davis: "We're actually working with Ocean Era to try to monitor how they're doing that. So you may know, especially in tropical areas, the near-surface waters are quite nutrient-poor. What makes them so beautiful and clear and snorkel-able, but in order to grow the seaweed, you need nutrients, and so we're working with them on a depth cycling farm that helps, you know, come to the surface and get sunlight during the day, but also you can sink it down and get to the deeper nutrients below."

Are there enabling technologies that could support this?

Kristen Davis: "Absolutely. Innovations in biochar production from seaweed, improvements in offshore infrastructure, and development of efficient processing techniques for converting seaweed into biofuels, fertilizers, and other products are all essential."

Finance: Is seaweed cultivation capital-intensive?

Kristen Davis: "Yes, but it depends on the scale. Small farms require relatively low capital investment, while larger offshore operations demand significant infrastructure and logistical support."

Who is likely to finance this?

Kristen Davis: "Initially, public-private partnerships will be key. Government funding can de-risk early-stage projects, attracting private investors such as pension funds and impact investors. Over time, carbon markets could provide a sustainable revenue stream."

How socially acceptable is this CDR value chain?

Kristen Davis: "One of my favorite parts of this project is getting a chance to work with seaweed farmers. We work with One Ocean Rainforest that's growing in Santa Barbara. They have a farm off of Santa Barbara, and we did a big experiment on that farm last summer. This summer, we're gonna go to the Faroe Islands, where they have been bigger. They have a huge production farm about the same species."

What would be needed to build trust?

Kristen Davis: "Transparent communication and local involvement are key. Partnering with coastal communities, Indigenous groups, and environmental organisations can help address concerns and ensure that projects benefit all stakeholders."

Are there any other points you'd like to raise?

Kristen Davis: "One thing we must remember is that seaweed cultivation is not a one-size-fits-all solution. It has great potential but must be implemented carefully, with rigorous scientific validation and community engagement. Scaling responsibly is the key to ensuring long-term success, both for carbon sequestration and for broader ecosystem benefits."

4.8 Goldman Sachs

Goldman Sachs' approach to carbon removal and net-zero strategy

Interviewee 1 (Samuel M.), ESG Investment Associate, Goldman Sachs

Thanks so much for taking the time to chat with us today...kick things off by having you give us a bit of an overview of how Goldman Sachs is approaching carbon removal as part of its broader net-zero strategy?

Goldman Sachs representative: Sure, happy to. So, at Goldman, we really see carbon removal as a critical piece of the bigger picture when it comes to transitioning to a net-zero economy. It's twofold for us. On one hand, we're looking internally, integrating carbon removal solutions into our own operations to hit our 2030 net-zero goals. On the other hand, we're actively investing in innovative carbon removal technologies and nature-based solutions that we believe can help drive decarbonization at a global scale.

When you're looking at investments in this space, how do you evaluate which carbon removal technologies make sense to invest in?

Goldman Sachs representative: It's definitely a detailed process. We run some pretty rigorous due diligence on emerging technologies, looking closely at scalability, cost, permanence – all those key factors. We look at both engineered approaches, like direct air capture, and nature-based solutions, like reforestation and soil carbon sequestration. Ultimately, we're seeking opportunities that can deliver measurable climate benefits while also making good long-term economic sense.

With Goldman Sachs recently exiting the Net-Zero Banking Alliance, how has that decision affected the firm's carbon removal investments, if at all?

Goldman Sachs representative: Yeah, that's been getting a lot of attention. Honestly, it's more about maintaining flexibility. The NZBA has broad, uniform targets, but we felt a more customized approach would let us be more effective – especially in terms of innovative climate financing. Exiting doesn't mean we're pulling back from net-zero commitments; it's more about tailoring our strategy to be nimble and impactful in how we invest, including in carbon removal.

Some former employees have suggested that political pressure and concerns around greenwashing played a role in scaling back certain sustainability strategies. What's your take on that?

Goldman Sachs representative: It's true the space has gotten a lot more politicized, especially recently. We're still very committed to responsible investing, but we've had to be thoughtful about navigating changing sentiment and regulatory scrutiny. That's meant revisiting some products and strategies to make sure everything stands up to evolving standards and expectations. It's an environment where careful stewardship matters more than ever.

Right – and how has Goldman Sachs' carbon removal strategy evolved under the current U.S. administration?

Goldman Sachs representative: Yeah, so honestly it's been a bit of a pivot. Under the Biden administration, we had all this momentum – the Inflation Reduction Act, a lot of government-backed support for carbon removal, public-private partnerships, new funding opportunities. We definitely leaned into that, built a lot around that policy environment.

But with the Trump administration now, it's pretty much a different world – again. A lot of that support has dried up, or at least gotten way less predictable. So, we've had to rethink things—be a lot more cautious, focus on investments that can stand up without relying on big federal incentives. Still committed, still in the space, but the risk calculus has changed for sure.

Can you talk a little about how you work with corporate clients around carbon removal?

Goldman Sachs representative: Absolutely. We're working across sectors, helping clients incorporate carbon removal into their net-zero pathways. That can involve advising on voluntary carbon markets, structuring carbon credit transactions, or financing new technologies. One example is our work with Apple on the Restore Fund, where we're helping scale nature-based solutions. We also support clients in developing integrated carbon strategies that combine removals with emissions reductions – basically thinking holistically about their carbon footprints rather than treating removal as a standalone fix. And we're looking at ways to structure innovative financing vehicles, like blended finance models, to help unlock more private capital for carbon projects. It's about making carbon removal something that's truly investable and scalable for the long haul.

What are some of the bigger challenges you see right now for scaling carbon removal investments?

Goldman Sachs representative: The biggest challenge is definitely market uncertainty. These technologies require major upfront capital, but the policy frameworks and carbon credit markets are still maturing. Strong MRV standards are critical to building investor confidence. We're optimistic, but it's going to take coordinated action.

Looking ahead, what role do you see Goldman Sachs playing as the carbon removal space develops?

Goldman Sachs representative: We really see ourselves as both a catalyst and a connector. We're bringing capital to early-stage solutions, advising clients on strategy, and engaging with policy-makers to help shape robust markets. We're committed to scaling solutions that can drive meaningful emissions reductions while also building viable, sustainable business models. We're continuing to expand our portfolio – looking especially at scalable and verifiable technologies. It's a tricky balance with expanding but also hedging risk. We're also deepening our partnerships with both corporate clients and public sector actors to co-develop financing structures. Long-term, we do want to see carbon removal fully integrated into mainstream financial markets, treated as a serious, investable asset class. There are a lot of shared goals in this space in the climate ESG, and across sectors.

If you look at the bigger picture, where do you think the whole CDR landscape is heading in the next few years?

Goldman Sachs representative: Yeah, that's a good question. I mean, it's still early days, right? We're seeing a lot of momentum, but also a lot of growing pains. I think you're going to see a pretty big shakeout – the projects and companies that can demonstrate real, verifiable impact are going to survive and scale, and the ones that can't are going to fall away. There's going to be more pressure – from investors, regulators, and the public – to prove that carbon removal is actually delivering what it promises. And honestly, that's a good thing. It'll force the sector to mature faster. I think we're headed toward a future where CDR is a mainstream part of the carbon markets, but it's going to take real work to get there - good communication, science, policy, and of course good finance, all pulling together.

4.9 Analysis and insights

The following is salient regarding the insights generated with those GHG-R finalists interviewed:

- Substantial resource in time and effort has been invested in developing technologies most of which are still *'in the lab'.* Those ventures whereby focus has been made as to how the technologies will be integrated into business model and interact with market realization were in the minority. The majority of technologies were too immature to consider downstream aspects yet.
- There were propositions that generated technologies to allow markets around CDR value chains to function. These were hindered by the lack of data – see above.
- Building on the techno-economics focus of the initiatives interviewed there was a clear push by Stanford and the individuals to develop demonstrations of technology performance making real world impact by, where possible, establishing beyond lab scale experiments as soon as technically feasible.

It is clear that without focus on market dimensions and limited consideration of business model design to realise commercial opportunities these ventures will struggle to scale.

The ESG specialist emphasised that the Trump administration would likely add to the uncertainty and therefore inhibit the ability to scale. The lack of focus on commercial and market making aspects is also likely why the traditional Californian venture capital model for scaling is not working as effectively as in other tech-plays which are attracting orders of magnitude more funding. Those interviewed were keen to learn from initiatives in Europe and UK. The positing of the interviews on Stanford finalists means that a representative insight has not been developed as to CDR business model development in the US. However, when cross-referenced with the fact that the Inflation Reduction Act flagship direct air capture hubs are technology-focused as well, and that tax credits incentivise incumbent actors such as oil and gas actors due to their post-commercial qualification and the insights from the roundtable– (see below) it does suggest that this is likely to be a systemic issue across the US geography.

5. CO_2RE Californian, Canadian and UK CDR collaboration opportunities mapping exercise

5.1. Context

A roundtable was held at the Hyatt Regency Sacramento on 21st March 2025. The roundtable brought together a select group of stakeholders, including representatives from the Californian government, Stanford Accelerator CDR-Flagship, Canada and key players from the UK. The Canadians have an MOU with California and are hosting of the G7, this year which has the potential to shape the geo-political framings around CDR and net zero more broadly. How formal the collaborative relationship would be was to be explored in the meeting. The intention ***was to therefore establish greater understanding as to the underpinning requirements for a Californian, Canadian and UK relationship around CDR*** via this tentative agenda:

- Identifying the most beneficial paths to advance the CDR sector across jurisdictions.
- Exploring state-level initiatives and their integration with private sector strategies.
- Developing actionable steps to operationalize these components.

Once mapping had been undertaken, it was intended to then consider how knowledge exchange mechanisms might be developed across the three jurisdictions in order to share success and lessons from across the UK-Canadian-

Californian/US jurisdictions – subject to appetite and funding. Rather than working in competition with other initiatives the intension was for this collaboration to form one component of a broader set of initiatives on a bottom-up basis. This would likely be co-ordinated by the State of the CDR sector Head of Partnerships under the supervision of Professor Greg Nemet who is seeking an institutional mechanism to share best practice at a global level, as well as via Noah Deich the former senior advisor at the US Department of Energy's Office of Fossil Energy and Carbon Management (FECM) seeking an international Advanced Market Commitment as well as other similar initiatives – possibly realising a broader diaspora so as to realise greater network effects.

5.2. Process

Twenty attendees from across the 3 jurisdictions contributed to discussions in a hybrid format over 5 hours – see Annex 1.1. These were recruited over the previous 3 months via online calls to manage expectations, prioritise individual agendas and share materials. The meeting was chaired by Craig Segall, an independent with substantive experience of all three jurisdictions. A transcript of the session was captured by Miriam Aczel and is available from the corresponding author of this report.

The agenda was structured around sharing insights as to activities, areas of collaboration to explore and exploit and next steps – as is detailed in Annex 1.2. Contributors delivered 8 presentations posited on ***– 'Carbon Dioxide Removal and their associated technologies: There potential application in industrial decarbonisation and economy wide net zero.'*** Four covered national and state CDR initiatives and four private sector and research initiatives. The presentations are available in this drive and shared reference materials in Annex 2.

The subsequent sessions were structured according to the following Areas of Collaboration (AOC) which emerged from discussions:

- ***Place-based lessons learned/regionalism.*** There are a number of CDR initiatives that have been successfully undertaken in respective jurisdictions. How can systemic lessons be effectively transferred?
- Transition between grant funded technology focused projects to ***business model/corporate level going concerns in order to crowd in private capital*** and generate functioning CDR and associated markets.
- How can ***academic generated evidence be translated into policy more efficiently*****?**
- ***Cross-cutting/shared interest.*** What systematic insights that should be shared across jurisdictions?

These are unpacked in section 5.3.

5.3. Mapping collaboration opportunities based on presentations and discussions.

The opportunity space for AOC as identified by the presentations outlined:

	Place-based/regionalism	business models: crowding in private capital and market creation	Academic evidence into policy	Cross-cutting/shared interest
1. Noah Deich: US DoE initiatives 2020 to 2024	• Infrastructure Law Bill $20.5 B in Hubs, testing and piloting for CDR. • Lessons learned – nimble, crowd in private sector, bankability and support infrastructure.	• Advocate for scale: encourage other governments and private voluntary actions.	• Preparation to scale: (1) ensure high-quality carbon accounting standards; and (2) support communities to advance projects.	• Leadership – take the baton from the last 4 years of US work. • Build successful projects. • Need for real projects on the ground for people to visit.
2. Rajinder Sahota: Californian initiatives	• Economic cost of climate change • LULUCF/NBS fundamental through natural and working lands. • CARB SB905 – establish a CCUS programme of which CDR is a part.	• 20MtCO_2 CDR by 2030 and 100 MtCO_2 by 2045 advocated through Governors Letter.	• CARB 905 establishing workshops with stakeholders. • Open questions to support regulatory development: permit, project and financial.	• Success in jurisdictions creates confidence to move forwards.
3. Daniel Kelter: Canada initiatives	• Canada has resources: land, industrial base, geological storage.	• Need to generate narrative. • Generate demand signal. $10M has been set aside as an initial/pilot purchase for permanent CDR. • Accelerate deployment	• 70 to 100 CDR companies based in Canada. • Legislatively required to set a 2035 climate target by 2025. • Collaboration on (1) policy; (2) G7 procurement; and (3) innovation funding.	
4. Mai Bui: UK Industrial Decarbonisation Clusters (IDC)	• IDC enabled engineering designs and demonstration with shared infrastructure; investment plans; multi-disciplinary research. • Clear route map to 2040 net zero.	• £270M public funds leveraged £1B in private funds. • Accelerate deployment projects; generate plans and research.	• 5 Industrial clusters across UK deploying CCS, sub-sea storage, hydrogen, low-carbon power stations, industrial infrastructure, flexible greener energy systems and fuel replacement technology. • 14MtCO_2 captured by 2030, 1.3 GW of Blue H_2 and all clusters net zero by 2040: need for market signals, permitting, business models and collaboration	
5. Chris Manson-Whitton: Hynet Industrial Cluster	• ~1 MtCO_2 CDR EfW plants plugging into an existing CCS pipeline. • Low carbon H_2 T&S. • Demand-led decarbonisation: 28 private actors, 6 involved in CDR.	• HyNet: £5Bn of private capital in phase 1; no grants, i.e. based on revenue-stabilised business models so that the private sector can invest.	Delivering carbon dioxide removals: • The fossil sector should unlock the infrastructure. • Care needed with opportunity cost e.g., valuable electrons. • Target energy from waste, cement, post-consumer waste wood, biogas upgrading. • Permanence is fundamental.	
6. Tyson Eckerle: Go-Biz ARCHES	• California 1 of 7 regional hubs across US. • Objective to fully decarbonise the regional economy in California. • Biogenic sources for H_2 feedstock 95%. • H_2 Targets: 2023 – 6,820 Mtpa; 2030/2 – 190,000 Mtpa; and 17,054 Btpa.	• A public-private partnership to create a sustainable statewide renewable, clean hydrogen (H2) market and ecosystem in California and beyond. • Open RfP followed by negotiations with $50+ B in private sector interest. • $1.2B DOE funds unlocks $11.7B in matching funds.	Issues to address within hubs: • Environmental justice. • Equity. • Economic leadership. • Workforce development. • Hydrogen market viability.	

7. Andy Creek: Kana, building a market architecture with data	$4.25tn: Value of UK pensions and 50% of UK asset owners are already investing in natural capital or will do so within the next 18 months. Barriers to development: (1) lack of high-quality, real-time data; (2) hard to value; (3) difficult to monitor risks; and (4) high-touch processes require a lot of manual oversight. • Need to bring data together in a market architecture to get patient capital into the sector: forward pricing curve, asset pricing, etc. • Natural capital investing can offer exciting approaches and returns within existing asset classes: (1) infrastructure; (2) real estate; (3) private equity; and (4) other alternatives.		Any investment structure in nature capital will need different return strategies: • *Capital growth* – land appreciation over time, combine with protection of the underlying land asset due to climate risk mitigation. • *Value growth* – increased land productivity due to reduced flooding. More desirable land due to climate resiliency. • *Cash flow growth* – payments for delivering flood mitigation from beneficiaries (council., corporates, insurers). Carbon or biodiversity unit sales from target interventions on the property.
8. Jeff Allen Brown: Stanford Accelerator, GHG-R flagship	• Cross-departmental initiative: engineering, business, medicine, education, humanities and law. • Reimagining academia and its value to society. Vision: Create a future where humans and nature thrive in concert and in perpetuity. Mission: Deep understanding of Earth, climate, and society to co-create knowledge and scalable solutions, in collaboration with partners worldwide. • Reverse engineering ideas into impact – speed and scale! In order to speed translation of Stanford research into scalable technology and policy solutions that address urgent global sustainability challenges to improve the quality of human life and our planet. • GHG-R flagship: remove gigatonnes of carbon dioxide equivalents from the atmosphere by mid-century. 20 projects across: (1) atmospheric; (2) soil and forestry; (3) terrestrial; and (4) oceanic – see link.		

5.4. Collaboration space: provisional responsibility allocations for AOC

Building on the 4 AOC as per the framework outlined in section 5.3, above – the chair requested that individuals nominate the priority areas to develop going forward and/or offers of outreach. The following were articulated within each of the AOC including their provisional nominated leads:

5.5.1. Place-based lessons/regionalism.

- How fast can we go down cost curves? The need to get away from single-factor learning curves to multi-factor, bottom-up learning curves for individual CDR value chains[17] **(Stanford).**
- What are the workforce benefits for the establishment of CDR sectors? What are the types of jobs, timeframe that jobs are generated and distributional implications? **(CCST)**
- How can trust be built within communities to develop CDR infrastructure projects? **(CARB).**
- Knowledge transfer workshop in Hynet, UK to allow sharing of best practice **(Progressive Energy).**

5.5.2. Business models to crowding in private capital – scaling through duplication

- Need for an investment model that crowds in $trillion-scale investments from asset managers such as Blackrock, Abu Dabi Sovereign fund, KKR, Brookfield etc. This requires market infrastructure and project best practice to be established and trust to be generated through a Raise -> Deploy -> Manage framework.[18] Once established in a progressive jurisdiction such as California, Canada and/or UK then should be duplicated and transferred to other jurisdictions that have the resources and appetite to establish a CDR sector. An initial first step in would likely involve policy-makers engaging in a direct dialogue with investors **(GO-Biz; CARB and Kana)**.
- The above investor centric perspective can then be used to shape the Standford initiative led by David Hayes his Policy Lab – which is seeking to improve accessibility to trusted climate performance data – in an initiative called *"Bridging the Climate Data and Decision-Making Divide".* The CDR theme is in need of structuring, which any investor-led initiative would facilitate and more importantly generate a path dependent route to scaling **(Stanford)**.

5.5.3 Academic evidence into policy

- Conducting a landscape analysis of policy-makers needs around CDR space possibly prioritised around a marginal abatement cost curve **(CCST and LLNL).**
- Rapid prototyping experimentation and piloting to learn lessons as per the culture generated at the Doerr Sustainability Accelerator at Stanford. Culture of the willingness to share data and get the material into the policy domain **(Stanford)**.
- *'Research Charter'* across geographical jurisdictions for prioritised CDR policy needs e.g., Stanford, Berkeley, Oxford, Imperial, plus other universities involved in CO_2RE and other US National Labs based in California. Need for an interdisciplinary culture and a unifying purpose **(CO_2RE-Stanford-LLNL-UNU).**
- Establishment of a repository of best-in-class CDR evidence accessible to policy-makers. Note that there was a Global CDR Excellence Invitation run in Abu Dabi on 24 Feb 2025 by Oxford, UK FCDO and the Bridge Institute **(CO_2RE-Stanford-LLNL-UNU) – *Mark to follow-up in the first instance via DESNZ*.**

5.5.4. Cross-cutting/shared interest

- Reframing the net zero agenda/overapplication of the Precautionary Principle: capacity generation and education amongst audiences and publics. Effectively communicating the 'do nothing' counterfactual is critical **(Project 2030/CARB).**
- Understanding the fundamental role of nature-based solutions **(CARB/GO-Biz).**
- Language and standards **(CO_2RE).**
- What is the target cost that is being considered for economically acceptable CDR – is it $100 t$CO_2$? Under what techno-economic assessment framework – see above in 4.1? **(Stanford)**
- MRV needs to be cents in the dollar rather than the proportions that they presently make up costs which can be up to 50%[19] **(Stanford).**

It is noteworthy that a multi-day conference was tentatively proposed by CCST, which if scoped appropriately, would potentially shape/provide a framework for all of these initiatives, facilitate the sharing of success across jurisdictions and understand gaps that need addressing (CCST).

There was clear appetite to share lessons across jurisdictions. It was also clear that the needs of each jurisdiction and the members that made up each region sought very different interactions with counterparties. The heterogeneity of the needs being a manifestation of the technologies that make up the CDR sector and the very different way that CDR policy initiatives and start-ups have been established and scaled in UK, California and Canada. This suggests that a bottom-up approach to institutional systems to share success and disseminate best practice.

6. A bottom-up approach to the establishment of institutional systems to share success and disseminate best practice – "Carbon Dioxide Removal Knowledge Exchange Hub" to a Global Centre of CDR Excellence

6.1 Conceptual framework: pain-points that need to be addressed

The CDR initiatives in California, Canada and UK have been generated in isolation, with interventions tailored to specific geographical jurisdictional strengths, innovation frameworks and actor needs. Based on the insight from the roundtable on 21st March there are limited mechanisms for knowledge exchange and sharing of successes across jurisdictions from the last 5 years.

Any knowledge exchange hub would therefore need to address the following:

- the limited mechanisms for knowledge exchange and sharing of successes across jurisdictions; and
- that risk sharing collaborations are needed to reduce uncertainty for CDR ventures.

Knowledge exchange mechanisms should facilitate:

- Facilitate process, commercial and technology innovation for CDR ventures;
- Share success and best practices across jurisdictions;
- Explore collaborations and partnerships for the next phase of negative emissions investment;
- Explore new policy design approaches which capture of the sector's complexity at the frontier of market development to address demand uncertainty; and
- Risk-sharing public-private approaches allow governments to guide the sector whilst providing a backstop to risk for private sector partners.

Who is the knowledge exchange hub for…?

- Governments (federal/national, state, municipal)
- Incumbent energy-intensive sector (CCS T&S Spine Network)
- Innovators (incumbent spin-outs doing new things & new entrants)

A bottom-up approach would allow a number of polycentric initiatives that are being established which are tailored to specific partners needs e.g. The FCDO-Abu Dabi-Bridge Institute Centre of Excellence, the State of CDR Head of Partnerships, National Advance Market Commitment Initiative, and this California-Canada-UK collaboration, etc. The polycentric initiatives can be stitched together based on the different strengths, divergent initiatives and policy interventions in different jurisdiction by *'Start by starting'* scaled experimentations to test, iterate and improve the knowledge exchange propositions from the bottom-up through governance framework through a virtual infrastructure and then physical. The physical aspects might be considered a Centre of Excellence.

Experimental mechanisms will be established to share knowledge to calibrate assumptions are sound and inform both how the knowledge exchange ecosystem should be governed, and how best to extend the range and scope of future activities. When the ecosystem seeks multiple actors collaborating on generating insight which influences government and regulatory policy and will be viewed by participants as fair and representative – kernels of success can be considered to have been realised.

Over time, the ecosystem might successively increase in scale and complexity, involving more innovators on opportunities of widening scope. It will build consensus and international architectures for CDR development. A schema as to how it might be developed is made below via 3 horizons – see figures 2 and 3.

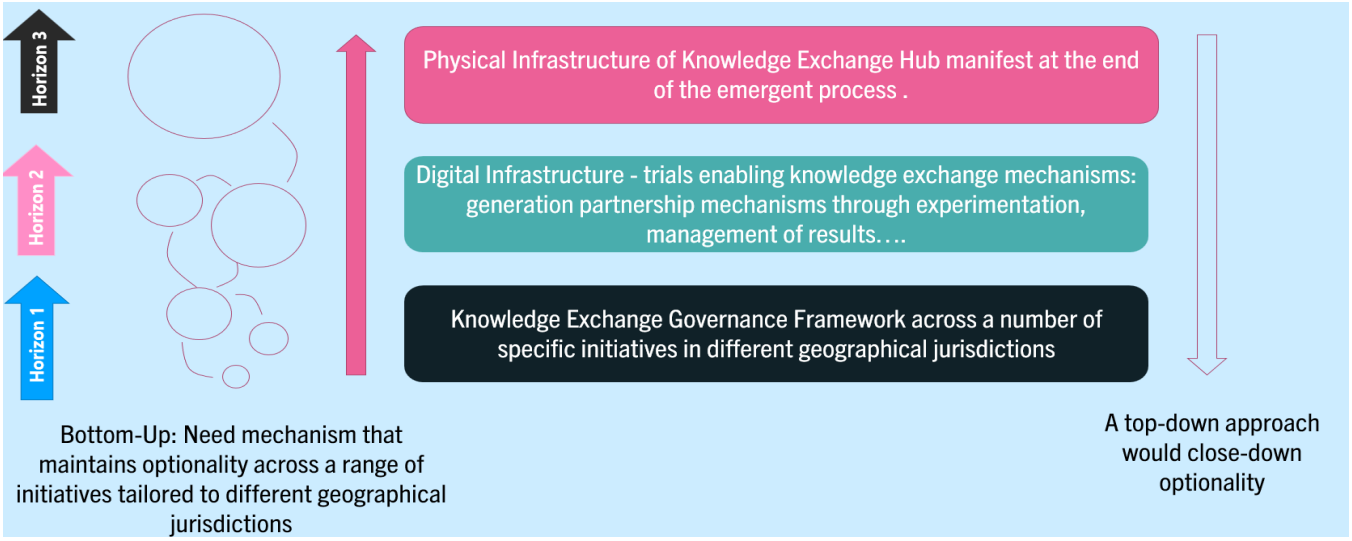

Figure 2 *shows how a bottom-up approach can allow the tailoring of initially bilateral relationships between CDR centres of development in a lean way keeping optionality open through getting the governance established to facilitate knowledge exchange (Horizon 1), then stitching together new partners through digital infrastructure (Horizon 2) and then finally emergent is a physical knowledge exchange hub which might be a centre of excellence – Horizon 3.*

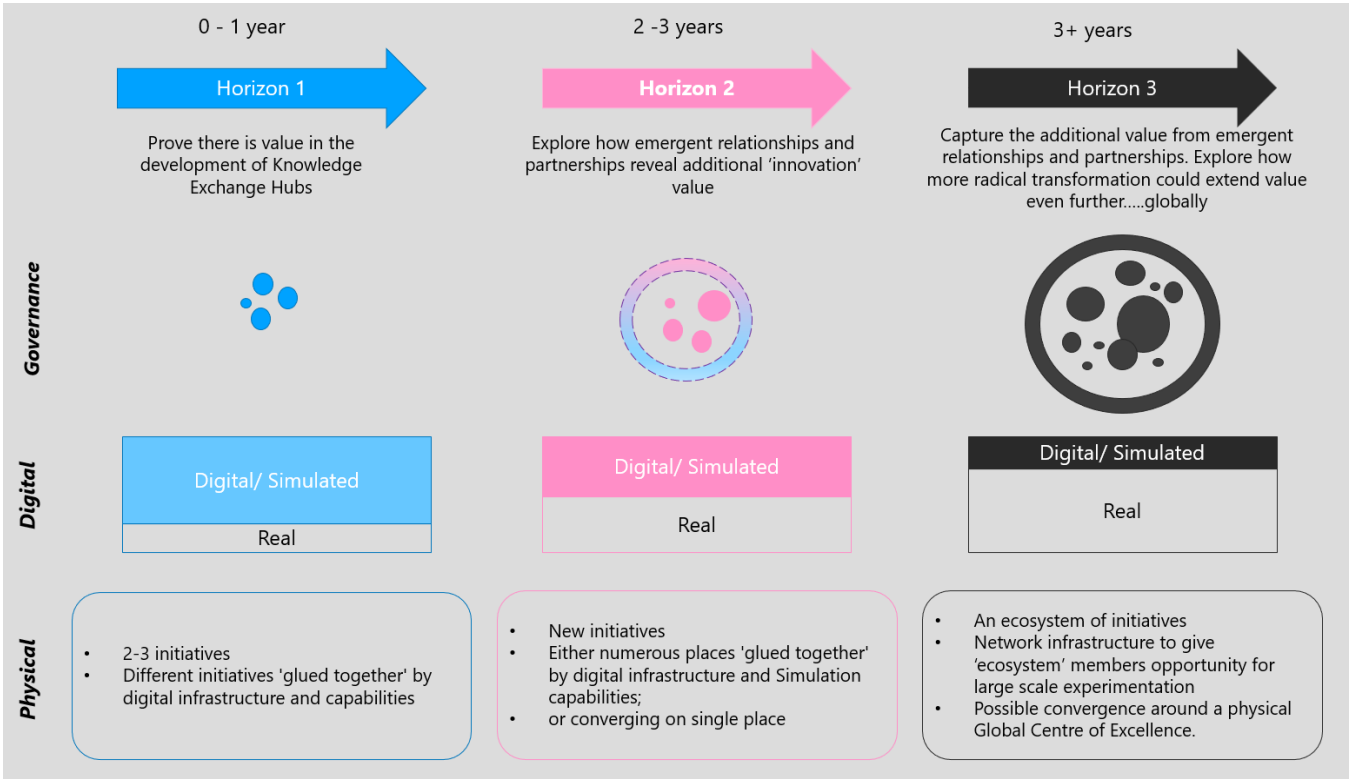

Figure 3: *Timeline and schematization of how the knowledge exchange hub would evolve from simple relationships established from the bottom up across Horizon 1 to 3 and the role of governance and digital infrastructure in maintaining optionality.*

7. Next steps: integration with other ecosystem 26+ workshops and GGR-D Programme insights

The US Ecosystem 26+ engagement has generated much insight and allowed further fidelity as to how the US is operationalizing its substantive CDR subsidy regime, the uncertainty created by the 2024 Presidential election and the opportunities that might arise from collaboration and co-ordination.

With the CDR sector needing to become a global industry the need for collaboration and co-ordination is essential. It is glaringly absent at present across data, market infrastructure, technology, commercial and business model dimensions etc. Like UK CDR actors, US actors are seeking to transition to the next stage of CDR sector establishment, development and scaling. The initiatives interviewed suggest that there is a substantive focus on technology development and little on commercialisation and market development. It is clear that the US CDR sector requires an urgent, deliberate and strategic shaping set of state and federal interventions to generate commercial opportunities – which will be extremely unlikely to materialise under the present US Administration. The withdrawal of the US from international climate initiatives will therefore mean that bottom-up initiatives will be more likely to result in advancement of the sector. The opportunity and collaboration space has been shaped by the convening of a roundtable in Sacramento on 21st March.

With CO_2RE funding coming to an end in Q3, 2025, this initiative will be handed over to the State of the CDR sector Head of Partnerships under the supervision of Professor Greg Nemet who is seeking an institutional mechanism to share best practice at a global level, as well as via Noah Deich the former senior advisor at the US Department of Energy's Office of Fossil Energy and Carbon Management (FECM). Timing is as important with the UK government being very interested in engaging in a collaboration. They were, however, keen to ensure that the UK had delivered a project to showcase and therefore engage meaningfully in any collaboration including the proposed *'Sharing of Success'* Conference and proto-knowledge exchange platform. This might therefore mean that the Horizon 1 articulated as part of the proposal to develop the relationship between the Californian state government, Canadians and the UK government be extended to late 2026 and/or early 2027.

Annexes:

1: Agenda and attendees for the Sacramento Mapping Roundtable

2: Sacramento Mapping Roundtable reference materials

3: References

Annex 1: Agenda and attendees

A1.1. Attendees

US/California

- ***In-person***: Craig Segall, independent (Chair); Roger Aines, Lawrence Livermore National Laboratory; Jeff Allen Brown, Stanford Doerr Sustainability Accelerator – GHG-R Flagship; Rhianna Hohbein and Jason John, California Council On Science & Technology; Tyson Eckerle, GO-Biz; and Deepika Nagabushian, Project 2030.
- ***Remote****:* Rajinder Sahota, CARB; Jan Mazurek, Climate Works Foundation; and Noah Deich, Stripe Fellow.

Canada

- ***In-person***: Miriam Aczel, United Nations University.
- ***Remote:*** Daniel Kelter, Carbon Removal Canada.

United Kingdom

- ***In-person:*** Natasha Martirosian, David Contreras Diaz and Mark Workman, CO_2RE.
- ***Remote****:* Mai Bui, Industrial Decarbonisation Challenge, Innovate UK; Chris Manson-Whitton, CEO, Progressive Energy (Hynet Industrial Cluster); Andy Creek, CEO, Kana; and Steve Smith, Executive Director, CO_2RE

A1.2 Agenda

Scope of session

The roundtable will cover **'Carbon Dioxide Removal and their associated technologies: their potential application in industrial decarbonisation and economy wide net zero.'** This therefore frames the session as the technology value chain that is essential to address residual emissions from hard to abate sectors as well as the associated technologies of which carbon capture and storage infrastructure will be an integral component.

The intended outcome will be to shape a proposition as to how success might be shared across geographical jurisdictions in the next 4 years and the mechanisms by which that might be operationalised.

09:00: Coffee and networking at the Carmel AB, Hyatt Regency Sacramento.

09:15: Online attendees to call in.

09:30 (PST/16:30 GMT) to 11:30 (PST/18:30 GMT) – Session 1:

- Chair to call the meeting – introductions and ethics.
- Presentation by Dr Steve Smith, Executive Director CO_2RE Hub and Oxford Net Zero.
- ***National and State CDR initiatives*** – (12 minutes + 3 Q&A) (1) US: Noah Deich; (2) California: Rajinder Sahota; (3) Canada Daniel Kelter; and (4) UK: Dr Mai Bui.
- *Might be subject to some reordering with Rajinder's possible appointment at the Governor's office.*
- ***Regional agendas*** – (5 minutes + 5 Q&A) (1) GO-Biz, Tyson Eckerle; (2) Progressive Energy, Chris Manson-Whitton; (3) Kana, Andy Creek; and (4) Stanford GHG-R Flagship Doerr Accelerator, Jeff Allen Brown.

11:30 to 11;50 (PST/18:30 to 18:50 GMT) – break and coffee.

11:50 to 13:00 (PST/18:50 to 20:00) – Session 2: Strengths and gaps/opportunities for collaboration' across geographical jurisdictions will be prioritised for discussion. Objectives of the session include:

- Identifying the most beneficial paths to advance the CDR sector with an understanding of top 3 areas for collaboration across the jurisdictions.
- Explore how potential/possible collaborations might be realised across a number of existing mechanisms and/or the identification of the need for new ones as considered justified.

13:00 to 13:15 (PST/20:00 to 20:15 GMT) – some UK participants to leave and break for working lunch.

13:15 to 14:15 (PST/20:15 to 21:15 GMT) Session 3 – based on the outputs from Session 2 detail as to potential next steps forward. Objectives of the session include:

- Explore potential steps forward: how to operationalize components of the collaboration unpacked in Sessions 1 and 2.
- Timeline with go/no-go decision gates.

14:15 (PST/21:15 GMT) – Chair calls the meeting to a close and disperse.

Annex 2: Reference materials

The following materials were made available by participants of the meeting on 21st March in the work-up to the meeting and/or from material within their presentations:

UK

- Innovate UK – Enabling net zero: progress on deploying CCS to decarbonise UK industrial clusters.
- **Challenge Completion Report –** summary of programme and the achievements. https://www.ukri.org/wp-content/uploads/2024/07/IUK-29072024-Industrial-Decarbonisation-Challenge-External-Completion-Report-Digital-V1.pdf
- **Enabling Net Zero – A Plan for UK Industrial Cluster Decarbonisation.** Summary of the regional cluster plans and how they contribute to Net Zero. https://www.ukri.org/publications/enabling-net-zero-a-plan-for-uk-industrial-decarbonisation/
- **Enabling Net Zero – Progress on Deploying CCS to Decarbonise UK Industrial Clusters.** Summary of the infrastructure projects and recommendations for action - https://www.ukri.org/wp-content/uploads/2024/10/IUK-111024EnablingNetZeroProgressDeployingCCSDecarboniseUKIndustrialClusters.pdf
- A fairly recent HyNet overview report. IDC-Report.pdf
- Interesting document from Viridor, one of our energy waste partners, on how they plan to be a "Climate Positive" company (their much better terminology for "Negative Emissions"/CDR). vir020_vision2045_carboncapture_awasteopportunity_60.pdf
- A brief HyNet video (Covers wider HyNet).

Carbon Removal Canada:

- RFI for the LCFPP and Carbon Removal
- GoC News Release: Government of Canada commits to purchase carbon dioxide removal services to green government operations and achieve net-zero emissions
- GoC News Release: President of the Treasury Board announces plan to support greener government operations
- Ready for Removal policy report
- Procuring with Purpose policy report

US

- State's actionable climate plan here: 2022 Scoping Plan Update

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[2] Committee on Climate Change, 2020. Sixth Carbon Budget dated 17th December 2020.

[3] https://www.CDRprogramme.org.uk/ and https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-ccus-track-1-cluster-sequencing-evaluation

[4] Cuthbertson, M., et al. 2024. Without mandated demand for Carbon Dioxide Removal – High integrity GtCO2-scale global deployment will be jeopardized: Insight from US economic policy 2020–23. Applied Energy 372 (2024) 123806.

[5] Financial Times dated 28th January 2025. US judge blocks Donald Trump's plan to freeze federal grants and loans. Temporary order caps day of chaos as White House forced to clarify move to halt government programmes.

[6] Smith, S. M., Geden, O., Gidden, M. J., Lamb, W. F., Nemet, G. F., Minx, J. C., Buck, H., Burke, J., Cox, E., Edwards, M. R., Fuss, S., Johnstone, I., Müller-Hansen, F., Pongratz, J., Probst, B. S., Roe, S., Schenuit, F., Schulte, I., Vaughan, N. E. (eds.) The State of Carbon Dioxide Removal 2024 - 2nd Edition. DOI 10.17605/OSF.IO/F85QJ (2024). https://www.stateofcdr.org/edition-2-resources-1

[7] Hardisty, A and Workman, MHW., 2024. A Collective Intelligence assembly approach to informing responsive net zero policy design: A Carbon Dioxide Removal UK case study. Collective Intelligence Volume 3:2: 1–15 DOI: 10.1177/26339137241254099. https://journals.sagepub.com/doi/full/10.1177/26339137241254099

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