Written evidence submitted by the Greenhouse Gas Removal Demonstrators (GGR-D) Programme

The Greenhouse Gas Removal Demonstrators (GGR-D) Programme consists of five demonstrator projects, investigating novel removal techniques at various sites around the country, and a national Hub named CO_2RE. Funded by UKRI, it is the largest research programme on the topic and includes leading researchers and experts from universities across the UK. Our expertise covers economics, environmental science, engineering, systems modelling, law, social science and business & innovation studies.

We have track records of working in this area with industry, publics and policymakers, and welcome the opportunity to inform Parliament's thinking.

Here we provide answers to specific questions in the Call for Evidence document regarding Negative Emissions Technologies (NETs), which is an equivalent term for Greenhouse Gas Removal (GGR).

What contribution could NETs (through DACCS, BECCS, and/or other NETs) make to achieving net zero by 2050?

There is a wide range of NETs that can feasibly contribute. These approaches are well-characterised in a 2018 report on Greenhouse Gas Removal by the Royal Society and Royal Academy of Engineering[1] (to which several members of the GGR-D consortium contributed). The report finds that a range of methods give a UK technical potential for 2050 of around 130 million tonnes of CO2 per year ($MtCO_2$/yr). This is very much an upper estimate, given the other barriers to deployment discussed below.

Regarding the scope of this particular enquiry, there is no clear and universal distinction between "nature-based solutions" and "technological solutions"[2]. We find it more useful to categorise NETs by the ultimate form of storage involved, and the methods of carbon capture and conversion involved. Storage can be grouped broadly into two forms: geological (*e.g.*, underground in depleted oil and gas wells or saline aquifers, or by mineralisation) and biological (*e.g.*, woodland, soils and wetlands).

Here in our response we focus on methods involving geological storage, as these include BECCS and DACCS and all tend to be at an earlier stage of development. It is important to keep in mind the wider forms of NETs, though, and that a portfolio approach which includes all of these is desirable.

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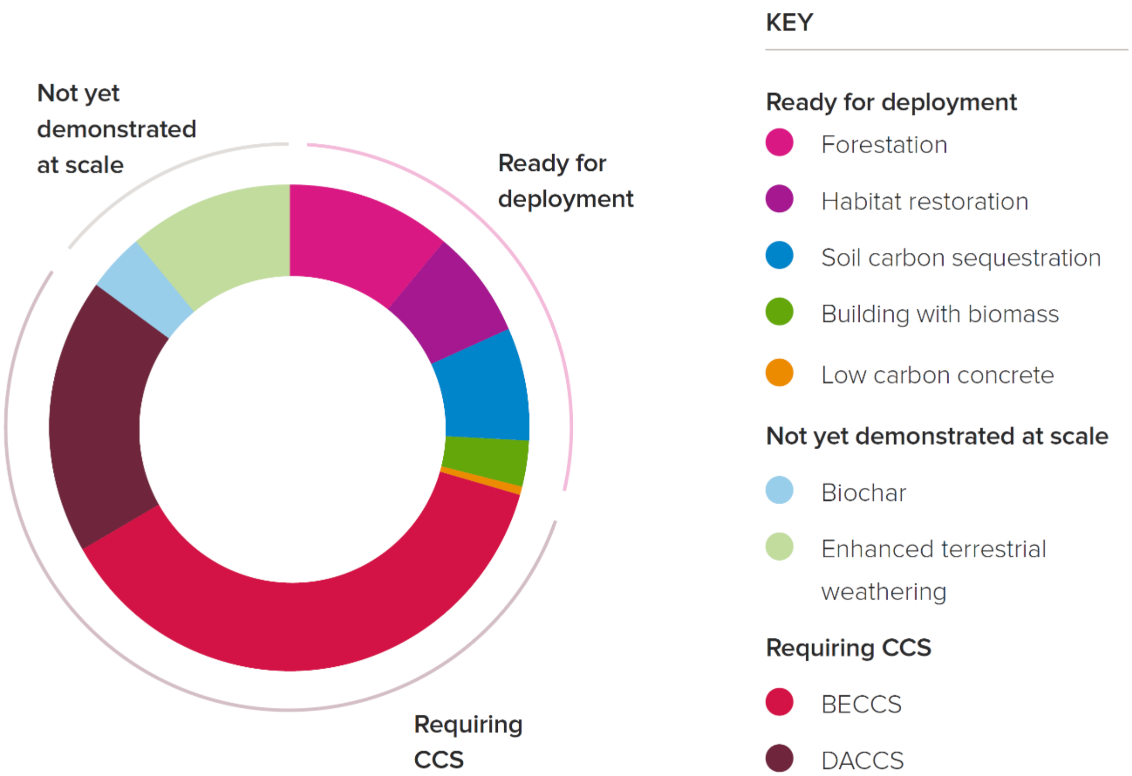
[1] Royal Society and Royal Academy of Engineering (2018) Greenhouse Gas Removal

[2] Osaka S & Bellamy R (2021) Framing "nature-based" solutions to climate change. WIREs Climate Change



Range of feasible NET approaches, and their technical potential in the UK for 2050 as a fraction of the ~130 $MtCO_2$/yr total (left). Source: ref [1]

Which 'hard to decarbonise' sectors could benefit most from NETs, and which should be prioritised?

'Hard to decarbonise' sectors are often assumed to include agriculture, aviation and shipping[3,4]. None of these sectors are without opportunities to reduce emissions, however, and there is evidence that often-assumed high levels of future demand are neither necessary nor inevitable[5,6]. Hence, in choosing what to prioritise, it is important to avoid over-allocating emissions "space" for particular sectors and to avoid over-reliance on NETs.

At what technological stage are current NETs, and what is the likely timeframe that will allow NETs to be operational at scale in the UK?

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[3] Lóránt A & Allen B. Net-zero agriculture in 2050: how to get there? Report by the Institute for European Environmental Policy (2019)

[4] Committee on Climate Change. *The sixth carbon budget.* The UK's path to Net Zero. (2020)

[5] Gössling, S., Hanna, P., Higham, J., Cohen, S. & Hopkins, D. Can we fly less? Evaluating the 'necessity' of air travel. *Journal of Air Transport Management* **81**, 101722 (2019)

[6] Committee on Climate Change. *Policies for the sixth carbon budget and net zero*. (2020)

NETs refers to a range of approaches with different characteristics. A recent report published by BEIS [7] sets out these approaches, their technology readiness levels (TRLs) and potential timeframes for scaling. Biological NETs are generally more mature and lower cost, however all NETs face some uncertainty in scaling due to the influence of wider system factors such as land availability, infrastructure timelines, accounting methodologies, and funding.

For DACCS, there are a number of non-commercial demonstration units around the world, such as Climeworks and Carbon Engineering. For BECCS, Drax in the UK has demonstrated commercial scale combustion of biomass, together with the pilot scale capture of CO_2 from a biomass exhaust stream. More generally, this technology has been demonstrated globally in the context of natural gas sweetening since around 1930. In North America, several thousand miles of high-pressure CO_2 pipeline have been transporting 10's of millions of tonnes of CO_2 since the 1970s. Geological storage has been safely operated in the North Sea by Norway for 20 years. In other words, all elements of the BECCS supply chain have been demonstrated at scale.

With other NETs, *e.g.*, biochar, enhanced weathering, and afforestation, the challenge is not so much the capture of carbon, but rather the monitoring, reporting and verifying (MRV) of the carbon stock. MRV protocols for these are largely undeveloped, and without them there is no prospect of their commercial deployment in a compliance-based context.

HMG's net zero strategy has articulated an ambition to remove 5 $MtCO_2$/yr of CO_2 by 2030, which is eminently achievable with BECCS and DACCS, subject to the availability of adequate CO_2 transport and storage infrastructure (which is also required for the deployment of CCS technology more generally for power, industry and hydrogen generation).

What are, and have been, the barriers to further development of NETs? How can such barriers be overcome?

We have identified six broad societal needs in order to achieve NETs at scale by 2050 in the UK:

- A clear strategic vision for NETs, to ensure buy-in across supply chains. The government has made a step forward in this regard with its target of 5 MtCO2/yr removal by 2030.
- Social robustness, developing an ethical and social license to operate. Deployment at scale needs to align to publics' wider values regarding their work, their environment, and fair procedures. Any perception that NETs are being used to justify high-carbon policies elsewhere in the economy will be extremely damaging[8,9].
- Innovation bringing down technology costs. The UK has innovation capabilities within research institutions, universities and the private sector which can be brought together to create spill-over effects[10] and sufficient critical mass to deliver cheaper, more scalable NETs. A report for the

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[7] Element Energy and the UK Centre for Ecology and Hydrology for BEIS. Greenhouse gas removal and their potential UK deployment. (2021)

[8] Cox, E., Spence, E., Pidgeon, N., 2020. Public perceptions of Carbon Dioxide Removal in the US and UK. Nature Climate Change.

[9] Cox, E., Pidgeon, N., Spence, E., 2021. But they told us it was safe! Carbon dioxide removal, fracking, and ripple effects in risk perceptions. Risk Analysis. Article in Press.

US Government in 2019[11] highlighted the vital role that federal funding played in the past in delivering technologies we enjoy today; this was echoed by a recent paper on public investment in renewables[12]. Both argue that public funding will be highly effective at mobilizing private investment when developing clean technologies[13].

- Supportive policies and governance, enabling successful business models to emerge. Most significantly, the carbon removal sector lacks a market to support the deployment of NETs. The NETs options that currently look most scalable require infrastructure for CO_2 transport and storage, and so business models are a shared need with CCS development for other uses in energy and industry.
- Strong MRV (Monitoring, Reporting and Verification). International accounting rules for BECCS are in place[14] but different aspects of bioenergy lifecycle (land use change, cultivation, transport, conversion, capture and storage) are reported in different sectors. As a result, the whole lifecycle effects of bioenergy systems are not well captured by national greenhouse gas inventories. Moreover, there are currently no accounting rules in place for reporting of DACCS[15].
- Decision-support tools for government, businesses, land managers and investors. This includes improved representation of different NETs in models used by BEIS and others to determine pathways to meet climate goals. Given the deep uncertainty around NETs and long-term mitigation actions more generally, tools need to allow diverse decision-making groups with different value sets make decisions which are robust to future scenarios[16] .

What, if any, are the links and co-benefits to other technological innovations, such as sustainable aviation fuel or sustainability in the energy sector?

Sustainable aviation fuels can be derived from biomass feedstocks and direct air capture. Advances in these areas will therefore benefit both low-carbon fuels and BECCS and DACCS. Analysis suggests that low e-fuel costs are contingent on substantial reductions in the cost of DAC, currently representing 15-25% of fuel cost[17].

Moreover, BECCS and DACCS require infrastructure for CO_2 transport and storage, and so business models to support this are a shared need with CCS development for other uses in energy and industry, which also have a strategic role to play in reducing emissions[18]. More generally, monetizing the collateral benefits associated with GGR deployment, would ultimately reduce their costs.

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10 Edgerton 2010 -Britain's War Machine -Chapter 8: Boffins. Penguin Books pp442.

11 Energy Futures Initiative and Bipartisan Policy Centre 2019 -Carbon Removal: Comparing Historical Federal Research Investments with the National Academies' Recommended Future Funding Levels

12 Deleidi, M; Mazzucato, M and Semienuk, G (2020) Neither crowding in nor out: Public direct investment mobilising private investment into renewable electricity projects. Energy Policy, 140, 111195.

13 Mazzucato 2014 The Entrepreneurial State, Anthem Press. pp237

14 IPCC Guidelines for National Greenhouse Gas Inventories from 1996, and relevant updates from 2006 and 2019

15 .Global CCS Institute 2021 - Carbon Removal with CCS technologies. dated January 2021 pp13

16 https://doi.org/10.1016/j.envsci.2019.10.002

17 Sherwin E.D. Electrofuel Synthesis from Variable Renewable Electricity: An Optimization-Based Techno-Economic Analysis *Environmental Science & Technology* **2021** *55* (11), 7583-7594

What are the trade-offs between availability of land and availability of sustainable biomass to make NETs a viable option in and beyond the UK?

Land requirements depend not only on demand for biomass but also land productivity. Management practices can increase productivity and therefore help reduce trade-offs. For instance, since 1950, the southern US has maintained approximately 82 Mha of forested land under management. During this time, the amount of biomass on land has more than doubled (5.2 -> 10.8 billion m^3), together with the amount of biomass being harvested (from 142 to 272 million m^3)[19]. This is the source of some biomass used by UK power plants which could be converted to BECCS.

Opportunities of reducing land use may also arise when biomass feedstocks are cultivated to maximize carbon sequestration (under- and over-ground), rather than the production of useful energy[20].

What are the options for the storage of captured carbon, whether onshore or offshore?

Storage in depleted gas fields is the most important storage type for the UK, with low risk and wide regional distribution[21]. The UK's opportunities for depleted oilfield storage occur in the Central and Northern North Sea, closest to capture opportunities for emissions in Scotland. Saline aquifer storage opportunities have potentially large scale and widespread distribution around the UK, and major potential is identified in the Southern North Sea and offshore Scotland, both of which should be progressed as a fallback to oil and gas options.

What other drawbacks for the environment and society would need to be overcome to make NETs operational?

Many NETs have potentially significant impacts on biodiversity, especially when applied at scale necessary for meaningful removal. For BECCS in particular, the areas of highest potential bioenergy yield overlap significantly with current and future protected areas[22]. Since DACCS systems generally avoid land use change, food competition and ecosystem implications (*e.g.*, soil quality change), they are likely to cause less harmful environmental side-effects compared to biologically-based NETs. However, in addition to posing water issues in some water scarce areas, DACCS causes release of pollutants due to raw material production, i.e., chemical manufacture. These side-effects need to be carefully investigated to determine the overall effectiveness of each method.

Several potential social drawbacks need to be addressed. Nature-based solutions (NbS) tend to be perceived as more benign, and as delivering co-benefits for publics and environments. To some extent this is correct;[23] however, this also stems from the way in which NbS have been framed in research and in policy,[24] and from challenges in adequately communicating the scale at which these techniques would

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[18] BEIS. Net Zero Strategy: Build Back Greener. (2021)

[19] Forest2Market. Historical perspective on the relationship between demand and forest productivity in the US South.(2017)

[20] D. Sandalow, R. Aines, J. Friedmann, C. McCormick and D. Sanchez, Biomass carbon removal and storage (BiCRS) roadmap, ICEF (2021)

[21] IEAGHG technical report. CCS deployment in the context of regional developments in meeting long term climate change objective (2017)

[22] The Royal Society. Greenhouse gas removal. (2018)

[23] Smith, P. *et al.* Land-Management Options for Greenhouse Gas Removal and Their Impacts on Ecosystem Services and the Sustainable Development Goals. *Annual Review of Environment and Resources* **44**, 255–286 (2019).

need to be deployed[25]. There is public concern that NETs are a 'non-transition', failing to tackle the root cause of the problem, or that they will be used to allow elites and businesses to continue their unsustainable activities[18]. One means of overcoming this would be to position NETs as part of a joined-up policy narrative for tackling climate change, including a portfolio of measures to reduce emissions across all parts of the economy, and a halting of policy support for high-carbon activities. A further issue is that a large majority of the UK public now perceive climate change as immediate and urgent.[26] Unfortunately, this means that novel NETs are perceived as likely too slow to address the issue, at the same time as being unsustainable in the long-term. Resolving this temporal dilemma is a priority for societal acceptance of NETs deployment.

Given the proposed role of NETs in climate change modelling, is there a danger of over-reliance on these technologies in net zero strategies?

Models used to generate global mitigation pathways currently include few NETs approaches (usually BECCS and afforestation). This is part of the reason for large-scale deployment in these pathways, and attendant concerns. To avoid irreversible negative impacts on natural ecosystems, the inclusion and evaluation of a wider range of NETs approaches is crucial[27,28].

Risk of over-reliance stems not only from exceedance of sustainable levels, but also the fact that these technologies are currently at very small levels of deployment and may not scale as planned. While this applies to BECCS, DACCS and some other NETs, it applies too to some emission-reduction technologies such as low-carbon aircraft. A mitigation-wide approach to avoiding over-reliance on speculative techniques and reducing deployment failures is thus needed. Government could address this by setting targets to over-achieve the desired outcome, and/or redundancy in measures to achieve those targets[29].

How should the UK Government support the further development of NETs?

We address this question in the context of priorities for the "immediate term", i.e., within this parliament, and in the medium term (*e.g.*, 2030 – 2050).

In the immediate term, UK Government will have an important role to play in actively supporting the commercial deployment of NETs and establishing frameworks for regulation and oversight for the ongoing audit of captured and stored carbon. Consideration of the way in which NETs will interact with

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[24] Bellamy, R. & Osaka, S. Unnatural climate solutions? *Nature Climate Change* **10**, 98–99 (2020).

[25] Cox, E., Spence, E. & Pidgeon, N. Public perceptions of Carbon Dioxide Removal in the US and UK. *Nature Climate Change* (2020).

[26] Capstick, S. *et al. Public opinion in a time of climate emergency*. (2019).

[27] Heck, V., D. Gerten, W. Lucht, and A. Popp. 2018. Biomass-Based Negative Emissions Difficult to Reconcile with Planetary Boundaries. *Nature Climate Change* 8 (2): 151–55.

[28] Smith, Pete, Steven J. Davis, Felix Creutzig, Sabine Fuss, Jan Minx, Benoit Gabrielle, Etsushi Kato, et al. 2015. Biophysical and Economic Limits to Negative CO2 Emissions. *Nature Climate Change* 6 (1): 42–50.

[29] Smith, S.M. A case for transparent net-zero carbon targets. *Commun Earth Environ* **2,** 24 (2021). https://doi.org/10.1038/s43247-021-00095-w

the Emissions Trading System (ETS) is also a priority. The current UK ETS[30] focuses on the right to emit and does not provide for credits generated by NETs.

Further development of NETs in the medium term will require addressing the six barriers identified above as well the roll-out of CO_2 transport and storage infrastructure. Clarity will be required on the carbon liability value chain, with whom the liability rests in the context of a reversal of any given sink, and finally clarity on ownership of long-term liability for the carbon sink. This is inherently complex, as stored CO_2 will have come from a range of sources. At the same time, ensuring that polluting sectors are reducing their emissions will be a necessary pre-requisite for public buy-in to NETs[31].

What policy changes, if any, are needed to ensure the UK gains a competitive advantage and remains at the cutting edge of this sector?

While the UK has several innovative NETs projects funded through UKRI and BEIS, it is important to note that other countries have an arguable advantage. There are existing NETs pilot plants in, *e.g.*, Switzerland, Canada and Iceland. Similarly, regions like Norway, Canada, or the US have existing CCS projects at commercial scale, whereas the UK has repeatedly failed to deliver CCS projects at commercial scale. There are a number of international examples from which lessons can be learned. These include the US, having well MRV rules for geologic sequestration[32], and the Northern Lights project in Norway, a cross-border CO_2 transport and storage infrastructure aiming at storing up to 1.5 $MtCO_2$ per year by 2024. The UK should seek to establish CO_2 transport and storage infrastructure, set world-leading MRV protocols and continue to incubate NETs innovation.

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30 Greenhouse Gases Emission Trading Scheme Order 2020

31 Cox, E., Spence, E. & Pidgeon, N. Public perceptions of Carbon Dioxide Removal in the US and UK. *Nature Climate Change* (2020).

32 NETL and DOE. Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations. (2009).