DNZ | DELIVERING NET ZERO

WORKSHOP BACKGROUND BRIEFING

GREENHOUSE GAS REMOVAL

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Greenhouse Gas Removal (GGR) refers to anything that removes and sequesters previously emitted greenhouse gases. Most of the focus is placed on removing carbon dioxide (CO_2). GGR is distinct from emissions reduction technologies, which reduce the entry of greenhouse gases into the atmosphere. A diverse range of GGR technologies have been proposed, at many different stages of technology development (see Table 1 and Fig. 2).[1]

WHY GREENHOUSE GAS REMOVAL?

The role of GGR in global climate projections varies widely, and the pathways developed by the Intergovernmental Panel on Climate Change (IPCC) (Fig. 1) have been critiqued for assuming the future availability of too much GGR. However, even the alternative proposals generally require some form of GGR, usually in the form of forestry.[2] GGR has also been proposed as a means of allowing the world to 'overshoot' temperature targets. Many 1.5°C scenarios involve some degree of overshoot, and therefore require GGR at very large scale in the latter half of the 21st Century to bring temperatures back down.[3] However, overshoot is an extremely risky proposal, because of the risk that GGR proposals might not emerge as planned, as well as the risk that feedbacks in the climate system might create irreversible effects. In this respect, cumulative emissions are far more important than the end target; higher cumulative emissions caused by overshooting will increase the severity of climate impacts on biodiversity, ecosystems and human society.

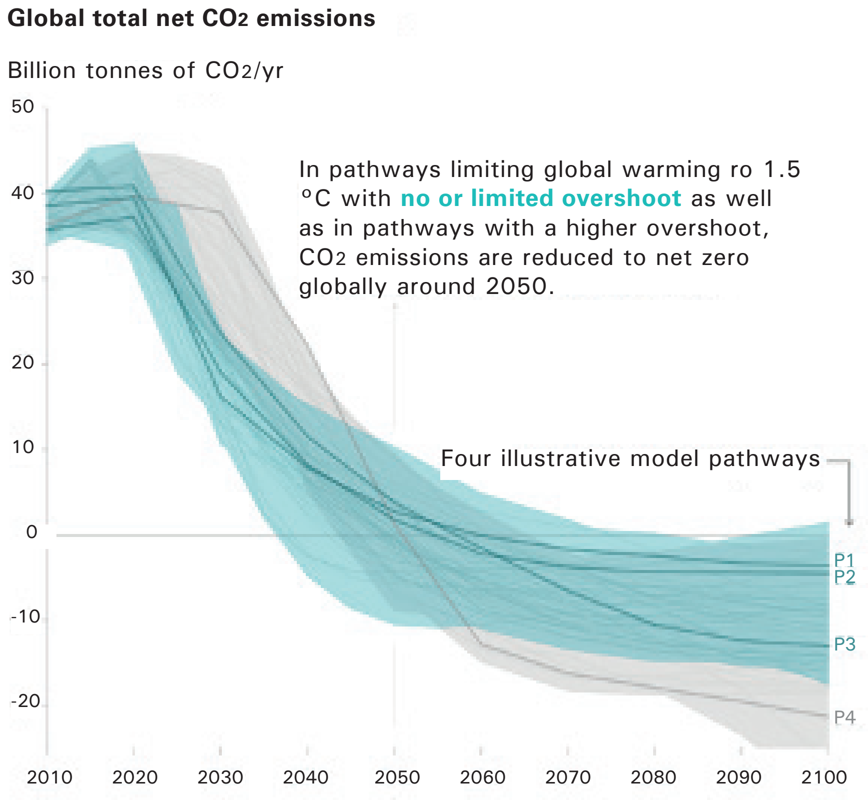

Fig.1. IPCC model pathways demonstrate the need for GGR to limit global temperature increase to 1.5°C

In the UK, the introduction of the net zero target means that some GGR will be required. This is primarily due to the probability of continued emissions from difficult-to-decarbonise sectors, such as aviation, shipping and agriculture. Recent estimates suggests that even in a scenario of hugely ambitious efforts to reduce emissions, the UK would need to remove and sequester 90 million tonnes of CO_2 ($MtCO_2$) every year by 2050 to compensate for recalcitrant emissions in these sectors.[4] For the UK, the most important goal remains to reduce emissions as much as possible, at least in line with the Carbon Budgets. GGR can then be used to abate the very small proportion of emissions which cannot reasonably be avoided. Not meeting near-term emissions reduction targets would be risky, because of the early stage of most GGR proposals and the risks associated with relying too much on such early-stage innovation.

The ClimeWorks plant in Switzerland, one of the world's first Direct Air Capture demonstration projects.
Image: Getty

GREENHOUSE GAS REMOVAL TECHNOLOGY PROPOSALS

Table 1: List of major GGR proposals and estimates of 2050 per annum CO_2 sequestration potential ('Seq') and a central estimate of cost. Table sources: Endnotes[1,7,9,13,23]

METHOD	DESCRIPTION	CONCERNS	SEQ UK	SEQ GLOBE	COST ($US/t)
Afforestation / reforestation	Planting trees or reforesting previously deforested areas	Land-use conflicts Release of CO_2 by disturbance, fire	15 Mt	0.5 – 3.6 Gt	5 - 50
Soil Carbon Sequestration (SCS)	Changing land management and farming practices to increase the carbon content of soil	Soils reach saturation Vulnerable to disturbance Increase of other GHGs from soil, e.g. NOx	0 - 10 Mt[5]	2 – 5 Gt	0 - 100
Habitat restoration	Restoring or constructing carbon-dense ecosystems e.g. wetlands, peatlands, coastal ecosystems.	Increased non-CO_2 GHGs e.g. methane Limited sequestration potential Competition for land	0 - 5 Mt[6]	?	0 - ?
Building materials	Building with wood; producing concrete which stores CO_2	Small overall sequestration potential Slow rate of turnover of new buildings	5 Mt	?	Negligible
Bioenergy with CCS (BECCS)	Biomass burnt to generate electricity or hydrogen, with CCS of the resulting CO_2	Limited biomass resource, land competition Environmental impacts Availability and safety of CCS sites	50 Mt	0.5 – 5 Gt	100 - 200
Biochar	Ag. waste burned via pyrolysis to produce charcoal, which is buried	Supply of biomass wastes Decreases surface albedo Impacts on plants and soils uncertain	0 - 5 Mt	0.5 – 2 Gt	30 - 120
Enhanced Weathering	Rock weathering accelerated by finely crushing rocks and spreading them on soils	High energy use from mining & crushing rocks Possible leaching of heavy metals into soils Alkalinity input to watercourses: impact unknown	15 Mt	2 – 4 Gt	50 - 200
Direct Air Capture (DACCS)	Industrial processes to extract CO_2 from ambient air, with CCS	High cost, not yet demonstrated at scale Noise and aesthetic impacts on communities Availability and safety of CCS sites	25 Mt	0.5 – 5 Gt	100 - 300
Ocean Fertilisation	Adding iron, nitrogen or phosphates to ocean water to stimulate phytoplankton growth	Potential disruption of the ocean carbon system Not as effective as hoped for removing carbon Prohibited by international law	0	0.5 – 44 Gt	0 – 460
Ocean Alkalinity	Increasing ocean alkalinity by additions of e.g. limestone	Potential disruption of the ocean carbon system Likely prohibited by international law	0	?	20 – 100[7]
Blue Carbon	Restoring or constructing coastal eco-systems which store CO_2 e.g. salt-marshes & kelp forests	Uncertain sequestration potential Need for rapid shift from net source to net sink[8] Competition with industries e.g. fishing	?	0.13 – 0.8 Gt[9]	10
Other GHGs	Techniques to sequester methane, N_2O, CFCs	A range of techniques have been proposed, but are largely untested at present	0	?	?

The table is not exhaustive, with some emerging proposals not included. Sequestration and cost estimates are highly uncertain and should be treated with caution. Cost estimates vary extremely widely, and are often sourced from projects with vested economic interests; for example, estimates for DACCS vary between $15/t and $1000/t.

Understanding CO_2 sequestration potential requires accurate Monitoring, Reporting and Verification (MRV). This is a major challenge for many GGRs, particularly when using international supply chains or offsetting. The UK 2050 scenario in Table 1 assumes only UK-deployed GGRs (in other words, no international offsetting), although imports of biomass feedstocks are included and may be needed to realise BECCS at scale. The global trade of biomass has been the subject of much concern about social and environmental impacts, as well as potentially resulting in a net increase in CO_2 emissions due to land-use change.[10]

GGR is distinct from Carbon Capture and Storage (CCS), because capturing and storing CO_2 from a power plant which is burning fossil fuels merely reduces the CO_2 going into the atmosphere, it does not remove previously-emitted CO_2. Some GGR proposals such as BECCS and DACCS (defined in Table 1) require CCS as a part of their overall process. GGR is also distinct from Carbon Capture and Utilisation (CCU). Many existing GGR demonstration projects capture CO_2 and utilise it in horticulture, beverages, and enhanced oil recovery, but this returns the CO_2 quickly to the atmosphere. Exceptions include using CO_2 in longer-lasting products such as concrete. Such proposals are at an early stage but could help to provide a commercial market for captured CO_2. Mineral carbonation by injecting CO_2 directly into permeable rocks has been proposed as an alternative to CCS, with a small-scale demonstration in Iceland. Like CCS, this should only be considered a GGR when it is paired with removal techniques such as direct air capture.[11]

TIMESCALE

Many GGR techniques are at a very early stage of development, or low Technology Readiness Level (TRL).[12] The process of technology development takes time, yet to tackle climate change on the urgent timescales required, GGR must be developed and commercialised in a fraction of the time taken by most of today's low-carbon technologies. Many of the techniques at higher TRL are fundamentally constrained in their ability to sequester large amounts of CO_2 over long timeframes, because they are at risk of disturbance (for instance, through changes in land management practices or wildfires), and because the CO_2 content of natural sinks such as soils saturate after a period of time.[13] For this reason, there is a need to promote innovation in low-TRL ideas that may be able to sequester larger amounts of CO_2 for the long-term.

UK innovation policy for GGR does not express a preference for any particular GGR technique over others. Some of the higher TRL techniques, such as planting trees, are already widely practised, although would need much scaling up to act as significant GGR. Others, such as BECCS and DACCS, are currently being researched. The UK has earmarked £100m of new public funding for GGR research over the next five years. 70% of this is for techniques at TRL 4-7 before the start of the project; the remaining 30% are required to meet minimum TRL of 3-4 by the year 2026.

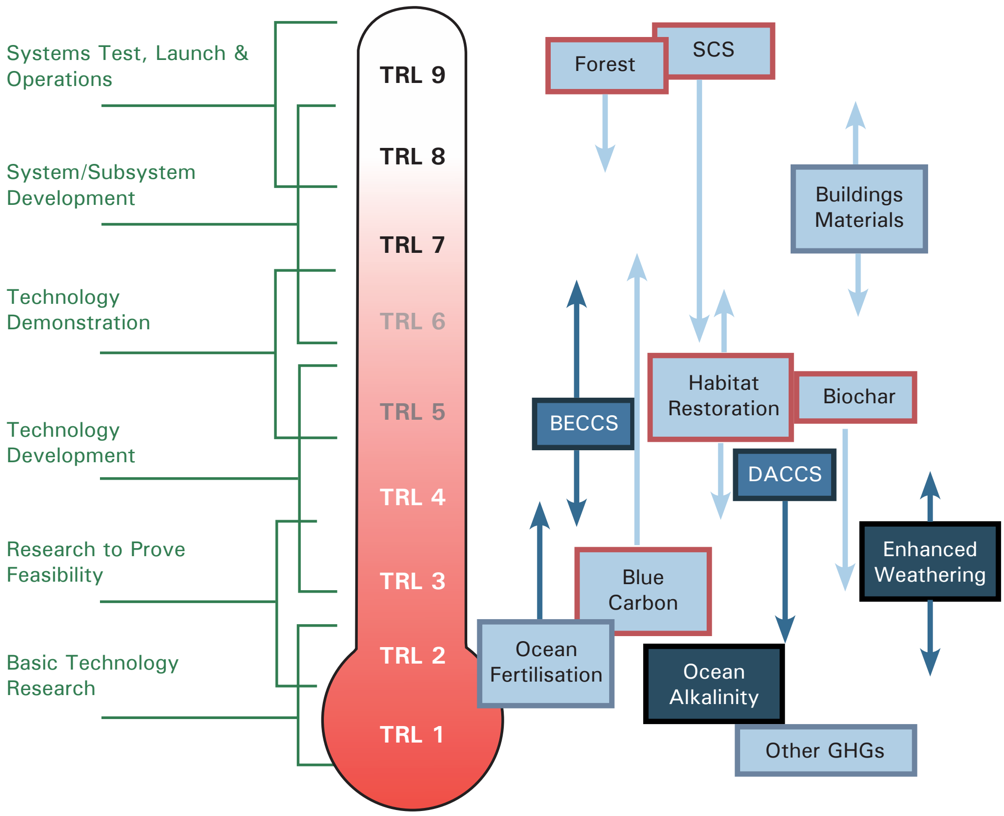

Chart showing TRL, with error bars, and longevity of storage for major GGR proposals. Darker blue boxes indicate longer CO_2 storage, with shortest duration ~20 years (SCS), and the longest around 100,000 years. A red border indicates sequestration vulnerable to disturbance. TRL image sourced from NASA.

SOCIETY AND ETHICS

We know from other technologies such as Genetic Modification and nanotechnology that societal issues must be considered early on, as part of responsible innovation processes. GGR should not be thought of as purely an engineering or modelling challenge. For many of the more novel proposals, people are unlikely to be supportive unless they are developed as part of a more ambitious portfolio of climate policies.[14] Perceptions are also likely to be highly conditional – in other words, they will depend on the manner in which a project or proposal is carried out.[15] Perceptions of technologies 'messing with nature' are likely to be important, and therefore techniques involving forestry, sequestration in soils and habitat restoration are likely to be preferred, provided they are carried out in a way which maximises environmental co-benefits.[16] The degree of controllability and reversibility of risks is also important, and people are likely to be more concerned about techniques which take place in an open, interconnected environment such as the ocean.[17]

Ethicists and publics are concerned that GGR merely 'treats the symptoms' of the problem, rather than the cause, because GGR does not address underlying problems such as unsustainable lifestyles and severe structural inequality.[18] GGR could actually divert attention away from action to reduce emissions, a risk known as 'mitigation deterrence'.[19] For example, many carbon offsetting schemes rely on afforestation, without a guarantee that the forests will be adequately maintained for long enough to sequester the promised amount of CO_2. Those which offer high levels of guarantees are much more expensive, and still cannot secure against risk of unexpected CO_2 release, for instance due to fire.

MARKETS AND POLICIES

GGR at the scale required for the UK will require multiple £ billions worth of investment per annum, roughly equivalent to 1-2% of total tax revenues by 2050.[20] The lack of an economic incentive to scale up these technologies is a major barrier. Existing policies such as Emissions Trading Schemes are not currently set up to provide payments for emissions removed. Other policies have been proposed, including Contracts for Difference whereby GGR companies would be assured a price for the CO_2 removed; a certificate mechanism whereby polluters would be obliged to remove a certain amount of the CO_2 they produce;[21] tax credits for sequestered CO_2 (currently in use in the USA); or a carbon tax on the order of at least £140 per tonne CO_2.[22] Considering the urgent timescales and the diversity of proposals, GGR at scale will require a suite of supporting and targeted policies, as well as the existence of large-scale CCS infrastructure.

Clearly, a portfolio of measures to meet emissions targets is required. GGR must exist alongside ambitious measures to reduce emissions in the first place, and policy-makers must be mindful of the risk that GGR will reduce incentives to pursue these measures. However, any portfolio involves synergies and trade-offs between diverse objectives. For example, GGRs such as afforestation, BECCS and biochar require land, which could result in trade-offs against objectives such as food security or biodiversity.[22] In fact, estimates of the sequestration potential of BECCS have been downgraded considerably over the past few years, as it has become apparent that the scale of BECCS suggested by many models is not possible in a sustainable way.[23] Other GGRs such as Direct Air Capture and Enhanced Weathering require large amounts of energy, which might trade off against energy security and demand reduction objectives.[24] GGR will also compete for resources with the decarbonisation objectives of other sectors such as transport and heating, because many low-carbon energy technologies also require large amounts of land, biomass, decarbonised electricity, funding and skills. Some techniques, such as habitat restoration and soil carbon sequestration, could be ‘win-wins’ with multiple co-benefits for food, biodiversity and wellbeing. Such low-regrets options are advisable in the immediate term,[25] but alone they probably cannot sequester enough CO_2 over the long term to be able to meet net zero targets.

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