CHAPTER 1

Introduction

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Greenhouse gas removal (GGR) technologies, also known as carbon dioxide removal (CDR), are understood to be essential to all scenarios consistent with a 1.5 °C target. Technologies that provide net removal of CO_2 emissions include nature-based solutions (*e.g.*, afforestation, reforestation and coastal blue carbon), enhanced weathering, biochar, soil carbon sequestration, ocean fertilisation, direct air capture of CO_2 (DAC) and bioenergy with carbon capture and storage (BECCS). Advancing these GGR technologies forward will require scale-up and commercialisation. Importantly, we will need to identify which GGR pathways can be relied upon to be a material option within the portfolio of solutions, and which will be niche players. The key areas of GGR that require further development in understanding include the climate repair value, the permanence of the carbon removal (*e.g.*, one year or 1000 years), the types of services provided (*e.g.*, environmental, energy) by each GGR option, how cost might vary in different regions, and the protocols for monitoring, reporting and verification (MRV).

1.1 Where Are We Now?

Referencing the 2015 Paris Agreement at the beginning of books and research papers has emerged as an almost unspoken convention amongst the community who are concerned with climate change. In the year 2015, the

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world agreed to the now famous ''well below 2 °C'' target, with the equally famous aspiration to meet a more stringent 1.5 °C target, and anthropogenic CO_2 emissions of 35.2 Gt per year.[1]

In 2018, the IPCC published their special report on 1.5 °C[2] which, *inter alia*, highlighted the importance of reducing greenhouse gas emissions to net zero by ''around 2050'', and also firmly established the need to remove CO_2 from the atmosphere, both as part of the transition to net zero and also as being integral to the overarching 1.5 °C aspiration.

By 2019, starting with the UK, an increasing number of corporations and nations pledged to achieve a net zero emissions goal. National pledges to reach net zero cover 61% of global emissions, 68% of the global economy, and 52% of the global population.[3] In sum, 124 countries are committed to, or are actively considering net zero targets. In short, the direction of travel appears clear, and it would appear that net zero targets are becoming the norm. Importantly, both the EU and US appear to be actively considering border carbon adjustment mechanisms (BCAM)[4–6] to address issues surrounding carbon leakage, and China has pledged to peak emissions by 2030 and thereafter decline to net zero by 2060.[7] It would appear difficult to say that we are lacking in ambition.

However, ambition is one thing, results are decidedly another. By 2019, total anthropogenic CO_2 emissions had increased to 36.4 Gt per year[1] – an increase of approximately 3.5% relative to 2015. The year 2020 brought with it the COVID-19 pandemic and an associated reduction in CO_2 emissions to 34.07 Gt per year.[1] This is instructive in that it indicates the extent of reduction that can be achieved *via* behavioural change alone.

On the 6th of August 2021, the IPCC published the contribution of Working Group I to their Sixth Assessment Report.[8] It was widely reported as being a ''code red for humanity''[9] with similarly bombastic language having been used by a variety of media outlets, and the current Biden administration[10] emphasising the need for action with POTUS tweeting ''*We can't wait to tackle the climate crisis. The signs are unmistakable. The science is undeniable. And the cost of inaction keeps mounting*''.[11] However, on the 12th of August 2021, the Biden administration also called on OPEC to boost oil production so as to avoid ''harming the ongoing global recovery (from the economic impact of the COVID-19 pandemic)''. Similarly, China has announced an additional forty three coal-fired power plants and thirty five million tonnes of coal-dependent ironmaking capacity in the first half of 2021.[12] It would appear that the net zero goals are rapidly in danger of becoming ''more honoured in the breach than the observance.''

1.2 What To Do?

Given the above, it seems increasingly clear that whilst efforts to mitigate climate change through the now-conventional methods of fuel switching, renewable energy, the use of nuclear power, and deploying CO_2 capture and storage (CCS) technology ought to be accelerated where possible, achieving

the aforementioned climate change targets is going to increasingly rely on the ability to remove CO_2, and potentially other greenhouse gases, from the atmosphere at the gigatonne scale.

This practice of greenhouse gas removal (GGR), also known as carbon dioxide removal (CDR), is now extensively used as a shorthand to refer to an increasing portfolio of approaches to achieve this aim. From the so-called nature-based solutions (NBS), such as soil carbon sequestration (SCS), to afforestation and reforestation (AR) to more technology-focused approaches such as biochar (BC), enhanced weathering (EW), direct air CO_2 capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS). Importantly, this list only refers to some of the land-based approaches, and it is important to recognise that, given that approximately 71% of the earth's surface is water, and that the oceans have absorbed tens of billions of tonnes of CO_2 since the industrial revolution, there is merit in considering approaches to remove CO_2 directly from the oceans as well as from the atmosphere. Many of these approaches involve ''fertilising'' the oceans in some way, or the restoration of coastal or ''blue carbon'' ecosystems, or finally the cultivation and harvesting of ocean biomass for use in marine-BECCS approaches.

It is important to recognise that, despite its prominence in current national and international policy discourse, and the arguably near-commercial status of BECCS and DACCS concepts, the field of GGR is very much in its infancy, and there remain many questions that are, as yet unanswered.

1.3 Conclusions

So, how can GGR move forward? This will, inevitably, rest upon the scale-up and commercialisation of the various options so we can quickly discern between which GGR pathways can be relied upon to be a material element of the portfolio of solutions, and which are niche players.

To achieve this, there are several key steps forward, which include the following:

1. We need to quantify the climate repair value provided by each of the GGR pathways. Anthropogenic CO_2 in the atmosphere is a problem because it is such a long-lived greenhouse gas. Thus, in order to fully compensate for the impact of a given CO_2 emission, an equivalent amount of CO_2 will need to be permanently removed from the atmosphere at approximately the same time.
2. We need to decide what ''permanent'' means in this context. Does it mean one year, or one million? Or perhaps something in between.
3. We need to distinguish between the environmental service of carbon removal and the other services that the various GGR pathways can provide. For example, DACCS is something that one would pursue exclusively for reasons of climate repair. BECCS provides a combination of GGR and energy services. Afforestation, however, can provide a range

of services in addition to carbon management, such as air quality, water management, biodiversity, and ecosystem services, amongst others. All of these services ought to be explicitly valued.

4. The cost of delivering credible GGR will vary around the world. Each nation will have its own supply curve, and it is not obvious why these comparative advantages should not be exploited to deliver cost-optimal GGR in combination with a rigorous monitoring, verification and regulatory regime.
5. In order to write a contract for the provision of GGR services, it will be necessary to know (a) when CO_2 removal begins, (b) at what rate CO_2 is being removed, and (c) when a given store is saturated, and a project can be completed. Achieving these outcomes will require the development of detailed monitoring, reporting and verification (MRV) protocols. These will need to be credible, and internationally recognised.

Finally, we have learned from recent experience during the COVID-19 pandemic that initiating and rapidly scaling new infrastructure is challenging, to say the least, and that best results are achieved by leveraging existing assets and flexing them. In this context, existing emissions trading schemes (ETS) may provide a good option for the commoditisation of GGRs. Understanding how credible GGRs can be integrated with an ETS is an option which ought to be explored with alacrity.

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