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Specialty Grand Challenge: Negative Emission Technologies

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INTRODUCTION

The United Nations painted a dire picture of humanity's future in its recent climate report (IPCC, 2018). It warned that failing to act on carbon dioxide (CO_2) emissions will lead to vanishing sea ice and melting glaciers, increased storm events, and ports and islands at risk due to rising sea levels. The report was sobering to many, but not to scientists tasked with developing solutions to climate change. We know that even if we reach previously stated emission goals, even if we replaced all coal-fired power plants with cleaner resources like wind- or sun-generated electricity, even if we found ways to otherwise reduce ongoing emissions, it would not be enough. We must also pull existing CO_2 out of the atmosphere if we are to avoid the worst impacts of climate change ("Negative Emission Technologies" or NETs) (Fuss et al., 2018; Minx et al., 2018; Nemet et al., 2018). Investing in NETs now will be more affordable than a future of ever-more devastating storms, wildfires, high tides, famines, and diseases.

Under a business as usual scenario we may see a 4°C increase in global temperatures by 2100, which will have a substantial pervasive impact on our planet and society. The economic cost alone for exceeding 2.5°C may be up to 2% of global income (IPCC, 2014a). We have already reached 1°C of warming (IPCC, 2018).

The scale of the challenge is daunting. The largest emission scenario used by the UN, which is our current trajectory, predicts that humanity may create >7,000 billion tons of CO_2 over the next 80 years. If we are to avoid 2° of warming, we must limit the accumulation in the atmosphere to under 500 billion tons CO_2 (or 1/3 of this to limit to 1.5°) (Lowe and Bernie, 2018). It is essential that we deviate away from our business as usual trajectory, and substantially limit the amount of CO_2 that is created. Given that our energy infrastructure has unavoidably committed us to creating several hundred billion tons of CO_2 over the next two decades (Davis and Socolow, 2014), it seems likely that not only will we need to store considerable quantities of CO_2, but also remove excess CO_2 from the atmosphere. The IPCC predicts that between 20 and 60 billion tons of CO_2 may need to be stored underground every year (IPCC, 2014b). If so, CO_2 management will become one of the largest industries, equivalent in scale to food production (HANPP, ~15 billion tons Krausmann et al., 2017), construction materials (cement, steel, aggregate >60 billion tons USGS, 2016; Reichl et al., 2018), and fossil fuels (coal, oil, gas, ~20 billion tons).

HOW TO REMOVE GREENHOUSE GASES FROM THE ATMOSPHERE

NETs propose to accelerate Earth's natural processes by growing plants, increasing soil organic carbon stocks, weathering alkaline-rich rocks and increasing ocean alkalinity, and also via "synthetic forests" that draw CO_2 from the air with far more efficiency than a natural forest. Unlike carbon capture devices in smokestacks that prevent CO_2 release from power and manufacturing facilities, carbon dioxide removal focuses CO_2 that is already in the air. Additionally, carbon dioxide removal helps treat CO_2 emissions that are difficult to eliminate, such as those from automobiles and airplanes.

Figure 1 presents the range of NETs that have been proposed and could be considered either by the mechanism on which they remove greenhouse gases from the atmosphere (biomass growth, mineral dissolution, or directly captured) or where the greenhouse gases are ultimately stored (above/below ground biomass, marine biomass, carbonate minerals, dissolved carbonate, or physical trapping of CO_2, in products). Between the mechanism of removal and the storage location there is potential for complex interaction pathways. For instance, biomass energy carbon capture and storage (BECCS) involves growing and burning biomass in a power station, and purifying/pressurizing the CO_2 for injection underground. However, the CO_2 produced from this process may also be reacted with silicate minerals ("mineral carbonation") to store the CO_2 in carbonates or used to accelerate the weathering of limestone.

Most of NETs research to date focuses on removing CO_2 from the atmosphere (other greenhouse gases, e.g., methane

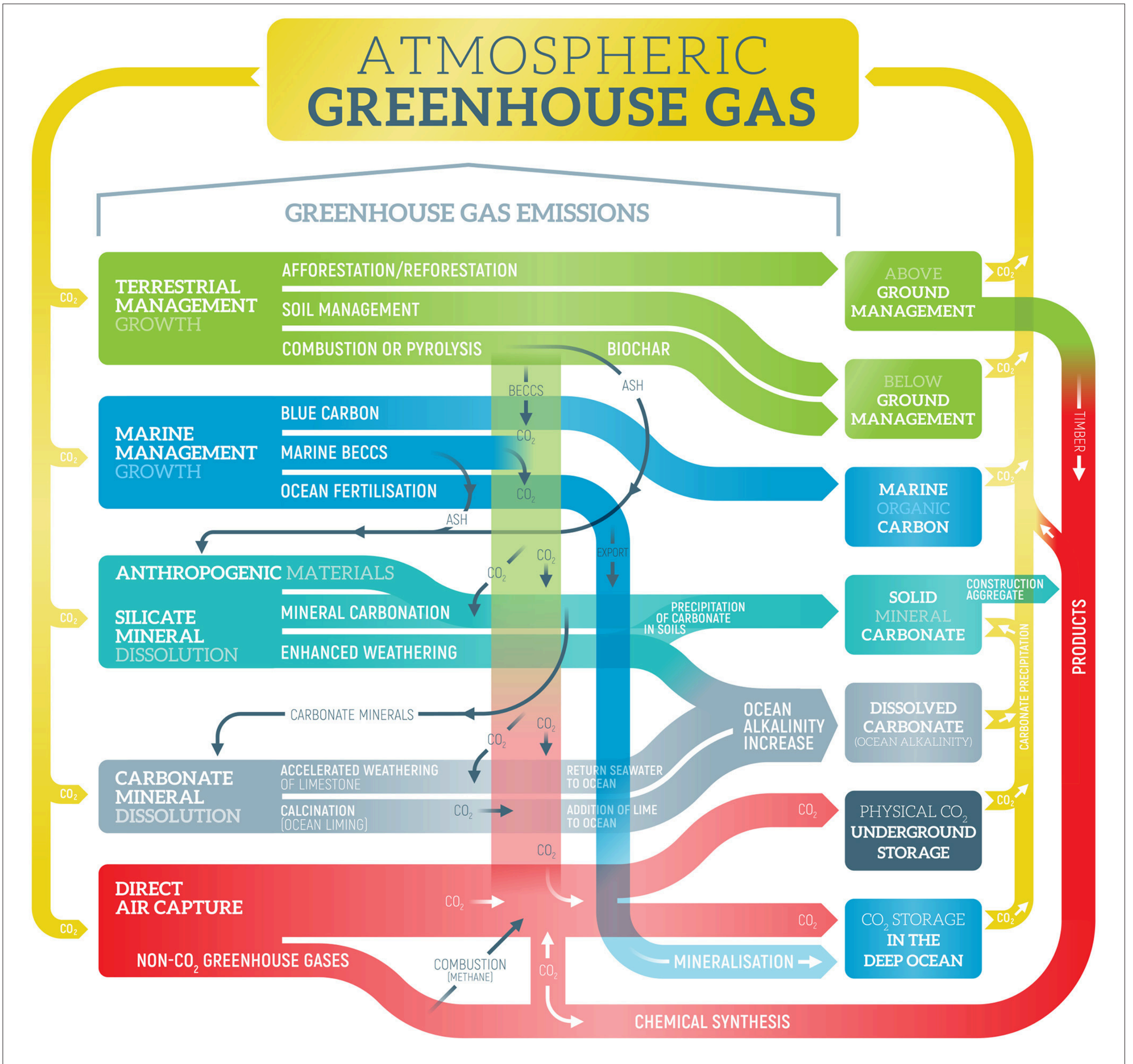

FIGURE 1 | Flows of negative emission technologies between "mechanisms" (biomass growth, mineral dissolution, direct air capture) and "storage locations" (above/below ground biomass, carbonate minerals, ocean alkalinity, physical CO_2 storage underground, products).

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