Ocean Fertilization: At a Glance

Marine plants and algae, like phytoplankton, take up CO_2 during photosynthesis, and this can increase the ocean's uptake of atmospheric CO_2. Ocean fertilization (OF) would use ships to dump specific limiting nutrients into the surface ocean—nitrogen, phosphorus, silica, or, in the most researched example to date, iron—to promote phytoplankton growth through algal blooms. The method assumes that a sufficient quantity of the uneaten phytoplankton from these blooms would then die and sink, transporting carbon into the deep ocean or seafloor sediment for longer-term storage.

Potential Scale of Carbon Storage: Estimates of OF's ability to capture CO_2 vary from less than 1 gigatonne to 5 gigatonnes of carbon per year (GtC yr^{-1}), with 1 GtC yr^{-1} considered most likely.[36] This range in rates stems from different model assumptions about how fast the dead phytoplankton would sink and/or be eaten by predators, nutrient cycling, the specific form of the nutrient that is added, deployment location, and ocean currents.[37] Achieving any significant level of CO_2 capture with OF would require amending vast areas of the ocean (e.g., adding iron to the entire Southern Ocean and the Atlantic, Pacific, and Indian Ocean basins south of 30° S).

Cost: Most fertilization methods are likely to be relatively low in cost, less than $50 per ton of CO_2 captured.[38] Iron-based OF requires the smallest amount of material per ton of CO_2 captured.[39] However, industrial processes that create the fertilizing material can also emit additional CO_2, especially in the case of industrially produced nitrogen fertilizers, making life-cycle greenhouse gas emissions analyses for these processes important.[40]

Duration of Carbon Storage: OF is expected to offer carbon storage on an average of 10 to 100 years, with some carbon being stored beyond 100 years.[41] What happens to the phytoplankton that blooms—whether it is eaten and turned back into CO_2 in the upper water column or in deep water, or it is buried in sediment—heavily affects carbon storage duration for OF methods.[42]

Technical Readiness: OF experiments using iron in the 1990s and 2000s confirmed that fertilization does induce phytoplankton blooms and carbon capture, but scientists found that only some of these blooms led to longer-term carbon storage or atmospheric CO_2 drawdown beyond already naturally occurring processes.[43] New satellite, sensor, and modeling technologies may help reduce uncertainties around the carbon storage capacity of OF.[44]

Potential Risks and Benefits (Social and Environmental): Blooms created by ocean iron fertilization have attracted grazers and predators; some have speculated that enhanced phytoplankton productivity could increase the growth rate of fish populations, such as salmon.[45] Scientists have also speculated that OF could divert nutrients that support phytoplankton growth in other locations ("nutrient robbing") or contribute to harmful algal blooms, water column acidification, or low-oxygen zones.[46] There is no evidence of these consequences from OF field experiments conducted to date, which have been limited in spatial and temporal scales.

Outstanding Questions: The additionality and durability of CO_2 storage from OF are not well known. Verification of CDR via OF is likely to be challenging, especially due to the large areas involved, long supply chains for fertilizing materials, use of seagoing vessels, effects of ocean circulation, and overall biogeochemical complexity of the ocean.[47] Implications of OF for ocean ecosystems are also not well known, and concerns have been raised by the scientific community about harmful algal blooms and phytoplankton community shifts leading to broader ocean ecological changes.[48] There are also significant legal questions surrounding the addition of fertilizing materials to the ocean, which could fall under definitions of ocean dumping.[49]

36 National Academies of Sciences, Engineering, and Medicine (hereinafter NASEM), *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration* (Washington, D.C.: National Academies Press, 2022), https://doi.org/10.17226/26278.

37 Ibid.

38 Ibid.

39 Ibid.

40 Seyedehhoma Ghavam et al., "Sustainable Ammonia Production Processes," *Frontiers in Energy Research* 9 (2021), https://doi.org/10.3389/fenrg.2021.580808.

41 NASEM, *A Research Strategy*.

42 Ibid.

43 Ibid.

44 Ibid.

45 Ibid.

46 Ibid.; Philip W. Boyd et al., "Potential Negative Effects of Ocean Afforestation on Offshore Ecosystems," *Nature Ecology & Evolution* 6 (2022): 675–83, doi:10.1038/s41559-022-01722-1; Joo-Eun Yoon et al., "Reviews and Syntheses: Ocean Iron Fertilization Experiments—Past, Present, and Future Looking to a Future Korean Iron Fertilization Experiment in the Southern Ocean (KIFES) Project," *Biogeosciences* 15, no. 19 (2018): 5847–89, https://doi.org/10.5194/bg-15-5847-2018.

47 NASEM, *A Research Strategy*.

48 Ibid.

49 Ibid.