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Geoengineering: Ocean Iron Fertilization

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Geoengineering: Ocean Iron Fertilization

SUMMARY

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Congress has shown growing interest in and support for geoengineering techniques as a means to remove carbon dioxide (CO_2) from the atmosphere. *Geoengineering* is a field of study that involves large-scale technological interventions to manipulate the processes that affect Earth's climate, generally with the aim of countering climate change. Geoengineering techniques that stimulate or amplify natural processes that remove CO_2 from the atmosphere (e.g., afforestation, ocean fertilization) may be of particular interest to Congress, due to the relatively low cost of research, development, and deployment of these techniques compared with geoengineering techniques that rely on novel or industrial-scale technologies. For example, CO_2 is transferred into the deep ocean via the physical process of overturning circulation and the biological process known as the *biological pump*. Ocean iron fertilization (OIF), an ocean-based geoengineering technique, aims to increase the rate of atmospheric CO_2 transfer to the deep ocean by stimulating the biological pump through the addition of iron (a key nutrient) to the surface of the ocean. Modeling studies indicate that OIF has the potential to remove CO_2 from the atmosphere for hundreds to thousands of years.

Ocean-based geoengineering policy measures focused on reducing atmospheric CO_2 concentrations often point to ocean fertilization as one potential method. To date, 13 OIF experiments have occurred from 1993 to 2009 in regions of the open ocean with the aim of amplifying the biological pump for atmospheric CO_2 sequestration in the deep ocean. According to researchers, 1 of the 13 experiments documented increased carbon levels in the deep ocean. The other 12 OIF experiments did not observe increased carbon levels in the deep ocean or were too short-lived to make measurements. Outstanding research questions include (1) assessing the effectiveness of OIF as a geoengineering technique; (2) determining environmental and ecological consequences, if any; and (3) determining to what degree consequences are associated with this technique.

Congress may consider authorizing further study of OIF's effectiveness at removing CO_2 from the atmosphere. Existing federal research infrastructure and equipment funded through congressional appropriations (e.g., ocean-observing satellites, Argo profiling floats) could provide additional insight into OIF's effectiveness at sequestering atmospheric carbon in the deep ocean. Federal research studies supported by Congress also could provide an understanding of potential unintended outcomes of OIF, if any, and to what degree they may occur. An understanding of both OIF's effectiveness in removing CO_2 from the atmosphere and its potential environmental impacts could provide guidance for federal regulation of site-selection criteria for at-scale OIF, particularly OIF activities occurring within the U.S. exclusive economic zone (EEZ). In addition, OIF activities and their potential environmental impacts might be subject to authorities under existing federal laws, such as the Marine Protection, Research, and Sanctuaries Act (P.L. 92-532) and the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (P.L. 109-479).

Most OIF studies have occurred in international waters, where iron tends to be scarcer relative to coastal waters under the jurisdiction of individual nations. Adding iron to ocean regions with existing high biological productivity may not amplify the biological pump. Over the past two decades, international bodies—including those to which the United States is a party—have produced nonbinding guidelines to limit or restrict ocean fertilization experiments. To date, international agreements generally have categorized ocean fertilization to mitigate climate change as marine scientific research, allowing for small-scale fertilization activities that comply with agreements to protect the marine environment and limit marine pollution. Congress may consider the geopolitical consequences of OIF activities and potential differences of interpretation, such as viewing it as transboundary pollution.

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Introduction to Geoengineering

Carbon dioxide (CO_2) concentrations in the atmosphere have been rising largely due to human activities, such as the combustion of fossil fuels for transportation and electrical power generation. For each of the last four decades, as atmospheric CO_2 concentrations have continued to increase, average global temperatures have been successively warmer than in any preceding decade.[1] To limit, or mitigate, the rise of global temperatures, government policy measures typically have focused on reducing the emissions of CO_2 and other greenhouse gases (GHGs) to the atmosphere or enhancing the sinks that accumulate and store these gases.[2]

In 2021, the United States government, in an international declaration, stated its aim to be "on a path to achieve net-zero emissions, economy wide, by no later than 2050."[3] Certain climate change mitigation studies generally find that removing CO_2 from the atmosphere will be necessary to achieve net-zero global emissions over specified timeframes.[4]

Geoengineering is a field of study that involves large-scale technological interventions to manipulate the processes that affect Earth's climate, generally with an aim of countering climate change. Geoengineering is controversial and divides researchers. A complete examination of this controversy is outside the scope of this report. In short, critics of geoengineering assert that its use could result in unintended consequences and divert action from mitigation activities. These critics often call for either the establishment of an international framework on how to conduct geoengineering research or the implementation of strategies to reduce the sources of GHG emissions.[5] Those in favor of implementing geoengineering technologies argue that urgent action is needed to reduce the potential effects of rising atmospheric CO_2 concentrations.[6]

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[1] Intergovernmental Panel on Climate Change (IPCC), "Summary for Policymakers," in *Changing Climate 2021: The Physical Science Basis*, eds. V. Masson-Delmotte et al., 2021, p. SMP-5 (hereinafter referred to as IPCC AR6 *Physical Science Basis*).

[2] B. DeAngelo et al., "Perspectives on Climate Change Mitigation," in *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, eds. D.J. Wuebbles et al., U.S. Global Change Research Program (Washington, DC, 2017), p. 393, at https://science2017.globalchange.gov/downloads/CSSR_Ch14_Mitigation.pdf.

[3] *Net-zero emissions* means that some greenhouse gases (GHGs) are emitted, but these are offset by removing an equivalent amount of GHGs from the atmosphere and storing it permanently in soil, plants, or materials. Achieving *net-zero emissions* may be considered more feasible than releasing no GHGs to the atmosphere (i.e., *zero emissions*). (National Academies of Sciences, Engineering, and Medicine (NASEM), "Is it Possible to Achieve Net-Zero Emissions?," https://www.nationalacademies.org/based-on-science/is-it-possible-to-achieve-net-zero-emissions.) The United States of America Nationally Determined Contribution, "Reducing Greenhouse Gases in the United States: A 2030 Emissions Target," April, 22, 2021, p.15, at https://unfccc.int/sites/default/files/NDC/2022-06/United%20States%20NDC%20April%2021%202021%20Final.pdf.

[4] NASEM, *Negative Emissions Technologies and Reliable Sequestration: Research Agenda* (Washington, DC: The National Academies Press, 2019), p. 2 (hereinafter referred to as NASEM, *Negative Emissions Technologies*); and U.S. Global Change Research Program, *National Global Change Research Plan 2012–2021: A Triennial Update*, 2017, p. 37, at https://downloads.globalchange.gov/strategic-plan/2016/usgcrp-strategic-plan-2016.pdf. See also CRS In Focus IF11791, Mitigating Greenhouse Gas Emissions: Selected Policy Options, by Jonathan L. Ramseur et al.; and CRS Report R46947, U.S. Climate Change Policy, coordinated by Kate C. Shouse.

[5] For example, see Philip Boyd and Chris Vivian, "Should We Fertilize the Oceans or Seed Clouds? No One Knows," *Nature*, vol. 570 (June 11, 2019), at https://doi.org/10.1038/d41586-019-01790-7; and Dominic Lenzi et al., "Don't Deploy Negative Emissions Technologies Without Ethical Analysis," *Nature*, vol. 561 (September 19, 2018), at https://doi.org/10.1038/d41586-018-06695-5.

[6] For example, see Fred Pearce, "Geoengineer the Planet? More Scientists Now Say It Must Be an Option," *Yale Environment 360*, May 29, 2019, at https://e360.yale.edu/features/geoengineer-the-planet-more-scientists-now-say-it-must-be-an-option.

Geoengineering techniques are categorized as either carbon dioxide removal (CDR) methods or solar radiation management (SRM) methods. CDR methods address the warming effects of GHG by removing CO_2 from the atmosphere. SRM methods address Earth's energy balance by increasing the reflectivity of the Earth's atmosphere or surface, thereby reducing the amount of solar energy (heat) absorbed by the land and the ocean.[7] This report outlines CDR methods and focuses on one method in particular: ocean iron fertilization (OIF).

Terrestrial-based CDR methods include the following:

- *Direct air capture* uses technology to remove CO_2 from the atmosphere and then compresses it, aiming to permanently store the CO_2 underground.[8]
- *Afforestation* involves planting trees on land that has not recently been covered with forest, generally for the last decade or more, thereby increasing the amount of CO_2 removed via photosynthesis.[9]
- *Enhanced weathering* stimulates the natural geologic process of silicate rock weathering by scattering crushed silicate-rich rocks across land surfaces to invoke a chemical reaction that removes CO_2 from the atmosphere and stores it in soils.

Ocean-based CDR methods include the following:

- *Ocean fertilization* adds nutrients, such as iron, to the surface of the ocean to enhance CO_2 uptake by marine algae (phytoplankton) via photosynthesis.
- *Ocean pumping* brings deep ocean water, which is generally nutrient rich, to the surface to enhance CO_2 uptake by phytoplankton via photosynthesis.
- *Enhanced ocean alkalinity* increases the concentration of calcium, magnesium, or sodium ions in seawater, allowing these ions to chemically bind with CO_2 to form bicarbonate ions, which selected marine organisms subsequently use to build shells.
- *Direct ocean capture* uses technology for the removal of CO_2 from ocean water.[10]

Congressional interest in certain geoengineering techniques generally has grown over the past two decades. This report provides an overview of the ocean-based geoengineering technique of OIF, including the natural marine biological process that removes CO_2 from the atmosphere and how OIF could amplify this natural process. Because most OIF experiments have occurred in the open ocean (international waters), the report also outlines relevant international bodies and treaties. The report further discusses concerns over OIF's effectiveness as a CDR method and highlights issues Congress may consider, such as whether to authorize selected federal agencies to research the method more closely, focusing on learning more about potential environmental and ecological consequences.

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[7] Solar radiation management methods include enhanced albedo (reflectivity) of the Earth's surface or atmosphere, which might include space-based reflectors. See NASEM, *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance* (Washington, DC: The National Academies Press, 2021), at https://doi.org/10.17226/25762. For a discussion on the factors that alter the balance of incoming and outgoing radiation in Earth's climate system, see CRS Report R43229, *Climate Change Science: Key Points*, by Jane A. Leggett.

[8] See CRS In Focus IF11501, *Carbon Capture Versus Direct Air Capture*, by Ashley J. Lawson.

[9] *Reforestation* refers to planting trees or allowing trees to regrow on land that recently had been covered with a forest. See CRS Report R46312, *Forest Carbon Primer*, by Katie Hoover and Anne A. Riddle.

[10] Department of Energy, "Direct Removal of Carbon Dioxide from Oceanwater," at https://arpa-e.energy.gov/technologies/exploratory-topics/direct-ocean-capture.

Ocean Iron Fertilization

Ocean fertilization refers to the technique of adding iron or other nutrients to ocean areas with low biological productivity (i.e., low abundance of photosynthetic plankton, or phytoplankton). Ocean fertilization could enhance atmospheric CO_2 removal by increasing biological productivity, namely by stimulating the growth of phytoplankton, similar to afforestation on land. Ocean fertilization as a geoengineering technique is based on the concept that because phytoplankton capture atmospheric CO_2 and add photosynthetic carbon to their cells, stimulating the growth of phytoplankton could result in more atmospheric carbon captured and more photosynthetic carbon produced.[11] When phytoplankton die, their cells sink and may store atmospheric CO_2 in the deep ocean for hundreds to thousands of years.

Biological Pump

The *biological pump*, or *biological carbon pump*, is the natural process of cycling carbon through the ocean (**Figure 1**). Similar to plants on land, phytoplankton use energy from the sun and take up atmospheric CO_2 during photosynthesis to form organic carbon matter as part of their cells. Phytoplankton can either be consumed by larger organisms, such as zooplankton (e.g., krill), transferring carbon up the food chain, or it can die and sink to the deep ocean. In the deep ocean, the dead phytoplankton can be broken down by bacteria or can settle on the seafloor and be buried. If bacteria break down the organic carbon matter, the CO_2 is rereleased into the water and may remain in the water, isolated from the atmosphere, for years to decades. If buried, the organic carbon matter is stored in the ocean sediments for hundreds to thousands of years.[12] On average, studies show that approximately 10% of phytoplankton organic carbon matter settles from the sunlight zone to the dark zone; of that 10%, possibly less than 1% is buried in ocean sediments (**Figure 1**).[13]

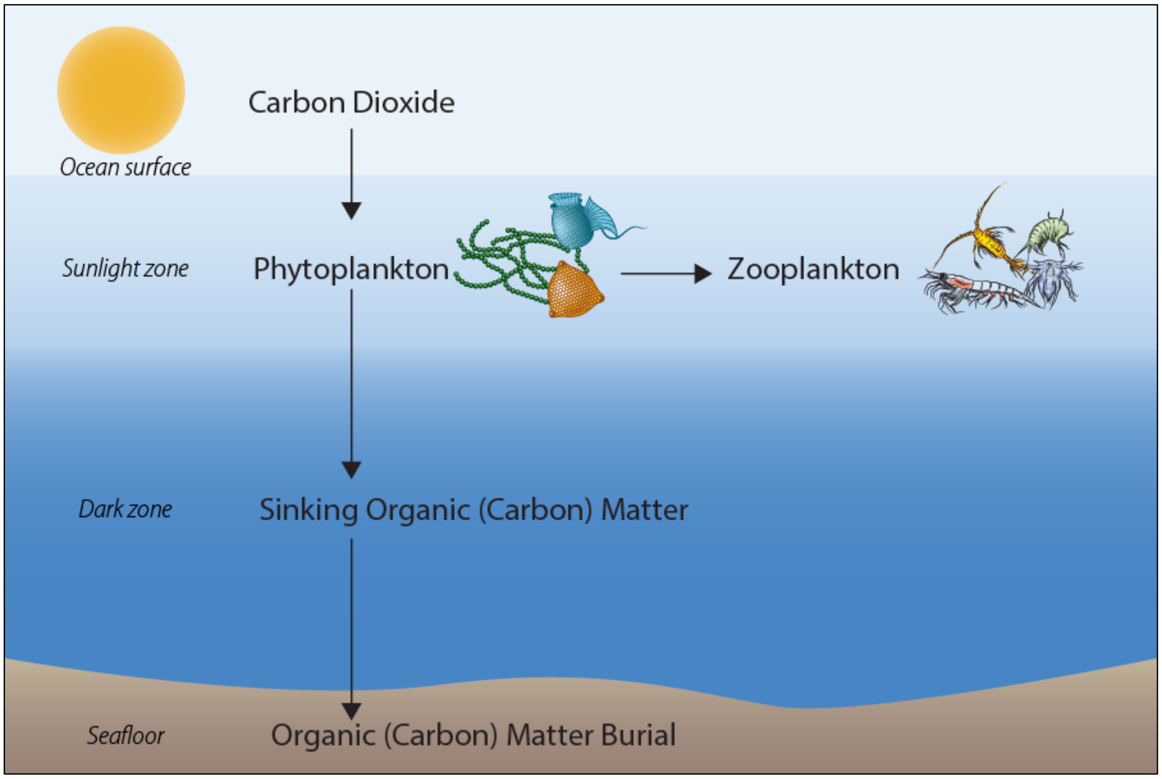
The biological pump is an important component of the global carbon cycle, which works over geological timescales (millions of years) and keeps atmospheric CO_2 concentrations in equilibrium with concentrations in the ocean. Similar to forests on land, the biological pump is a carbon sink, naturally removing CO_2 from the atmosphere in the short term and supporting the stabilization of Earth's climate over hundreds to thousands of years.

[11] NASEM, *Negative Emissions Technologies*, p. 29.

[12] NASEM, *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration*, (Washington, DC: The National Academies Press, 2022), p. 84, at https://doi.org/10.17226/26278 (hereinafter referred to as NASEM, *Research Strategy*).

[13] NASEM, *Research Strategy*, p. 84.

Figure 1. Biological Pump Schematic



Source: National Academies of Sciences, Engineering, and Medicine, *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration* (Washington, DC: The National Academies Press, 2022), p. 78, at https://doi.org/10.17226/26278.

Notes: The schematic does not show all of the pathways (e.g., bacterial respiration, oceanic upwelling) that can release carbon dioxide back into the water and the atmosphere. In the sunlight zone, carbon can be cycled back to the atmosphere on timescales of years to decades. In the dark zone, carbon can be cycled back to the atmosphere on 100-year timescales. Buried in the seafloor, carbon can be isolated from the atmosphere for thousands of years. Graphic created by CRS Visual Information Specialist Jamie Hutchinson.

Effects of Ocean Nutrients

The biological pump's strength—namely, how much carbon cycles through the ocean-atmosphere system—depends on the amount of nutrients in the ocean, among other factors.[14] Nitrogen, phosphorus, silica, and iron are important nutrients for the growth of phytoplankton, and they can be rare in the open ocean environment. This report focuses on the addition of iron to the surface of the ocean; the scientific community has primarily focused on iron because only relatively small amounts (in mass and volume) of iron may be needed for ocean fertilization relative to the amounts of nitrogen, phosphorus, and silica required for this process.[15]

[14] National Research Council (NRC), *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration* (Washington, DC: The National Academies Press, 2015), p. 56, at https://doi.org/10.17226/18805 (hereinafter referred to as NRC, *Climate Intervention*).

[15] NASEM, *Research Strategy*, pp. 77, 80, and 92.

Iron is naturally delivered to the ocean primarily by coastal and riverine sources, wind carrying terrestrial dust, and volcanic ash.[16] The farther from these sources, the scarcer iron becomes in the ocean's surface. Phytoplankton growth is limited by the availability of iron (and other nutrients). Thus, the growth of phytoplankton is strongest in coastal regions and weakens in the open ocean. Areas of the global ocean that have limited iron availability—conditions favorable for OIF experiments—are the equatorial Pacific, subarctic Pacific, and Southern Ocean.[17] Field observations and laboratory experiments suggest that adding iron to parts of the ocean that are not iron limited probably would not stimulate phytoplankton growth to the same extent as would adding iron to iron-limited areas.[18]

Experiments

Between 1993 and 2009, researchers conducted 13 OIF experiments in the open ocean environment—1 in the Atlantic,[19] 2 in the equatorial Pacific, 3 in the subarctic Pacific, and 7 in the Southern Ocean (**Figure 2**).[20] During these experiments, researchers added between 350 and 4,000 kilograms of iron to the ocean from a moving ship over an area of 25-300 square kilometers and observed the effects for periods between 10 and 40 days.[21] Iron for OIF may be sourced from land-based mining or may be obtained as byproduct from the iron and steel industry.[22]

[16] Warren Cornwall, "To Draw Down Carbon, Ocean Fertilization Gets Another Look," *Science*, vol. 374, no. 6574 (December 2021), p. 1424 (hereinafter referred to as Cornwall, "Draw Down Carbon").

[17] NASEM, *Research Strategy*, p. 83.

[18] Ibid. p. 78.

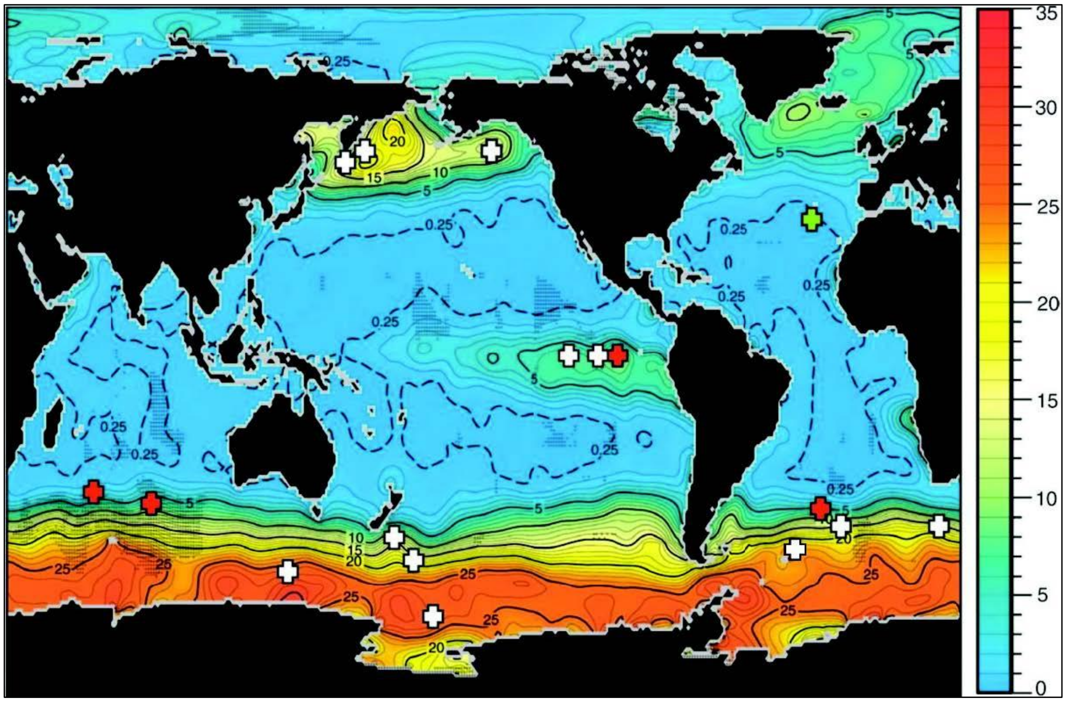
[19] The Atlantic Ocean is not an iron-limited region. The Atlantic experiment differed from the other 12 experiments in that both iron and phosphorus were added to the ocean. P. W. Boyd et al., "Mesoscale Iron Enrichment Experiments 1993-2005: Synthesis and Future Directions," *Science*, vol. 315, no. 5812 (February 2007), p. 613.

[20] Elise Johansen, "Ocean Fertilization," in *The Law of the Sea and Climate Change*, eds. Elise Johansen, Signe Veierud Busch, and Ingvild Ulrikke Jakobsen (Cambridge, UK: Cambridge University Press, 2021), p.186 (hereinafter referred to as Johansen, "Ocean Fertilization").

[21] NASEM, *Research Strategy*, p. 81; and NOAA, *Ocean Fertilization: The Potential of Ocean Fertilization for Climate Change Mitigation*, Report to Congress, 2010, p. 13 (hereinafter referred to as NOAA, *Ocean Fertilization*).

[22] The land-based impacts from mining are beyond the scope of this report. NASEM, *Research Strategy*, pp. 92 and 195.

Figure 2. Site Locations of Ocean Iron Fertilization Experiments, 1993-2009



Source: National Academies of Sciences, Engineering, and Medicine, *A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration* (Washington, DC: The National Academies Press, 2022), p. 79, at https://doi.org/10.17226/26278.

Notes: Approximate site locations for ocean iron fertilization (OIF) experiments (white crosses) and an iron and phosphorus fertilization experiment (green cross). Red crosses mark the site locations of natural OIF experiments and are not discussed in this report. Colors and contours correspond to annual nitrate concentrations (micromoles per liter, shown on the color bar on the right) of the top 10-20 meters of the surface of the ocean. Regions with relatively high nitrate concentrations (warm colors) tend to be scarce in iron.

According to researchers, the OIF experiments conducted in the equatorial Pacific and the Southern Ocean produced phytoplankton blooms (i.e., an increase in the total mass of phytoplankton in a given ocean area).[23] However, these experiments did not provide clear evidence that blooms increased rates of sinking carbon—a necessary step for OIF to serve as carbon removal.[24] Of the 13 experiments, 1 found that OIF increased carbon levels in the deep ocean.[25] The other 12 OIF experiments did not observe increased carbon levels in the deep ocean or were too short-lived to make measurements.[26] The short observation period of these experiments made it difficult to understand if phytoplankton growth was sustained and, if so, for how long. Some researchers contend that studies incompletely addressed the short- and long-term environmental and ecological consequences of OIF in the study region versus in adjacent regions.[27]

[23] NASEM, *Research Strategy*, p. 81; and NOAA, *Ocean Fertilization*, pp. 13 and 18.

[24] 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*, vol. 15 (October 2018).

[25] Cornwall, "Draw Down Carbon," p. 1424; and NOAA, *Ocean Fertilization*, p. 20.

[26] NOAA, *Ocean Fertilization*, p. 20.

[27] NASEM, *Research Strategy*, p. 81; and NOAA, *Ocean Fertilization*, p. 20.

International Guidelines for Ocean Fertilization

Most OIF experiments have occurred in the open ocean where iron is scarce, and beyond the exclusive economic zone (EEZ) of coastal nations.[28] These areas in the open ocean are subject to international agreements. Early OIF experiments were conducted largely without international oversight. No international body or agreement is specifically devoted to ocean fertilization. International bodies have produced nonbinding guidelines for future ocean fertilization experiments.[29]

The London Convention and the London Protocol

The principal international instruments addressing the potential impacts of ocean fertilization on the marine environment are the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, known as the *London Convention*,[30] and the 1996 Protocol to the London Convention, known as the *London Protocol*.[31] The United States is a party to the London Convention and is not a party to the London Protocol. Both the convention and the protocol provide sets of international standards that attempt to guide and limit ocean fertilization.

In 2008, the International Maritime Organization adopted a nonbinding resolution under the London Convention that allows for only ocean fertilization activities that fall within the scope of "legitimate scientific research."[32] As a party to the London Convention, the United States supported this 2008 resolution. The U.S. Environmental Protection Agency (EPA) is responsible for implementing the convention's guidelines for the dumping of wastes and other matter at sea under the Marine Protection, Research and Sanctuaries Act (MPRSA; P.L. 92-532).[33]

In 2013, the parties to the London Protocol agreed to amend the protocol to limit ocean fertilization for research purposes.[34] This amendment would become legally binding only if ratified by two-thirds of the parties to the protocol, and only those parties that ratified the amendment would be bound by it. There are 53 parties to the London Protocol, and, as of June 2022, the amendment has not been ratified. The United States is not a party to the protocol, so the amendment (if ratified) would not limit U.S. activities.

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[28] United Nations Framework Convention on the Law of the Sea (UNCLOS), Article 57 states, "the exclusive economic zone shall not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured." The United States is not a party to UNCLOS.

[29] NASEM, *Research Strategy*, p. 79.

[30] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), London, December 29, 1972, in force August 30, 1975, 1046 UNTS 138.

[31] 1996 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Protocol), November 7, 1996, in force March 24, 2006, 36 ILM 1.

[32] Resolution LC-LP.1 of the International Maritime Organization, *Report of the 30th Consultative Meeting and the 3rd Meeting of Contracting Parties*, LC 30/16, Annex 6, December 9, 2008.

[33] Marine Protection, Research and Sanctuaries Act (MPRSA; P.L. 92-532; 33 U.S.C §§1401 et seq.). Environmental Protection Agency, "Marine Protection, Research and Sanctuaries Act (MPRSA) and Federal Facilities," at https://www.epa.gov/enforcement/marine-protection-research-and-sanctuaries-act-mprsa-and-federal-facilities#:~:text=The%20Marine%20Protection%2C%20Research%2C%20and,or%20economic%20potentialities%20(33%20U.S.C.

[34] International Maritime Organization, *On the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities*, Resolution LP.4(8), October 2013, at https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/LCLPDocuments/LP.4(8).pdf.

Convention on Biological Diversity

The objectives of the United Nations Convention on Biological Diversity (CBD) are to conserve and sustainably use the components of biodiversity, among others.[35] A decision under the CBD rejects OIF as a means for climate mitigation until scientists better understand the potential associated risks for the environment and biodiversity, including socioeconomic and cultural impacts.[36] In 2008, the CBD issued a statement requesting member states restrict ocean fertilization activities, with the exception of "small scale studies within coastal waters" for the purpose of specific scientific research.[37] The United States is not a Party to the CBD.[38]

Antarctic Treaty System

The Antarctic Treaty System (ATS) established the legal framework for Antarctica and the surrounding Southern Ocean.[39] The ATS guarantees free access and research rights for the international community to undertake research activities that fall within its geographic scope.[40] The United States is a Party to the ATS. Parties to the treaty are to take certain actions prior to undertaking any activity in the region. For example, parties are to develop an environmental assessment, provide advance notice to other parties, share data with other parties, and prevent marine pollution.[41] Ocean fertilization occurring in the Southern Ocean may be subject to attention by the Scientific Committee and Commission of the 1980 Convention on the Conservation of Antarctic Marine Living Resources under the ATS.[42]

United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1994 with the aim of preventing "dangerous" human interference with the climate system.[43] Under the UNFCCC, the Kyoto Protocol calls for the promotion and implementation of climate technologies.[44] In terms of carbon credits, the Kyoto Protocol's Clean Development Mechanism

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[35] Convention on Biological Diversity (CBD), "Introduction," at https://www.cbd.int/intro/.

[36] Conference of the Parties to the CBD, Decision IX/16, *Biodiversity and Climate Change* (A.4), May 2008, at https://www.cbd.int/doc/decisions/cop-09/cop-09-dec-16-en.pdf (hereinafter referred to as CBD Decision IX/16).

[37] CBD Decision IX/16 (C.4).

[38] CBD, "List of Parties," at https://www.cbd.int/information/parties.shtml.

[39] For more information on Antarctica, see CRS Report R46708, *Antarctica: Overview of Geopolitical and Environmental Issues*, by Pervaze A. Sheikh, Bruce Vaughn, and Kezee Procita.

[40] The Antarctic Treaty, 402 U.N.T.S. 71, entered into force June 23, 1961, at https://documents.ats.aq/ats/treaty_original.pdf. See Department of State, "Antarctic Treaty," at https://2009-2017.state.gov/t/avc/trty/193967.html.

[41] NOAA, *Ocean Fertilization*, p. 30.

[42] Antarctic Climate and Ecosystems Cooperative Research Centre, "Position Analysis: Ocean Fertilisation: Science and Policy Issues," 2008, p. 14, at https://www.whoi.edu/fileserver.do?id=56383&pt=10&p=39472.

[43] United Nations, "What Is the United Nations Framework Convention on Climate Change?," at https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change. See CRS Report R46204, *The United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Agreement: A Summary*, by Jane A. Leggett.

[44] Article 10(c), Kyoto Protocol to the United Nations Framework Convention on Climate Change (Kyoto Protocol), Kyoto, December 11, 1997, in force February 16, 2005, 2303 UNTS 162.

does not recognize ocean fertilization as a way to create carbon credits for regulated international trade.[45] The United States is a Party to the UNFCC and is not a Party to the Kyoto Protocol.[46]

Within the UNFCCC, the Paris Agreement calls for holding the average global temperature increase to "well below 2˚C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5˚C above pre-industrial levels."[47] The Paris Agreement does not mandate or authorize the use of geoengineering techniques. Some scientists believe a range of CDR methods must be implemented to achieve the Paris Agreement's objectives.[48] As part of the United States reentering the Paris Agreement, the National Climate Task Force established "a new target for the United States to achieve a 50-52 percent reduction from 2005 levels in economy-wide net greenhouse gas pollution in 2030" in its "Nationally Determined Contributions" (NDC) submission to the UNFCCC.[49] The U.S. NDC makes no reference to geoengineering techniques.

United Nations Convention on the Law of the Sea

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) does not specifically address ocean-based geoengineering techniques, but several of its principles and concepts may apply to ocean fertilization activities.[50] The United States is not a Party to UNCLOS. The United States recognizes that the convention reflects customary international law and complies with many of its provisions.[51]

The United Nations and other international bodies generally categorize ocean fertilization experiments as *marine scientific research*. UNCLOS provides general principles for this category of research, including that research be conducted in compliance with the convention's international standards for the "protection and preservation of the marine environment."[52]

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[45] A *carbon credit* represents CO_2 emissions reductions or sequestration that businesses, organizations, and individuals can earn, buy, trade, or sell on the carbon market. Three U.S.-based companies that are no longer in business (GreenSea Venture, Planktos, and Climos) proposed using ocean fertilization to enter into the carbon trading market. Jeff Tollefson, "Ocean-Fertilization Project off Canada Sparks Furore," *Nature*, vol. 490 (October 2012), p. 458; NOAA, *Ocean Fertilization* p. 13; and NRC, *Climate Intervention*, p. 59. For information on the carbon market, see CRS Report R46956, *Agriculture and Forestry Offsets in Carbon Markets: Background and Selected Issues*, by Genevieve K. Croft et al.

[46] United Nations Framework Convention on Climate Change (UNFCCC), "The Kyoto Protocol – Status of Ratification," at https://unfccc.int/process/the-kyoto-protocol/status-of-ratification.

[47] The Paris Agreement entered into force on November 4, 2016. See "Decision 1/CP.21: Adoption of the Paris Agreement," in *Report of the Conference of the Parties on Its Twenty-First Session, Held in Paris from 30 November to 13 December 2015,* UN Doc. FCCC/CP/2015/10/Add.1, Annex 21, p. 21, at http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf.

[48] IPCC, "Summary for Policymakers," in *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, eds. V. Masson-Delmotte et al., 2018, p. 17.

[49] White House, "FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Targe Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies," press release, April 22, 2021, at https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/. For more information on "Nationally Determined Contributions," see CRS In Focus IF11746, *United States Rejoins the Paris Agreement on Climate Change: Options for Congress*, by Jane A. Leggett.

[50] 1982 UNCLOS, Montego Bay, December 10, 1982, in force November 16, 1994, 1833 UNTS 397.

[51] Department of State, "Law of the Sea Convention," at https://www.state.gov/law-of-the-sea-convention/.

[52] UNCLOS, Article 240(d).

Some environmental groups consider ocean fertilization a form of pollution and a potential threat to the marine ecosystem.[53] UNCLOS defines *pollution of the marine environment* as

> the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.[54]

Because UNCLOS does not describe a level of environmental harm and biological tolerance in its definition of pollution, it may not be possible to categorize all future ocean fertilization experiments as pollution.[55] Conversely, given that ocean fertilization adds nutrients to the surface of the ocean for the purpose of removing CO_2 from the atmosphere and sequestering it in the deep ocean, some may consider this technique to be protecting the marine environment from climate change impacts.[56]

Issues for Congress

In recent appropriations, Congress has recommended and funded several direct air capture research activities—technologies that remove CO_2 from the atmosphere.[57] Instead of relying on technologies to remove carbon from the atmosphere, OIF would amplify the naturally occurring biological pump. Because OIF is stimulating a biological process, models suggest that its cost of deployment at scale could range from $30 to $300 per metric ton CO_2 (/t CO_2);[58] by contrast, direct air capture technologies are estimated at $100-$1,000/t CO_2.[59] However, some environmental nongovernmental organizations contend that OIF would be impractical and costly.[60]

In a 2017 U.S. House Committee on Science, Space, and Technology hearing on geoengineering, a climate engineering witness discussed "at scale" deployment of ocean fertilization in a prepared statement. The witness noted that "ocean iron fertilization could increase marine phytoplankton, increasing CO_2 uptake through photosynthesis, some unknown fraction of which may ultimately be sequestered in the deep ocean by settling of biological detritus. At scale this approach would have significant implications for ocean ecosystems."[61]

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[53] Quirin Schiermeier, "Convention Discourages Ocean Fertilization," *Nature*, vol. 196 (November 2007), at https://doi.org/10.1038/news.2007.230; and Greenpeace Research Laboratories, *A Scientific Critique of Ocean Iron Fertilization as a Climate Change Mitigation Strategy*, September 2007, p. 14, at https://www.greenpeace.to/publications/iron_fertilisation_critique.pdf (hereinafter referred to as Greenpeace, *Scientific Critique*).

[54] UNCLOS, Article 1(4).

[55] Johansen, "Ocean Fertilization," p.193.

[56] Three U.S.-based companies (GreenSea Venture, Planktos, and Climos) that are no longer in business pursued ocean iron fertilization (OIF) as a climate change mitigation measure. NOAA, *Ocean Fertilization*, p. 2.

[57] For specific appropriations funding for direct air capture research, see CRS In Focus IF11501, *Carbon Capture Versus Direct Air Capture*, by Ashley J. Lawson.

[58] An investment of approximately $1-2 million for OIF activities reportedly could cover the cost of iron and a chartered ship. NASEM, *Research Strategy*, pp. 92 and 97; and P. Boyd, "Implications of Large-Scale Iron Fertilization of the Oceans," *Marine Ecology Progress Series*, vol. 364 (July 2008), pp. 216-217.

[59] NASEM, *Negative Emissions Technologies*, p. 190.

[60] Greenpeace, *Scientific Critique*, p. 14.

[61] U.S. Congress, House Committee on Science, Space, and Technology, *Geoengineering: Innovation, Research, and Technology*, joint hearing, 115th Cong., 1st sess., November 8, 2017 (Washington, DC: GPO, 2017).

Funding for Ocean Iron Fertilization Research[62]

Some researchers in the U.S. scientific community estimate that as much as $2.5 billion is needed over the next decade to further study ocean-based geoengineering and how implementation of these techniques might impact the ocean.[63] A better understanding of the ocean uptake of atmospheric CO_2 and the impacts associated with OIF could elucidate the criteria for purposefully selecting sites for fertilization.

Congressional funding for ocean research technology and equipment already provides data products that could be useful for monitoring and verifying the effectiveness of ocean fertilization. For example, National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration satellites that measure chlorophyll concentrations can estimate the size of phytoplankton blooms.[64] Researchers could use satellite observations to study the development and duration of blooms created via ocean fertilization.[65] Ocean-based research monitoring equipment (e.g., Argo profiling floats, autonomous surface vehicles, sediment traps) is suited to study the sinking from the surface to the deep ocean of atmospheric carbon incorporated into phytoplankton cells. Moreover, using federally supported ocean research technology and equipment to monitor ocean waters adjacent to a fertilized area could serve as a control and could allow for observations on the bloom's size, spatial extent, and impact on the physical and chemical properties of the ocean. For instance, Congress directed NOAA to expand coverage of the Biogeochemical Argo fleet in FY2022.[66] According to some stakeholders, an expanded Biogeochemical Argo fleet would allow for additional direct observations of biological productivity, oceanic uptake of atmospheric CO_2, and carbon export into the deep ocean.[67]

In the Energy Act of 2020 (enacted as Division Z of the Consolidated Appropriations Act, 2021; P.L. 116-260), Congress directed the U.S. Department of Energy (DOE) to establish a research program for carbon removal options.[68] The law mentions several carbon removal options that may be included in the research program but does not explicitly mention ocean fertilization. Congress could consider giving DOE or other agencies additional guidance regarding federal research into OIF. Congress also could consider oversight action related to DOE's carbon removal research programs and the extent to which DOE is coordinating with other relevant agencies, such as NOAA.

[62] For more information on federally funded oceanic research, see CRS Report R47021, *Federal Involvement in Ocean-Based Research and Development*, by Caitlin Keating-Bitonti.

[63] See Warren Cornwall, "Panel Calls for $2.5 Billion in Ocean Geoengineering Research," *Science*, December 8, 2021, at https://www.science.org/content/article/panel-calls-2-5-billion-ocean-geoengineering-research.

[64] National Aeronautics and Space Administration (NASA), "Remote Sensing," at https://science.nasa.gov/earth-science/oceanography/living-ocean/remote-sensing; and NASA, "VIRRS Single-Sensor S-NPP and NOAA-20 Anomaly Products," at https://coastwatch.noaa.gov/cw/satellite-data-products/ocean-color/anomaly.html.

[65] NASEM, *Research Strategy*, p. 85.

[66] H.Rept. 117-97 referenced by the explanatory statement accompanying the FY2022 Consolidated Appropriations Act (P.L. 117-103).

[67] University of California San Diego, "BioGeoChemical Argo Mission," at https://argo.ucsd.edu/expansion/biogeochemical-argo-mission/.

[68] Energy Act of 2020, 42 U.S.C. §16298d.

Research of Ocean Iron Fertilization's Environmental and Ecological Impacts

Some groups contend that, under UNCLOS, ocean fertilization could be considered *pollution of the marine environment* due to the addition of nutrients to the ocean's surface.[69] Congress may consider authorizing research studies to quantify the environmental effects of OIF, if any. For example, some research indicates that ocean fertilization might result in oxygen loss in regions of the ocean.[70] Other studies suggest iron fertilization might increase atmospheric concentrations of nitrous oxide, which could counteract some of the climate benefits of OIF.[71]

Adverse impacts associated with ocean fertilization may include the growth of phytoplankton associated with harmful algal blooms,[72] and acidification of the deep ocean, which could harm deep-sea corals.[73] U.S.-based proposals for ocean fertilization within the EEZ could be subject to authorities under federal laws, such as the Marine Protection, Research, and Sanctuaries Act (P.L. 92-532); Coastal Zone Management Act (P.L. 109-58); National Marine Sanctuaries Act (P.L. 106-513); and Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (MSA; P.L. 109-479), among others. For example, the MSA requires federal agencies to consult with NOAA on proposed, funded, authorized, or undertaken activities that may adversely affect the marine habitat.[74] In addition to evaluating whether ocean fertilization proposals might trigger a review under the MSA, Congress could consider stand-alone legislation that provides a framework for ocean fertilization activities taking place within the U.S. EEZ.

Another consideration could be to determine whether OIF is a form of transboundary pollution and how OIF might fit into existing international law. Although one nation might weigh the climate change mitigation aspects of OIF more favorably than the environmental costs, other nations may consider the addition of nutrients that spread into their EEZs to be pollution. In addition, a 2009 Royal Society report points to *nutrient robbing*, where nutrients in the area of fertilization reduce biological productivity in adjacent regions. Nutrient robbing could affect the marine food web, including fisheries.[75] If the nutrient-robbed area falls within another nation's EEZ, this could present potential geopolitical issues.[76] Congress may consider legislation that regulates the scale and siting of ocean fertilization activities to limit ocean fertilization's impacts on adjacent marine ecosystems, particularly those within a neighboring nation's EEZ.

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[69] Johansen, "Ocean Fertilization," p.192.

[70] R. S. Lampitt et al., "Ocean Fertilization: A Potential Means of Geoengineering?," *Philosophical Transactions of the Royal Society*, vol. 366 (August 2008), pp. 3930-3931.

[71] NRC, *Climate Intervention*, p. 61.

[72] NASEM, *Research Strategy*, p. 90. For more information on harmful algal blooms, see CRS Report R46921, *Marine Harmful Algal Blooms (HABs): Background, Statutory Authorities, and Issues for Congress*, by Eva Lipiec.

[73] NASEM, *Research Strategy*, p. 91; and The Royal Society, *Geoengineering the Climate: Science, Governance and Uncertainty* (London, UK: The Royal Society, 2009), p. 18 (hereinafter referred to as Royal Society, *Geoengineering the Climate*).

[74] §305(b) of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (P.L. 109-479); and NOAA, *Ocean Fertilization*, p. 31.

[75] Royal Society, *Geoengineering the Climate*, p. 18; and NOAA, *Ocean Fertilization*, p. 27.

[76] Philip W. Boyd, "Geopolitics of Geoengineering," *Nature Geoscience*, vol. 2, no. 812 (December 2009), p. 812.

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