

GOVERNANCE OF OCEAN-BASED CARBON DIOXIDE REMOVAL RESEARCH UNDER THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA

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There has been a spate of research in recent years indicating that achievement of the temperature objectives of the Paris Agreement can only be effectuated through both aggressive decarbonization of the global economy and large-scale deployment of so-called carbon dioxide removal (CDR) approaches. While much of the early focus of CDR research was on terrestrial options, such as afforestation, direct air capture, and bioenergy with carbon capture and storage, more recently, many in the scientific and policy community have increasingly focused on potential ocean-based approaches, including ocean fertilization, ocean alkalinity enhancement, macroalgae harvesting, and ocean upwelling and downwelling. However, while research on these approaches has proceeded, the regulatory process to oversee such research remains amorphous. This article seeks to establish the contours for regulation of ocean-based CDR under the United Nations Convention on the Law of the Sea (UNCLOS). It discusses the potential risks and benefits of the most prominently discussed ocean CDR options and suggests how UNCLOS's provisions on marine scientific research might be applied to ensure effective global governance of such research.

INTRODUCTION

It is becoming increasingly clear that achievement of the Paris Climate Agreement temperature objectives¹ will require the global community to engage in both extremely rapid and aggressive decarbonization of the world economy *and* deployment of atmospheric carbon dioxide removal (CDR) approaches at a

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1. Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104 [hereinafter Paris Agreement]. The treaty calls upon the parties to seek to hold increases in temperature “to well below 2°C above pre-industrial levels,” and to pursue “efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.” *Id.* at 3. In 2021, the parties to the Paris Agreement acknowledged that “impacts of climate change will be much lower at the temperature increase of 1.5°C compared with 2°C and *resolves* to pursue efforts to limit the temperature increase to 1.5°C. U.N. Framework Convention on Climate Change, Report of the Conference of the Parties Serving as the Meeting of the Parties to the Paris Agreement on its Third Session, held in Glasgow from 31 October to 13 November 2021, ¶ 21, FCCC/PA/CMA/2021/10/Add.1 (Mar. 8, 2022).

substantial scale.² It is contemplated that carbon dioxide (CO₂) removal will be necessary to balance out “residual emissions” from “hard to abate” sectors, such as steel and agriculture, as well as to reduce atmospheric concentrations of carbon dioxide related to historical, or “legacy,” emissions responsible for ongoing climatic damage.³

Carbon dioxide removal is defined by the United Nations’ Intergovernmental Panel on Climate Change (IPCC) as “the process of removing CO₂ from the atmosphere” primarily by “either enhancing existing natural processes that remove carbon from the atmosphere . . . or using chemical processes to, for example, capture CO₂ directly from the ambient air and store it.”⁴

Of the integrated assessment model scenarios in the IPCC’s Fifth Assessment Report that achieve the Paris Agreement’s upper-level temperature targets, 87% contemplated the need for extensive deployment of CDR options.⁵ Moreover, the IPCC has since concluded that “all pathways that limit increases in warming to 1.5°C above pre-industrial levels with limited or no overshoot” require large-scale adoption of CDR.⁶ CDR is also identified as a “key element” in scenarios that likely limit temperature increases to 2°C.⁷

In many of these scenarios, the scale of requisite CO₂ removal is as much as 10–20 gigatons of CO₂ (GtCO₂) per year in the latter half of this century.⁸ This would translate into removal of a whopping 700–1,000 GtCO₂ from the atmosphere between 2011–2100 to effectuate “stabiliz[ation of] temperatures at either 1.5°C or 2.0°C above pre-industrial levels.”⁹ Moreover, deployment of CDR

2. See Wil Burns et al., *Introduction*, in *CLIMATE GEOENGINEERING: SCIENCE, LAW & GOVERNANCE* 1, 6 (Wil Burns et al. eds., 2021); Christian Breyer et al., *On the History and Future of 100% Renewable Energy Systems Research*, 10 *IEEE ACCESS* 78176, 78196 (2022).

3. Matthias Honegger et al., *Who Is Paying for Carbon Dioxide Removal? Designing Policy Instruments for Mobilizing Negative Emissions Technologies*, *FRONTIERS CLIMATE*, June 7, 2021, at 1, 2; Felix Schenuit et al., *Carbon Dioxide Removal Policy in the Making: Assessing Developments in 9 OECD Cases*, *FRONTIERS CLIMATE*, Mar. 4, 2021, at 1, 4–5; David Kramer, *Carbon Dioxide is Suddenly Obtaining Credibility and Support*, *PHYSICS TODAY*, June 2022, at 26, 27.

4. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE [IPCC], *GLOBAL WARMING OF 1.5°C* 394 (Valérie Masson-Delmotte et al. eds., 2018) [hereinafter *GLOBAL WARMING*].

5. Michael Obersteiner et al., *How to Spend a Dwindling Greenhouse Gas Budget*, *NATURE CLIMATE CHANGE*, Jan. 2018, at 7, 7.

6. *GLOBAL WARMING*, *supra* note 4, at 17; see also IPCC, *CLIMATE CHANGE 2022: MITIGATION OF CLIMATE CHANGE*, at SPM-47 (2022) [hereinafter *CLIMATE CHANGE 2022*] (“The deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO₂ or [greenhouse gas] emissions are to be achieved.”).

7. *CLIMATE CHANGE 2022*, *supra* note 6, at TS-94. While there are some scenarios-based studies that outline a path to achieve climate objectives without carbon removal, most contemplate policy and individual behavioral measures that may not prove credible. See Mark Diesendorf, *Scenarios for Mitigating CO₂ Emissions from Energy Supply in the Absence of CO₂ Removal*, 22 *CLIMATE POL’Y* 882, 887–92 (2022).

8. Matthias Honegger & David Reiner, *The Political Economy of Negative Emissions Technologies: Consequences for International Policy Design*, 18 *CLIMATE POL’Y* 306, 308 (2018).

9. JAMES MULLIGAN ET AL., *WORLD RES. INS.*, *TECHNOLOGICAL CARBON REMOVAL IN THE UNITED STATES* 5 (2018).

is viewed by some as a means to ameliorate impacts on vulnerable populations and industries during the decarbonization transition.¹⁰

Much of the early focus on the potential role of CDR was on land-based approaches. These options include afforestation/reforestation initiatives to enhance uptake of carbon dioxide via photosynthesis,¹¹ efforts to increase uptake of carbon dioxide in soils,¹² direct air capture,¹³ bioenergy with carbon capture and storage (BECCS),¹⁴ and enhanced mineral weathering.¹⁵

However, there are increasing questions about whether these terrestrial options alone can deliver the requisite levels of carbon dioxide removal, as well as serious concerns about the sustainability of many of these options at large-scale deployment.¹⁶ This has led many proponents of carbon dioxide removal to call for research into the potential role of ocean-based options.¹⁷ This is consistent with a more general focus in recent years on the potential role of the oceans in the realm

10. Miranda Boettcher et al., *Navigating Potential Hype and Opportunity in Governing Marine Carbon Removal*, FRONTIERS CLIMATE, June 9, 2021, at 1, 3.

11. Jean-Francois Bastin, *The Global Tree Restoration Potential*, 365 SCI. 76, 76–79 (2019); see also *About the Challenge*, BONN CHALLENGE, <https://www.bonnchallenge.org/about> [<https://perma.cc/6NC2-H2SK>].

12. R. Lal, *Soil Carbon Sequestration to Mitigate Climate Change*, 123 GEODERMA 1, 2 (2004). “The term ‘soil C sequestration’ implies removal of atmospheric CO₂ by plants and storage of fixed C as soil organic matter.” *Id.* at 9; see also Keith Paustian et al., *Soil C Sequestration as a Biological Negative Emission Strategy*, FRONTIERS CLIMATE, Oct. 16, 2019, at 1, 1–2.

13. Jere Elfving et al., *Characterization and Performance of Direct Air Capture Sorbent*, 114 ENERGY PROCEDIA 6087–101 (2017). Direct air capture technologies can effectuate extraction of carbon dioxide from the atmosphere, with most approaches involving either passing ambient air through liquid solutions to separate out carbon dioxide or deploying solid sorbents that chemically bind with carbon dioxide. Sara Budinis, *Direct Air Capture*, INT’L ENERGY AGENCY (Sept. 2022), <https://www.iea.org/reports/direct-air-capture> [<https://perma.cc/8NUW-YYTC>].

14. BECCS involves the generation of energy with biomass feedstocks, which would remove carbon dioxide from the atmosphere in their growing phase, paired with carbon capture systems. Wil Burns & Simon Nicholson, *Bioenergy and Carbon Capture with Storage (BECCS): The Prospects and Challenges of an Emerging Climate Policy Response*, 7 J. ENV’T STUD. & SCI. 527, 528 (2017); see also Matthias Fridahl & Mariliis Lehtveer, *Bioenergy with Carbon Capture and Storage (BECCS): Global Potential, Investment Preferences, and Deployment Barriers*, 42 ENERGY RES. & SOC. SCI. 155, 156 (2018).

15. Enhanced mineral weathering seeks to accelerate the natural silicon mineral weathering process that takes up atmospheric carbon dioxide over the course of thousands of years by grinding up silicate-rich rocks to increase reactive surfaces and distributing the particles in regions with high weathering rates. Filip J.R. Meysman & Francesc Montserrat, *Negative CO₂ Emissions via Enhanced Silicate Weathering in Coastal Environments*, BIO. LETTERS, Apr. 5, 2017, at 1, 1–2; see also Benjamin Houlton, *Enhanced Weathering: Crushed Rocks Spread on Farmland Can Capture Billions of Tons of CO₂/Year*, ENERGY POST (July 21, 2020), <https://energypost.eu/enhanced-weathering-crushed-rocks-spread-on-farmland-can-capture-billions-of-co2-year/>.

16. See Matthias Honegger et al., *Potential Implications of Carbon Dioxide Removal for the Sustainable Development Goals*, 21 CLIMATE POL’Y 678, 682 (2021); Robin Chazdon & Pedro Brancalion, *Restoring Forests as a Means to Many Ends*, 365 SCI. 24, 25 (2019); William C.G. Burns, *Human Rights Dimensions of Bioenergy with Carbon Capture and Storage: A Framework for Climate Justice in the Realm of Climate Geoengineering*, in CLIMATE JUSTICE: CASE STUDIES IN GLOBAL AND REGIONAL GOVERNANCE CHALLENGES 149, 157–60 (Randall S. Abate ed., 2016).

17. See, e.g., *In-Depth Q&A: The IPCC’s Sixth Assessment on How to Tackle Climate Change*, CARBON BRIEF (Apr. 5, 2022), <https://www.carbonbrief.org/in-depth-qa-the-ipccs-sixth-assessment-on-how-to-tackle-climate-change>; see also Boettcher et al., *supra* note 10.

of “climate solutions.”¹⁸ This Article adopts the definition of “ocean-based CDR” advanced by the Aspen Institute’s Energy and Environmental Program as “a range of intervention techniques that: (1) take place primarily in the ocean, including in coastal regions; (2) extract CO₂ directly from the atmosphere, or from seawater leading to additional reduction of atmospheric CO₂; and (3) durably store the extracted CO₂ for a significant period of time.”¹⁹

There are a number of compelling reasons to scrutinize the potential role of the oceans for additional carbon removal options. Oceans cover approximately 70% of the world’s surface,²⁰ comprise more than 97% of the biosphere,²¹ and contain approximately fifty times more carbon than the atmosphere²² and twenty times more than terrestrial plants and soils.²³

Indeed, the world’s oceans “constitute[] the largest carbon sink, absorbing about 40% of anthropogenic CO₂ emissions since the beginning of the industrial era,”²⁴ and about 25% of current carbon dioxide emissions²⁵— approximately ten gigatons of CO₂ annually.²⁶ Moreover, it is believed that wide-scale deployment of ocean-based CDR could increase the oceans’ carbon sequestration capacity by as much as five to ten gigatons annually,²⁷ as well as potentially yield substantial ecosystem and economic co-benefits.²⁸

18. See Anne B. Christianson et al., *The Promise of Blue Carbon Climate Solutions: Where the Science Supports Ocean-Climate Policy*, FRONTIERS MARINE SCI., Apr. 29, 2022, at 1, 2; see also MORITZ VON UNGER ET AL., BLUE NATURE-BASED SOLUTIONS IN NATIONALLY DETERMINED CONTRIBUTIONS 4 (2020).

19. ENERGY & ENV’T PROGRAM, ASPEN INST., GUIDANCE FOR OCEAN-BASED CARBON DIOXIDE REMOVAL PROJECTS 7 (2021).

20. Adriana Fabra, *Marine Environment: Pollution and Fisheries*, in THE OXFORD HANDBOOK OF INTERNATIONAL ENVIRONMENTAL LAW 529, 529 (Lavanya Rajamani & Jacqueline Peel eds., 2d ed. 2021).

21. *Id.*

22. David P. Keller, *Marine Climate Engineering*, in HANDBOOK ON MARINE ENVIRONMENT PROTECTION 261, 265 (Markus Salomon & Till Markus eds., 2018).

23. Ken Buesseler et al., *Oceans Have 50 Times More Carbon Than the Atmosphere: A ‘Code of Conduct’ Can Rescue It*, THEPRINT (July 2, 2022), <https://theprint.in/environment/oceans-have-50-times-more-carbon-than-the-atmosphere-a-code-of-conduct-can-rescue-it/1020582/>.

24. Ibadillah A. Digdaya et al., *A Direct Coupled Electrochemical System for Capture and Conversion of CO₂ From Oceanwater*, NATURE COMM’NS, Sept. 4, 2020, at 1, 2; see also David Archer et al., *Atmospheric Lifetime of Fossil Fuel Carbon Dioxide*, 37 ANN. REV. EARTH & PLANETARY SCIS. 117, 119 (2009). “In the first millennium after the instantaneous CO₂ release, the trajectory of atmospheric CO₂ is dominated by CO₂ dissolution into the ocean and transport to depth.” Archer et al., *supra*, at 124.

25. Andrew J. Watson et al., *Revised Estimates of Ocean-Atmosphere CO₂ Flux Are Consistent with Ocean Carbon Inventory*, NATURE COMM’NS, Sept. 4, 2020, at 1, 1.

26. Wil Burns & Charles R. Corbett, *Antacids for the Sea? Artificial Ocean Alkalinization and Climate Change*, 3 ONE EARTH 154, 154 (2020); see also Pierre Friedlingstein et al., *Global Carbon Budget 2022*, 14 EARTH SYS. SCI. DATA 4814.

27. Adam Vaughn, *Engineering the Oceans*, NEW SCIENTIST, July 2, 2022, at 46, 47; see also ENERGY FUTURES INITIATIVE, UNCHARTED WATERS: EXPANDING THE OPTIONS FOR CARBON DIOXIDE REMOVAL IN

COASTAL AND OCEAN ENVIRONMENTS 42 (2020); Keller, *supra* note 22, at 265.

28. ENERGY FUTURES INITIATIVE, *supra* note 27, at 29.

Some of the most prominently discussed ocean-based CDR approaches include ocean iron fertilization (OIF), artificial upwelling/downwelling, “blue carbon” options, and ocean alkalinity enhancement options.²⁹ All of these options will be discussed in Part I of this Article.

Research into most ocean CDR approaches is still in nascent stages.³⁰ It is being conducted primarily by nonprofit and academic institutions³¹ or small start-up companies, with many of the latter hoping to sell carbon credits in voluntary carbon markets.³² However, as the U.S. National Academies of Sciences, Engineering, and Medicine (NASEM) recently observed in a major report on ocean CDR approaches, research and potential large-scale use of these approaches requires a clear and cohesive legal framework to minimize risks and promote investor and policymaker confidence.³³ However, the report further contends that the current legal framework is “highly fragmented,” and might involve the application of many provisions designed for regulation of other activities.³⁴

Because society is in “early days” in terms of vetting ocean CDR approaches, this Article will focus on the governance of research rather than deployment, though some of these principles will likely also be pertinent to deployment. More specifically, the focus will be on pertinent provisions of the United Nations Convention on the Law of the Sea (UNCLOS),³⁵ which is recognized as the primary international legal instrument to govern marine scientific research (MSR).³⁶ As such, this Article will not focus on potentially pertinent domestic legal and regulatory provisions, although approaches deployed within nations’ exclusive economic zones may primarily be governed by such measures.³⁷

29. See generally NAT’L ACADS. OF SCIS., ENG’G, & MED., A RESEARCH STRATEGY FOR OCEAN-BASED CARBON DIOXIDE REMOVAL AND SEQUESTRATION (2022) [hereinafter NASEM]; KERRY BRENT ET AL., CTR. FOR INT’L GOVERNANCE INNOVATION, GOVERNANCE OF MARINE GEO-ENGINEERING 10–15 (2019); Jean-Pierre Gatusso et al., *Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems*, FRONTIERS MARINE SCI., Oct. 4, 2018, at 1, 1.

30. See ENERGY FUTURES INITIATIVE, *supra* note 27, at 30–32; CLIMATE CHANGE 2022, *supra* note 6, at TS-94.

31. Jeff Tollefson, *Iron-Dumping Ocean Experiment Sparks Controversy*, SCI. AM. (May 24, 2017), <https://www.scientificamerican.com/article/iron-dumping-ocean-experiment-sparks-controversy/>.

32. See Adelle Peters, *This Carbon-Capture Tech Removes CO₂ from the Ocean by Making Seashells*, FAST CO. (June 3, 2021), <https://www.fastcompany.com/90642340/this-carbon-capture-tech-removes-co2-from-the-ocean-by-making-seashells>; Holly Stower, *Unlocking Blue Carbon Offsets – The Problems and Solutions for Ocean-Based Carbon Removal*, CLEANTECH GRP. (Aug. 5, 2021), <https://www.cleantech.com/unlocking-blue-carbon-offsets-the-problems-and-solutions-for-ocean-based-carbon-removal/>; James Temple, *Companies Hoping to Grow Carbon-Sucking Kelp May Be Rushing Ahead of the Science*, MIT TECH. REV. (Sept. 19, 2021), <https://www.technologyreview.com/2021/09/19/1035889/kelp-carbon-removal-seaweed-sinking-climate-change/>.

33. NASEM, *supra* note 29, at 39.

34. *Id.*

35. See generally U.N. Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 397 (entered into force Nov. 16, 1994) [hereinafter UNCLOS].

36. Marko Pavliha & Norman A. Martinez Gutiérrez, *Marine Scientific Research and the 1982 United Nations Convention on the Law of the Sea*, 16 OCEAN & COASTAL L.J. 115, 117 (2010); see also Hilde Woker et al., *The Law of the Sea and Current Practices of Marine Scientific Research in the Arctic*, MARINE POL’Y, Feb. 7, 2020, at 1, 1.

37. See ROMANY M. WEBB ET AL., SABIN CTR. FOR CLIMATE L., COLUM. L. SCH., REMOVING CARBON DIOXIDE THROUGH OCEAN ALKALINITY ENHANCEMENT AND SEAWEED CULTIVATION: LEGAL

This Article proceeds as follows: in Part I, it will focus on some key ocean CDR approaches, including sequestration potential, co-benefits, and risks of these respective options; in Part II, the Article will discuss key provisions of UNCLOS relevant to ocean-based CDR research.

I. OCEAN CDR: OVERVIEW

Ocean-based approaches are usually divided into two broad categories: (i) biotic approaches, which seek to boost primary production to capture dissolved CO₂ via photosynthesis and convert it into organic carbon which then can be sequestered; and (ii) abiotic approaches, which seek to convert carbon dioxide into carbonates or bicarbonates, or to convey carbon dioxide-rich water to the deep ocean.³⁸ This Article will now discuss a number of options in each category, with the caveat that these are intended only to be representative of the full range of ocean carbon dioxide removal options currently under discussion.³⁹

A. Biotic Ocean CDR

1. Ocean Iron Fertilization

One of the primary mechanisms for sequestration of carbon dioxide in ocean ecosystems is termed the “biological pump.”⁴⁰ Microscopic marine algae known as phytoplankton fix dissolved inorganic carbon dioxide in shallow waters through the photosynthetic process, converting the carbon dioxide into an organic form.⁴¹ While accounting for less than 1% of photosynthetic biomass, phytoplankton are responsible for approximately half of global carbon fixation.⁴²

The production of organic matter by phytoplankton in the photosynthetic process absorbs carbon dioxide from solution.⁴³ This facilitates more absorption of carbon dioxide from the atmosphere by lowering concentrations in the surface zone, increasing the concentration gradient.⁴⁴ “While the bulk of fixed organic carbon is remineralized in the upper layers of the ocean and released to the atmosphere, a portion is transported downwards by the sinking of dead phytoplankton biomass and zooplankton fecal pellets into the deep ocean and

CHALLENGES AND OPPORTUNITIES 4 (2022); NASEM, *supra* note 29, at 38; ENERGY FUTURES INITIATIVE, *supra* note 27, at 34.

38. Antonius Gagern, *Demystifying Ocean-Based Carbon Dioxide Removal: An Explainer*, OUR SHARED SEAS (Jan. 18, 2021), <https://oursharedseas.com/demystifying-ocean-based-carbon-dioxide-removal-an-explainer/>.

39. For a comprehensive treatment of such options, see generally JOINT GRP. OF EXPERTS ON THE SCI. ASPECTS OF MARINE ENV'T PROT., HIGH LEVEL REVIEW OF A WIDE RANGE OF PROPOSED MARINE GEOENGINEERING TECHNIQUES (2019) [hereinafter GESAMP].

40. BRENT ET AL., *supra* note 29, at 10.

41. See STEPHEN A. RACKLEY, CARBON CAPTURE AND STORAGE 523 (2d ed. 2017).

42. Sallie W. Chisholm et al., *Dis-Crediting Ocean Fertilization*, 294 SCI. 309, 309 (2001).

43. See Paul Falkowski, *Ocean Science: The Power of Plankton*, 483 NATURE S17, S18 (2012).

44. R.S. Lampitt et al., *Ocean Fertilization: A Potential Means of Geoengineering?*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A 3919, 3920 (2008).

sediments” on the ocean floor.⁴⁵ Carbon sinking to the level of sediments can effectuate sequestration for timescales of more than a century.⁴⁶

Proponents of OIF contend that optimal phytoplankton growth in regions such as the Southern (Antarctic) Ocean and equatorial Pacific is limited by the shortage of a critical micronutrient: iron.⁴⁷ These areas comprise about 25% of ocean surfaces.⁴⁸ Supporters of the so-called “iron hypothesis” argue that the dispersal of iron⁴⁹ in such regions could stimulate phytoplankton growth, ultimately resulting in enhanced carbon dioxide sequestration.⁵⁰

Some early modeling studies projected that OIF could offset a whopping 10–25% of the world’s annual carbon emissions.⁵¹ However, as thirteen field experiments have ensued,⁵² and model resolution has increased, these projections have, for the most part, been substantially trimmed back. One recent analysis projected that the maximum potential is probably no more than one gigaton of carbon annually.⁵³ Other studies have been even less sanguine, with one concluding that large-scale OIF deployment (20% of the world’s ocean surfaces) would only reduce atmospheric concentrations of carbon dioxide by fifteen parts per million (ppm).⁵⁴ The IPCC cited studies concluding that OIF could reduce atmospheric carbon dioxide concentrations by 15–33ppm, but only under “idealized” conditions.⁵⁵ However, some supporters have argued that more large-scale and granular assessments are necessary to make such determinations, providing a rationale for additional field research.⁵⁶ It is likely that further research on this approach will ensue over the next few years. For example, there are plans

45. BRENT ET AL., *supra* note 29, at 10; *see also* Andy Ridgwell, *Evolution of the Ocean’s “Biological Pump”*, 108 PNAS 16485, 16485 (2011); Jennie Dixon, *Iron Fertilization: A Scientific Review with International Policy Recommendations*, 32 ENVIRONS 321, 324–25 (2009).

46. BRENT ET AL., *supra* note 29, at 10; *see also* NASEM, *supra* note 29, at 78. *See generally* Victor Smetacek et al., *Deep Carbon Export from a Southern Ocean Iron-Fertilized Diatom Bloom*, 487 NATURE 313 (2012).

47. BRENT ET AL., *supra* note 29, at 10.

48. Lampitt et al., *supra* note 44, at 3924.

49. Most field experiments involving ocean iron fertilization have involved the addition of ferrous sulfate, a common agricultural fertilizer, to ocean waters. Phillip Williamson et al., *Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance*, 90 PROCESS SAFETY & PROT. 475, 477 (2012).

50. BRENT ET AL., *supra* note 29, at 10.

51. Hugh Powell, *Fertilizing the Ocean with Iron*, OCEANUS (Nov. 13, 2007), <https://www.whoi.edu/oceanus/feature/fertilizing-the-ocean-with-iron/>.

52. NASEM, *supra* note 29, at 81.

53. EUR. ACADS.’ SCI. ADVISORY COUNCIL, NEGATIVE EMISSION TECHNOLOGIES: WHAT ROLE IN MEETING PARIS AGREEMENT TARGETS? 18 (2018).

54. M.J.C. Crabbe, *Modelling Effects of Geoengineering Options in Response to Climate Change and Global Warming: Implications for Coral Reefs*, 33 COMPUTATIONAL BIOLOGY & CHEMISTRY 415, 418 (2009).

55. IPCC, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS 550 (Thomas F. Stocker et al. eds., 2013).

56. *See* Kerstin Güssow et al., *Ocean Iron Fertilization: Why Further Research Is Needed*, 34 MARINE POL’Y 911, 911–18 (2010); M.J.R. Fasham et al., *Development of a Robust Marine Ecosystem Model to Predict the Role of Iron in Biogeochemical Cycles: A Comparison of Results for Iron-Replete and Iron-Limited Areas, and the SOIREE Iron-Enrichment Experiment*, 53 DEEP-SEA RSCH. PART I: OCEANOGRAPHIC RSCH. PAPERS 333, 355 (2006).

afoot to conduct a field experiment in the Arabian Sea to assess whether seeding with iron-coated rice husks might suspend the nutrients for longer, and thus reduce the amount of iron that might have to be used in full-scale deployments.⁵⁷

OIF could also pose risks to both ecosystems and the livelihoods of those engaged in harvesting resources from the oceans. By design, OIF is intended to effectuate a shift to larger phytoplankton species that are heavy and can sink rapidly.⁵⁸ However, fundamental alteration of the base of the food web would result in transformation of both the structure and biogeochemical function of dependent communities, potentially altering global ocean ecosystems.⁵⁹

Additionally, OIF could deplete other non-limited nutrients, including nitrate or phosphate; in turn, this could reduce productivity downstream of where fertilization occurs, potentially resulting in a redistribution of fish resources, or even a net reduction.⁶⁰ Ultimately, “large regions of the temperate oceans would experience a decrease in primary production because of macronutrient limitations.”⁶¹ Indeed, the Southern Ocean supplies approximately 75% of the macronutrients that support the productivity of northern hemisphere waters, including fisheries.⁶² Moreover, it could result in a net decline in phytoplankton productivity, and thus negatively impact the global carbon budget.⁶³ Another potential avenue of future MSR in the context of ocean iron fertilization is assessment of whether the use of engineered nanoparticles could ameliorate the threat of nutrient robbing by increasing the efficiency of the process.⁶⁴

An additional concern is that OIF might foster toxic dinoflagellates known to produce algal blooms that could threaten human health and food security.⁶⁵ While the OIF field experiments to date have not supported this proposition, some

57. Warren Cornwall, *To Draw Down Carbon and Cool Off the Planet, Ocean Fertilization Gets Another Look*, SCI., (Dec. 15, 2021), <https://www.science.org/content/article/draw-down-carbon-and-cool-planet-ocean-fertilization-gets-another-look>.

58. Aaron L. Strong et al., *Ocean Fertilization: Science, Policy, and Commerce*, OCEANOGRAPHY, Sept. 2009, at 236, 256.

59. *Id.*; see also John J. Cullen & Philip W. Boyd, *Predicting and Verifying the Intended and Unintended Consequences of Large-Scale Ocean Iron Fertilization*, 364 MARINE ECOLOGY PROGRESS SERIES 295, 297 (2008).

60. DOUG WALLACE ET AL., INTERGOVERNMENTAL OCEANOGRAPHIC COMM’N, U.N. EDUC., SCI. & CULTURAL ORG., OCEAN FERTILIZATION: A SCIENTIFIC SUMMARY FOR POLICYMAKERS 8–9 (2010); see also Strong et al., *supra* note 58, at 244 (“[D]own-stream reduction in productivity could far outweigh the benefit of the initial iron-induced carbon sequestration in terms of a global carbon budget.”).

61. Ian S.F. Jones, *Contrasting Micro- and Macro-Nutrient Nourishment of the Ocean*, 425 MARINE ECOLOGY PROGRESS SERIES 281, 289 (2011); see also David P. Keller et al., *Potential Climate Engineering Effectiveness and Side Effects During a High Carbon Dioxide-Emission Scenario*, NATURE COMM’NS, Feb. 25, 2014, at 1, 7.

62. Philip W. Boyd, *Ocean Fertilization for Sequestration of Carbon Dioxide from the Atmosphere*, in GEOENGINEERING RESPONSES TO CLIMATE CHANGE 53, 67 (Tim Lenton & Naomi Vaughan eds., 2013); NASEM, *supra* note 29, at 87.

63. See Strong et al., *supra* note 58, at 244.

64. Peyman Babakhani et al., *Potential Use of Engineered Nanoparticles in Ocean Fertilization for Large-Scale Atmospheric Carbon Dioxide Removal*, 17 NATURE NANOTECH. 1342, 1343 (2022).

65. See SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY, SCIENTIFIC SYNTHESIS OF THE IMPACTS OF OCEAN FERTILIZATION ON MARINE BIODIVERSITY 11, 37 (2009).

researchers believe that large-scale deployment might pose this threat.⁶⁶ Finally, OIF could also exacerbate ocean acidification, with one study projecting that it would reduce pH in the Southern Ocean by an additional 0.15 units by 2100.⁶⁷

2. Seaweed Cultivation

As is true with terrestrial plants, seaweed uses photosynthesis to convert carbon dioxide into biomass.⁶⁸ Wild seaweed has removed carbon dioxide from the world's oceans, and thus ultimately the atmosphere, for more than 500 million years.⁶⁹ Recent studies suggest that wild seaweed sequesters approximately 173 million metric tons of carbon dioxide annually.⁷⁰ When seaweeds die and sink, a portion of the carbon sequestered in their biomass can end up being stored in sediments or the deep sea, locking the carbon away from exchange with the atmosphere.⁷¹ Some studies have suggested that this could sequester carbon for hundreds to thousands of years,⁷² though others have suggested that the timescales might be far more transient.⁷³

In recent years, a number of start-up companies have launched operations to farm seaweed for the express purpose of sinking it to the bottom of the ocean to effectuate carbon sequestration.⁷⁴ There are widely divergent estimates of how much carbon dioxide could ultimately be sequestered through this approach. NASEM's recent ocean CDR study concluded that a realistic number is about 0.1 GtCO₂ per year.⁷⁵ However, other studies have yielded more optimistic projections.⁷⁶

66. NASEM, *supra* note 29, at 89.

67. A. Oschlies et al., *Side Effects and Accounting Aspects of Hypothetical Large-Scale South Ocean Iron Fertilization*, 7 *BIOGEOSCI.* 4017, 4026 (2010).

68. Heather Kramp, *Seaweed Is About to Blow Your Climate Change Mind*, CAL. SEA GRANT (Aug. 29, 2019), <https://caseagrants.ucsd.edu/news/heather-kramp-seaweed-about-blow-your-climate-change-mind>.

69. Heather Smith, *Can Farming Seaweed Put the Brakes on Climate Change?*, SIERRA (June 28, 2021), <https://www.sierraclub.org/sierra/2021-2-summer/stress-test/can-farming-seaweed-put-brakes-climate-change>.

70. *Id.*

71. Dorte Krause-Jensen & Carlos M. Duarte, *Substantial Role of Macroalgae in Marine Carbon Sequestration*, 9 *NATURE GEOSCI.* 737, 737 (2016).

72. *See id.*

73. M. Troell et al., *Farming the Ocean – Seaweeds as a Quick Fix for the Climate?*, TAYLOR & FRANCIS ONLINE (Apr. 5, 2022), <https://www.tandfonline.com/doi/full/10.1080/23308249.2022.2048792>.

74. *See* Fred Bever, *'Run the Oil Industry in Reverse': Fighting Climate Change by Farming Kelp*, NPR (Mar. 1, 2021), <https://www.npr.org/2021/03/01/970670565/run-the-oil-industry-in-reverse-fighting-climate-change-by-farming-kelp>; PR Zen, *World Renowned Kelp Experts Answer Climate Distress Call, Join XPRIZE Carbon Removal Team Pull to Refresh*, DIGIT. J. (Feb. 11, 2022), <https://www.digitaljournal.com/pr/world-renowned-kelp-experts-answer-climate-distress-call-join-xprize-carbon-removal-team-pull-to-refresh>.

75. NASEM, *supra* note 29, at 95.

76. *See* GESAMP, *supra* note 39, at 59 (projecting a potential of approximately 0.6 GtCO₂ per year); Carlos M. Duarte et al., *Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?*, *FRONTIERS MARINE SCI.*, Apr. 12, 2017, at 1, 2. Seaweed can also be cultivated for other purposes, such as food or energy production. KOREY SILVERMAN-ROATI ET AL., SABIN CTR. FOR

Large-scale seaweed farming might also pose serious risks in ocean ecosystems. For example, the drawdown of nutrients in large-scale seaweed farming operations could lead to competition with native ecosystems, with potentially negative impacts on primary production and food webs.⁷⁷ It could also reduce trophic exchanges of energy, with negative impacts for fish and marine mammal populations.⁷⁸ Moreover, seaweed farming could result in the introduction of invasive species, carried by macroalgae, into offshore ocean ecosystems.⁷⁹

However, seaweed farming could also produce compelling co-benefits. This includes reduction of excessive nutrient loads from aquaculture operations,⁸⁰ cooling waters to create more propitious fish habitat and helping to ameliorate ocean acidification.⁸¹

3. Ocean Upwelling and Downwelling

Ocean upwelling and downwelling refer to the vertical movement of ocean water, transferring heat, salt, energy, organic and inorganic carbon, and nutrients between ocean surface waters and the deep ocean.⁸² As is the case with ocean fertilization, artificial ocean upwelling approaches seek to bring more nutrient-rich deep ocean water to the surface to maximize phytoplankton growth to increase

CLIMATE L., COLUM. L. SCH., REMOVING CARBON DIOXIDE THROUGH SEAWEED CULTIVATION: LEGAL CHALLENGES AND OPPORTUNITIES 3 (2021). However, while this can reduce carbon dioxide emissions in production processes, it will not effectuate long-term sequestration. Calvyn F.A. Sondak et al., *Carbon Dioxide Emission Potential of Seaweed Aquaculture Beds (SABs)*, 29 J. APPLIED PSYCH. 2363, 2369 (2017); John A. Raven, *The Possible Roles of Algae in Restricting the Increase in Atmospheric CO₂ and Global Temperature*, 52 EUR. J. PSYCH. 506, 507 (2017).

77. Carlos M. Duarte et al., *A Seaweed Aquaculture Imperative to Meet Global Sustainability Targets*, 5 NATURE SUSTAINABILITY 185, 189 (2022); see also P. Cabral et al., *Ecosystem Services Assessment and Compensation Costs for Installing Seaweed Farms*, 71 MARINE POL'Y 157, 157–63 (2016).

78. NASEM, *supra* note 29, at 114–15.

79. Wil Burns, *Can Kelp Help? The Potential Role of "Ocean Afforestation"*, ILLUMINEM (July 13, 2022), <https://illuminem.com/illuminemvoices/2bba1334-8bae-43f0-b543-73da972bb20b>. One recent study identified 1,200 species on drifting seaweed. Philip W. Boyd et al., *Potential Negative Effects of Ocean Afforestation on Offshore Ecosystems*, 6 NATURE ECOLOGY & EVOLUTION 675, 679 (2022).

80. NASEM, *supra* note 29, at 116.

81. *2040 & Marine Permaculture*, CLIMATE FOUND., <https://www.climatefoundation.org/2040-make-a-change.html> [<https://perma.cc/SWK2-BV55>]; Craig S. Young et al., *Kelp (Saccharina Latissima) Mitigates Coastal Ocean Acidification and Increases the Growth of North Atlantic Bivalves in Lab Experiments and on an Oyster Farm*, FRONTIERS MARINE SCI., Apr. 19, 2022, at 1, 14. Increasing uptake of carbon dioxide by the world's oceans has already resulted in a decline in ocean surface pH, and this is slated to drop much more substantially in the future, threatening ocean ecosystems and a wide array of species. Samuel Georgian et al., *Scientists' Warning of an Imperiled Ocean*, BIOLOGICAL CONSERVATION, Aug. 2022, at 1, 4.

82. NASEM, *supra* note 29, at 103.

carbon dioxide uptake.⁸³ Options to facilitate this could include airlift pump systems⁸⁴ and wave-powered systems.⁸⁵

To date, the limited research that has been conducted on artificial upwelling has concluded that the approach would yield, at most, modest sequestration of somewhere between 0.01 and 1.0 gigatons per year.⁸⁶ Moreover, if the approach was ever terminated, substantial amounts of heat from the deep ocean would ultimately be released into the atmosphere, resulting in a net increase in temperatures compared to a business-as-usual scenario.⁸⁷

Artificial upwelling could also pose risks to ocean ecosystems. Drawdown of carbon dioxide into the deep oceans through this process could exacerbate ocean acidification, potentially significantly decreasing ocean pH.⁸⁸ It could also restructure ocean ecosystems by favoring larger phytoplankton species, resulting in a shift from nutrient-poor to nutrient-rich species⁸⁹ and local depletion of nutrients that could affect downstream ecosystems.⁹⁰

However, the approach might also generate co-benefits, including enhancing fish stocks,⁹¹ and cooling ambient surface waters, which could help to ameliorate global warming impacts at the local or regional level.⁹² This could potentially reduce the severity of typhoons and coral bleaching.⁹³

By contrast, artificial ocean downwelling would entail the use of pumps to laterally displace downwelled water, replacing warmer surface waters. These waters would subsequently cool, taking up carbon dioxide via cooling-enhanced solubility.⁹⁴ However, modelling studies to date have concluded that ocean

83. ROMANY M. WEBB ET AL., SABIN CTR. FOR CLIMATE L., COLUM. L. SCH., REMOVING CARBON DIOXIDE THROUGH ARTIFICIAL UPWELLING AND DOWNWELLING: LEGAL CHALLENGES AND OPPORTUNITIES 3 (2022).

84. See generally Philip P. Kithil et al., *Ocean Carbon Dioxide Removal Using Wave-Powered Artificial Upwelling Pumps*, 17 J. OCEAN TECH. 11, 12–19 (2022); Nai-Kuang Liang & Hai-Kuen Peng, *A Study of Air-Lift Artificial Upwelling*, 32 OCEAN ENG'G. 731, 731–45 (2005).

85. See generally Shule Zhou et al., *Experimental Study on the Performance of a Wave Pump for Artificial Upwelling in Irregular Waves*, OCEAN ENG'G., Oct. 1, 2019, at 1; Kern E. Kenyon, *Upwelling by a Wave Pump*, 63 J. OCEANOGRAPHY 327, 327–31 (2007).

86. David A. Koweek, *Expected Limits on the Potential for Carbon Dioxide Removal from Artificial Upwelling*, FRONTIERS MARINE SCI., June 29, 2022, at 1, 7; NASEM, *supra* note 29, at 107.

87. A. Oschlies et al., *Climate Engineering by Artificial Ocean Upwelling: Channeling the Sorcerer's Apprentice*, GEOPHYSICAL RSCH. LETTERS, Feb. 2010, at 1, 4–5.

88. Susie J. Bauman et al., *Commentary, Augmenting the Biological Pump: The Shortcomings of Geoengineered Upwelling*, OCEANOGRAPHY, Sept. 2014, at 17, 21.

89. *Id.*; see also Lucia Zarauz et al., *Changes in Plankton Size Structure and Composition, During the Generation of a Phytoplankton Bloom, in the Central Cantabrian Sea*, 31 J. PLANKTON RSCH. 193, 193 (2009); Andrew Yool et al., *Low Efficiency of Nutrient Translocation for Enhancing Oceanic Uptake of Carbon Dioxide*, JGR: OCEANS, Aug. 2009, at 1, 12.

90. NASEM, *supra* note 29, at 110.

91. See Joaquin Ortiz et al., *Artificial Upwelling in Singular and Recurring Mode: Consequences for Net Community Production and Metabolic Balance*, FRONTIERS MARINE SCI., Jan. 12, 2022, at 1, 2; Brian Kirke, *Enhancing Fish Stocks with Wave-Powered Artificial Upwelling*, 46 OCEAN & COASTAL MGMT. 901, 902 (2003).

92. BRENT ET AL., *supra* note 29, at 11.

93. WEBB ET AL., *supra* note 83, at 5.

94. GESAMP, *supra* note 39, at 63; see also S. Zhou & P.C. Flynn, *Geoengineering Downwelling Ocean Currents: A Cost Assessment*, 71 CLIMATIC CHANGE 203, 205–06 (2005).

downwelling is “highly unlikely to ever be a competitive method of sequestering carbon in the deep ocean” due to impracticalities and costs,⁹⁵ as well as low sequestration potential.⁹⁶ As is the case with artificial upwelling, downwelling might yield co-benefits, including counteracting eutrophication and insufficient oxygen levels.⁹⁷ Research on this approach is ensuing, including by start-up companies.⁹⁸

B. Abiotic Approaches

1. Ocean Alkalinity Enhancement

When alkalinity is introduced into the ocean, pH is increased, which results in increased concentrations of carbonate ions, reductions in hydrogen ion concentrations,⁹⁹ and ultimately, a decrease in the concentration of aqueous carbon dioxide through conversion to carbonate and bicarbonate ions.¹⁰⁰ This creates a disequilibrium between atmospheric and ocean carbon dioxide levels, resulting in increased uptake of atmospheric carbon dioxide into the ocean.¹⁰¹ Some studies have estimated that this approach could effectuate sequestration of carbon dioxide for up to 100,000 years.¹⁰²

Proponents of a CDR approach called ocean alkalinity enhancement (OAE) have argued that dissolution of finely-ground “magnesium-rich minerals, such as serpentine, olivine, and peridotite” on the surface of the ocean could substantially increase ocean alkalinity.¹⁰³ Others have advocated the use of limestone, lime, or

95. Zhou & Flynn, *supra* note 94, at 215.

96. CARNEGIE CLIMATE GOVERNANCE INITIATIVE, EVIDENCE BRIEF: GOVERNING MARINE CARBON DIOXIDE REMOVAL AND SOLAR RADIATION MANAGEMENT 12; GESAMP, *supra* note 39, at 64.

97. See Anders Stigenbrandt & Bengt Liljebladh, *Oxygenation of Large Volumes of Natural Waters by Geo-Engineering: With Particular Reference to a Pilot Experiment in Byfjorden*, in MACRO-ENGINEERING SEAWATER IN UNIQUE ENVIRONMENTS 303, 303–304 (Viorel Badescu & Richard B. Cathcart eds., 2011).

98. See generally OCEAN-BASED CLIMATE SOLUTIONS, INC., ALL-NATURAL BIOGEOCHEMICAL CO₂ SEQUESTRATION IN DEEP OCEAN 1–2, 8 (2021); Matthew D. Eisaman et al., *CO₂ Extraction from Seawater Using Bipolar Membrane Electrodialysis*, 5 ENERGY & ENV'T SCI. 7346, 7347 (2012).

99. Andrew Lenton et al., *Assessing Carbon Dioxide Removal Through Global and Regional Ocean Alkalinization Under High and Low Emission Pathways*, 9 EARTH SYS. DYNAMICS 339, 340 (2018).

100. James S. Campbell et al., *Geochemical Negative Emissions Technologies: Part I. Review*, FRONTIERS CLIMATE, June 22, 2022, at 1, 19; ANTONIUS GAGERN ET AL., OCEANKIND, OCEAN ALKALINITY ENHANCEMENT: CURRENT STATE OF KNOWLEDGE AND POTENTIAL ROLE OF PHILANTHROPY 9 (2019).

101. GAGERN ET AL., *supra* note 100.

102. JESSICA N. CROSS ET AL., NAT'L OCEANIC & ATMOSPHERIC ADMIN., NOAA CARBON DIOXIDE REMOVAL RESEARCH 30 (2022).

103. Peter Psarras et al., *Slicing the Pie: How Big Could Carbon Dioxide Removal Be?*, WIRES ENERGY & ENV'T, Sept.–Oct. 2017, at 1, 15; see also Peter Köhler et al., *Geoengineering Impact of Open Ocean Dissolution of Olivine on Atmospheric CO₂, Surface Ocean pH and Marine Biology*, ENV'T RSCH. LETTERS, Jan. 21, 2013, at 1, 2.

quick lime to enhance oceanic alkalinity.¹⁰⁴ These materials can be sourced from natural or artificial minerals or industrial waste and byproducts.¹⁰⁵

The ultimate potential of OAE for removing carbon dioxide from the atmosphere is extremely speculative. This is because research is in its relative infancy, and is mostly restricted to modeling and laboratory studies, along with a few mesocosm experiments.¹⁰⁶ Reflective of the fact that research on this approach is in its early stages, estimates of potential effectiveness range from a very modest reduction of atmospheric carbon dioxide concentrations of 30 ppm¹⁰⁷ to much more optimistic assessments of between 166–450 ppm by 2100.¹⁰⁸

Deployment of OAE could also pose a number of serious risks to marine ecosystems. Toxic heavy metals found in olivine-containing rocks, including chromium, nickel, and cadmium, could adversely impact marine organisms by transforming biogeochemical cycling and undermine marine ecosystem services.¹⁰⁹ The process could also potentially disrupt the acid-base balance¹¹⁰ of some marine organisms, such as littoral crabs,¹¹¹ with unknown implications for many species.¹¹² There is also concern that OAE could cause spontaneous precipitation of calcium carbonate which could adversely impact coral reefs given their sensitivity to high levels of turbidity.¹¹³ Conversely, some studies have concluded that OAE could

104. See Spyros Foteinis et al., *Life Cycle Assessment of Ocean Liming for Carbon Dioxide Removal from the Atmosphere*, J. CLEANER PROD., Oct. 10, 2022, at 1, 2; Sarah Gore et al., *The Potential Environmental Response to Increasing Ocean Alkalinity for Negative Emissions*, 24 MITIGATION & ADAPTATION STRATEGIES FOR GLOB. CHANGE 1191, 1192 (2019); Tatiana Ilyina et al., *Assessing the Potential of Calcium-Based Artificial Ocean Alkalinization to Mitigate Rising Atmospheric CO₂ and Ocean Acidification*, 40 GEOPHYSICAL RSCH. LETTERS 5909, 5909 (2013).

105. See, e.g., Campbell et al., *supra* note 100.

106. Antonius Gagern et al., *Ocean-Based Carbon Dioxide Removal: A New Frontier in the Blue Economy*, MARINE TECH. SOC'Y J., Jan.–Feb. 2022, at 40, 43. “Mesocosms are ecological experiments consisting of multiple species with one or more trophic levels in a controlled space.” Krishna Venkatarama Sharma et al., *A Review of Mesocosm Experiments on Heavy Metals in Marine Environment and Related Issues of Emerging Concerns*, 28 ENV'T SCI. & POLLUTION RSCH. 1304, 1304 (2021).

107. T.M. Lenton & N.E. Vaughan, *The Radiative Forcing Potential of Different Climate Geoengineering Options*, 9 ATMOSPHERIC CHEMISTRY & PHYSICS 5539, 5553 (2009).

108. Ellias Y. Feng et al., *Could Artificial Ocean Alkalinization Protect Tropical Coral Ecosystems from Ocean Acidification?*, ENVTL. RSCH. LETTERS, July 8, 2016, at 1, 9.

109. Miriam Ferrer González & Tatiana Ilyina, *Impacts of Artificial Ocean Alkalinization on the Carbon Cycle and Climate in Earth System Simulations*, 43 GEOPHYSICAL RSCH. LETTERS 6493, 6493 (2016); Köhler et al., *supra* note 103, at 7.

110. “Following the onset of CO₂ exposure, animals that are acid–base ‘regulators’ counter an initial drop in blood pH through the retention and/or uptake of HCO₃⁻. This process allows acid-base regulators to correct pH to pre-exposure levels.” Rebecca L. Zlatkin & Rachael M. Heuer, *Ocean Acidification Affects Acid–Base Physiology and Behaviour in a Model Invertebrate, the California Sea Hare (Aplysia Californica)*, ROYAL SOC'Y OPEN SCI., Oct. 9, 2019, at 1, 2; see also Nia M. Whiteley et al., *Sensitivity to Near-Future CO₂ Conditions in Marine Crabs Depends on Their Compensatory Capacities for Salinity Change*, SCI. REPS., Oct. 23, 2018, at 1, 2.

111. Stefano Caserini et al., *Affordable CO₂ Negative Emission Through Hydrogen from Biomass, Ocean Liming, and CO₂ Storage*, 24 MITIGATION & ADAPTATION STRATEGIES FOR GLOB. CHANGE 1231, 1241 (2019).

112. Gemma Cripps et al., *Biological Impacts of Enhanced Alkalinity in Carcinus Maenas*, 71 MARINE POLLUTION BULL. 190, 191 (2013).

113. Feng et al., *supra* note 108, at 7.

potentially help ameliorate ocean acidification by offsetting the decreasing pH associated with ocean acidification, including in local areas.¹¹⁴

2. Electrochemical Approaches

Electrochemical carbon dioxide removal approaches are another method for enhancing ocean alkalization.¹¹⁵ These approaches can induce changes in ocean chemistry that ultimately result in the storage of carbon as dissolved bicarbonate, but it can also facilitate other processes to remove carbon dioxide from ocean waters. Electrochemical CDR approaches are divided into two broad categories: electro-dialytic and electrolytic.

Electro-dialytic approaches use electricity as an energy source to convert the most common elements of seawater, H₂O and NaCl, into acidic and basic solutions in separate ocean water compartments.¹¹⁶ The acidic solution can be used to strip dissolved inorganic carbon from the ocean; alternatively, the basic solution can be used to strip inorganic carbon by producing solid calcium carbonate.¹¹⁷ This solution can also be added to seawater to draw additional carbon dioxide into the ocean for storage as bicarbonate ions.¹¹⁸

Electrolytic options can split water and salt into hydrogen and oxygen and/or chlorine gases, as well as a byproduct, metal hydroxide.¹¹⁹ The hydroxide can be added to surface seawater, reacting with carbon dioxide to form alkaline bicarbonates.¹²⁰ This reduction in carbon dioxide in seawater can facilitate more atmospheric carbon dioxide entering the ocean, reducing atmospheric concentrations.¹²¹

While the potential of carbon capture from electrochemical methods is theoretically limitless,¹²² there are some imposing challenges to implementing this approach including cost and access to low- or zero-carbon emissions energy

114. Elisa Gentile et al., *Use of Aircraft in Ocean Alkalinity Enhancement*, SCI. TOTAL ENV'T, May 2022, at 1, 2; Jens Hartmann et al., *Enhanced Chemical Weathering as a Geoengineering Strategy to Reduce Atmospheric Carbon Dioxide, Supply Nutrients, and Mitigate Ocean Acidification*, 51 REVS. GEOPHYSICS 113, 134 (2013).

115. R. Sharifian et al., *Electrochemical Carbon Dioxide Capture to Close the Carbon Cycle*, 14 ENERGY & ENV'T SCI. 781, 785 (2021). See generally Kyle M. Diederichsen et al., *Electrochemical Methods for Carbon Dioxide Separations*, 2 NATURE REVS. METHODS PRIMERS, Sept. 8, 2022, at 1 (providing an overview of electrochemical carbon dioxide separation).

116. Digdaya et al., *supra* note 24.

117. *State of Technology*, OCEAN VISIONS (Aug. 5, 2021), <https://www2.oceanvisions.org/roadmaps/electrochemical-cdr/state-of-technology/#technologyreadiness>; see also Kurt Zenz House et al., *Electrochemical Acceleration of Chemical Weathering as an Energetically Feasible Approach to Mitigating Anthropogenic Climate Change*, 41 ENV'T SCI. & TECH. 8464, 8464–65 (2007).

118. *State of Technology*, *supra* note 117.

119. Greg H. Rau et al., *The Global Potential for Converting Renewable Electricity to Negative-CO₂-Emissions Hydrogen*, 8 NATURE CLIMATE CHANGE 621, 621 (2018); see also Litao Yan et al., *An Electrochemical Hydrogen-Looping System for Low-Cost CO₂ Capture from Seawater*, 7 ACS ENERGY LETTERS 1947, 1947 (2022).

120. Greg H. Rau, *Electrochemical CO₂ Capture and Storage with Hydrogen Generation*, 1 ENERGY PROCEDIA 823, 826 (2009).

121. Rau, *supra* note 119.

122. See generally *State of Technology*, *supra* note 117; see also NASEM, *supra* note 29, at 223.

sources and infrastructure to ensure that overall emissions would be net-negative.¹²³ Moreover, electrochemical approaches could pose risks to ocean ecosystems, such as potentially exacerbating ocean acidification in some regions,¹²⁴ and altering ocean chemistry in ways that could impact the distributions and concentrations of marine organisms.¹²⁵

II. REGULATION OF OCEAN CDR RESEARCH UNDER THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA

A. Overview

The United Nations Convention on the Law of the Sea (UNCLOS)¹²⁶ has been denominated “the constitution of the oceans.”¹²⁷ It “regulates in greater or lesser detail, almost every possible activity on, in, under, and over the sea.”¹²⁸ As set forth in its preamble, it establishes “a legal order for the seas and oceans which will facilitate international communication, and will promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment.”¹²⁹

The treaty was adopted in 1982 and entered into force on November 16, 1994.¹³⁰ It currently has 168 parties.¹³¹ While the United States has not ratified UNCLOS, it recognizes most of its provisions as within the domain of customary international law.¹³² This includes those parts most pertinent to ocean CDR research: marine science research and protection of the marine environment.¹³³

123. NASEM, *supra* note 29, at 224, 233.

124. Erika Callagon La Plante et al., *Saline Water-Based Mineralization Pathway for Gigatonne-Scale CO₂ Management*, 9 ACS SUSTAINABLE CHEMISTRY & ENG'G 1073, 1082 (2021).

125. NASEM, *supra* note 29, at 222–23.

126. UNCLOS, *supra* note 35.

127. Tullio Treves, *United Nations Convention on the Law of the Sea*, U.N. AUDIOVISUAL LIBR. OF INT'L L. (July 2008), <https://legal.un.org/avl/ha/uncls/uncls.html> [<https://perma.cc/CD3L-XF62>].

128. Robin Churchill, *The 1982 United Nations Convention on the Law of the Sea*, in *THE OXFORD HANDBOOK OF THE LAW OF THE SEA* 24, 24 (Donald R. Rothwell et al. eds., 2015).

129. UNCLOS, *supra* note 35, at 397.

130. *United Nations Convention on the Law of the Sea of 10 December 1982*, U.N. OCEANS & L. OF THE SEA, https://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm [<https://perma.cc/C9MX-45GN>].

131. *Chapter XXI: Law of the Sea: United Nations Convention on the Law of the Sea*, U.N. TREATY COLLECTION, https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_en [<https://perma.cc/C57W-UW3Z>].

132. Aditya Singh Verma, *A Case for the United States' Ratification of UNCLOS*, DIPLOMATIST (May 2, 2020), <https://diplomatist.com/2020/05/02/a-case-for-the-united-states-ratification-of-unclos/>; see also Off. of the Staff Judge Advoc., *U.S. Position on the UN Convention on the Law of the Sea*, 97 INT'L L. STUD. 81, 83 (2021).

133. Proclamation No. 10071, 85 Fed. Reg. 59165 (Sept. 9, 2020); see also WEBB ET AL., *supra* note 83, at 7; J. Ashley Roach, *Marine Scientific Research and the New Law of the Sea*, 27 OCEAN DEV. & INT'L L. 59, 62 (1996).

UNCLOS is strongly supportive of marine scientific research (MSR).¹³⁴ The treaty's objectives, as set forth in its preamble, include the promotion of "the study . . . of the marine environment."¹³⁵ Part XIII of UNCLOS calls upon both States and "competent international organizations"¹³⁶ to "facilitate the development and conduct of marine scientific research."¹³⁷ Moreover, all States are expressly accorded the right to conduct "marine scientific research."¹³⁸ The United Nations General Assembly and various United Nations entities have also recognized MSR as playing a "critical role in sustainable development."¹³⁹

However, the right to conduct MSR is subject to "the rights and duties of other States" under the Convention.¹⁴⁰ Part XIII of UNCLOS, which consists of twenty-eight articles, provides detailed rules for conducting MSR.¹⁴¹ While the provisions in Part XIII consistently use the term "researching State," their obligations encompass the conduct of both State-sponsored entities as well as activities within their control or jurisdiction conducted by private organizations.¹⁴²

Part XIII establishes a number of overarching principles for MSR, including that research activities must (i) be conducted exclusively for peaceful purposes; (ii) utilize "appropriate scientific methods and means"; (iii) not unjustifiably interfere with other legitimate uses of the sea; and (iv) be conducted in compliance with all relevant regulations, including the environmental provisions of the Convention.¹⁴³ Under UNCLOS, Flag States¹⁴⁴ that are parties to the treaty have the primary responsibility to ensure that their flagged vessels, including those that might engage in ocean CDR research, comply with UNCLOS provisions.¹⁴⁵

134. See Anna-Marie Hubert, *The New Paradox in Marine Scientific Research: Regulating the Potential Environmental Impacts of Conducting Ocean Science*, 42 OCEAN DEV. & INT'L L. 329, 332–33 (2011).

135. UNCLOS, *supra* note 35, at 397.

136. While the term "competent international organizations" is not defined under UNCLOS, it has been interpreted to include organizations like the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization. Tim Stephens & Donald R. Rothwell, *Marine Scientific Research*, in *THE OXFORD HANDBOOK OF THE LAW OF THE SEA* 559, 564 (Donald R. Rothwell et al. eds., 2015).

137. UNCLOS, *supra* note 35, at 495.

138. *Id.* at 495.

139. U.N. DIV. OF OCEAN AFFS. & INTERGOVERNMENTAL OCEANOGRAPHIC COMM'N, *PROMOTING MARINE SCIENTIFIC RESEARCH (MSR) UNDER THE UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS) I* (2014).

140. UNCLOS, *supra* note 35, at 495.

141. *Id.* at 495–503; see also Pavliha & Martinez, *supra* note 36, at 118; Woker et al., *supra* note 36, at 1.

142. UNCLOS, *supra* note 35, at 495; Kristoffer Svendsen, *Liability and Compensation for Activities in the Area*, in *THE LAW OF THE SEABED* 593 (Catherine Banet ed., 2020).

143. UNCLOS, *supra* note 35, at 495; see also Melissa Eick, *A Navigational System for Uncharted Waters: The London Convention and London Protocol's Assessment Framework on Ocean Iron Fertilization*, 46 TULSA L. REV. 351, 364 (2010).

144. "A flag state is a country where a company registers its commercial and merchant ships. The name for the term flag state comes from ships registering with a specific nation and then flying that flag to represent their registration with that country." *Flag State vs. Port State*, MAR. INST. OF TECH. & GRADUATE SCH. (Dec. 16, 2021), <https://www.mitags.org/flag-vs-port-state/>.

145. UNCLOS, *supra* note 35, at 432–33; FLETCHER SCH. OF L. & DIPLOMACY, TUFTS UNIV., *LAW OF THE SEA: A POLICY PRIMER* 49–59 (2017).

During the Third United Nations Conference on the Law of the Sea, the negotiators vetted a number of proposals to define the term “marine science research.” Ideas ranged from limiting the term’s application to pure research, to others that would have encompassed all scientific research, including applications designed to facilitate natural resource exploitation.¹⁴⁶ Ultimately, the term was left undefined, based on the conclusion by the negotiators that the provisions of Part XIII provided an adequate roadmap.¹⁴⁷

A good argument can be made that both pure and applied research can fall under the treaty’s MSR roadmap. UNCLOS clearly encourages “pure” or “basic” research in Part XIII—that is, research that seeks to improve the understanding of natural phenomena in ocean ecosystems.¹⁴⁸ States and competent organizations are called upon to “integrate the efforts of scientists in studying the essence of phenomena and processes occurring in the marine environment and the interrelations between them.”¹⁴⁹

However, Part XIII also addresses regulation of research pertinent to “exploration and exploitation of natural resources,”¹⁵⁰ strongly suggesting that the parties intended to encompass research with potential implications for commercial applications under the rubric of MSR.¹⁵¹ The U.N. Secretary-General’s report, *Oceans and the Law of the Sea*, supports this proposition, concluding:

In the absence of a formal definition, it has been suggested that marine scientific research under UNCLOS encompasses both the study of the marine environment and its resources with a view to increasing humankind’s knowledge (so-called “pure” or “fundamental” research), and research for the subsequent exploitation of resources (so-called “applied” research).¹⁵²

Patricia Birnie, an expert on the law of the sea, also concluded in her analysis of the scope of Part XIII that the term “marine scientific” research encompasses “any form of scientific investigation, fundamental or applied, concerned with the marine environment, i.e. that has the marine environment as its object.”¹⁵³

Of course, the ultimate objective of ocean-based CDR marine research would be to develop approaches that could effectuate large-scale removal of carbon dioxide from the atmosphere. However, the prospects to achieve this would all be premised on *understanding the marine environment* vis-à-vis application of such

146. See 4 CTR. FOR OCEANS L. & POL’Y, UNIV. OF VA., UNITED NATIONS CONVENTION ON THE LAW OF THE SEA 1982: A COMMENTARY 444–49 (Myron H. Nordquist et al. eds., 1990).

147. Alfred H.A. Soons, *Marine Scientific Research Provisions in the Convention on the Law of the Sea: Issues of Interpretation*, in THE UN CONVENTION ON THE LAW OF THE SEA: IMPACT AND IMPLEMENTATION 366 (E.D. Brown & R.R. Churchill eds., 1989).

148. See generally *What is Pure or Basic Research? + [Examples & Method]*, FORMPLUS, <https://www.formpl.us/blog/basic-research> [<https://perma.cc/89PB-LP7L>].

149. UNCLOS, *supra* note 35, at 496.

150. *Id.* at 497.

151. Mary George & Anneliz R. George, *Registration of BBNJ Research Activities: A Move Towards Transparency in Research Governance*, 11 J. E. ASIA & INT’L L. 121, 125 (2018).

152. U.N. Secretary-General, *Oceans and the Law of the Sea*, ¶ 203, U.N. Doc. A/62/66 (Mar. 12, 2007).

153. Patricia Birnie, *Law of the Sea and Ocean Resources: Implications for Marine Scientific Research*, 10 INT’L J. MARINE & COASTAL L. 229, 242 (1995).

approaches. And this would be premised on research in the marine environment. A good argument can be made that all aspects of ocean-based CDR research could easily fit under this conception of MSR. This includes, inter alia, the establishment of observational baselines of ocean systems against which proposed CDR interventions would be measured; assessment of the potential positive and negative impacts of ocean CDR approaches on ocean environments; assessment of the potential permanence of carbon sequestration in ocean ecosystems; and development and testing of monitoring, reporting, and verification protocols for ocean carbon sequestration.¹⁵⁴

B. Regulation of Ocean-Based CDR Research Under UNCLOS: A Zonal Analysis

Ocean-based CDR research can be conducted within areas designated under UNCLOS as territorial seas,¹⁵⁵ exclusive economic zones,¹⁵⁶ the Area,¹⁵⁷ and the high seas.¹⁵⁸ Part XIII reflects the “zonal approach” of UNCLOS, whereby the rights of coastal States generally diminish moving seaward.¹⁵⁹ In the following sections, this Article will discuss ocean-based CDR MSR in the territorial seas, exclusive economic zone, and high seas

1. Territorial Sea

During the negotiations of UNCLOS, coastal States argued that States or private entities should have to obtain their consent if they wish to engage in MSR in coastal waters.¹⁶⁰ The incorporation of this principle in the treaty constituted a clear victory over the position of many large States that actively engaged in ocean research, who argued that researchers should only have to provide advanced notification to coastal States.¹⁶¹

A coastal State’s right to regulate MSR is greatest in territorial waters, which extend up to twelve nautical miles from a coastal baseline.¹⁶² Coastal States have “the exclusive right to regulate, authorize and conduct marine scientific research in their territorial sea.”¹⁶³ A coastal State is not required to grant consent for MSR within its territorial sea.¹⁶⁴

154. See generally Philip Williamson & Jean-Pierre Gattuso, *Carbon Removal Using Coastal Blue Carbon Ecosystems Is Uncertain and Unreliable, with Questionable Climatic Cost-Effectiveness*, FRONTIERS CLIMATE, Jul. 28, 2022, at 1, 1; ENERGY & ENV’T PROGRAM, *supra* note 19, at 14–15.

155. UNCLOS, *supra* note 35, at 496.

156. *Id.* at 418.

157. *Id.* at 448.

158. *Id.* at 432–33.

159. See Craig H. Allen, *Protecting the Oceanic Gardens of Eden: International Law Issues in Deep-Sea Vent Resource Conservation and Management*, 13 GEO. INT’L ENV’T L. REV. 563, 588 (2001).

160. Jorge A. Vargas, *U.S. Marine Scientific Research Activities Offshore Mexico: An Evaluation of Mexico’s Recent Regulatory Legal Framework*, 24 DENV. J. INT’L L. & POL’Y 1, 5–6 (1995).

161. See *id.* at 35.

162. See UNCLOS, *supra* note 35, at 400.

163. *Id.* at 496.

164. Porter Hoagland et al., *Law of the Sea*, in ENCYCLOPEDIA OF OCEAN SCI. 526, 533 (John H. Steele ed., 3d ed. 2019).

Moreover, MSR can only be conducted with the express consent of the coastal State, subject to conditions it sets forth.¹⁶⁵ Conducting MSR within the territorial sea of a coastal State without its authorization is deemed to be “prejudicial to the peace, good order or security of the coastal State,” and thus could preclude a vessel’s right to innocent passage in territorial waters.¹⁶⁶ These same principles apply by extension to a State’s internal waters¹⁶⁷ and the archipelagic waters of States.¹⁶⁸

Thus, any State or private entity wishing to engage in CDR-related MSR in territorial seas will be subject to the coastal State’s pertinent environmental and resource management laws and regulations.¹⁶⁹ For example, focusing on ocean-based CDR research that might take place in U.S. territorial waters, CDR approaches involving the placement of matter or materials into the ocean to assess sequestration potential and risks, such as ocean alkalization enhancement, ocean fertilization, or seaweed cultivation, would likely be regulated under the Marine Protection, Research, and Sanctuaries Act (MPRSA).¹⁷⁰ MPRSA seeks to “prevent or strictly limit” the “dumping” of materials in U.S. waters to avoid negative impacts.¹⁷¹ The term “dumping” is capaciously defined as “disposition of a material,”¹⁷² and the term “material” is defined to encompass “matter of any kind or description.”¹⁷³ The Act prohibits dumping of “any material” in U.S. territorial waters without the issuance of a permit to (i) any person transporting said materials from the United States,¹⁷⁴ (ii) any “vessel or aircraft registered in the United States or flying the United States flag” or any United States governmental entity transporting materials from any location,¹⁷⁵ and (iii) any person proposing to dump materials transported from a location outside the United States into its territorial sea or contiguous regions if it may affect the territorial zone.¹⁷⁶

MPRSA’s regulatory framework might pose challenges to the permitting of some ocean-based CDR research approaches. For example, the regulations establish specific limitations on dumping that might result in the introduction of non-indigenous species.¹⁷⁷ This might occur in the context of seaweed cultivation research. MPRSA provisions also call for an assessment of the effects of changes in alkalinity that might occur as a consequence of depositing materials in water bodies,¹⁷⁸ which could be pertinent to any research related to ocean alkalinity

165. UNCLOS, *supra* note 35, at 496.

166. *Id.* at 404–05.

167. A State’s internal waters are those found “on the landward side of the baseline of the territorial sea.” *Id.* at 401. This includes lakes, rivers, and tidewaters. FLETCHER SCH. OF L. & DIPLOMACY, *supra* note 145, at 11–18.

168. Pavliha & Martinez, *supra* note 36, at 121.

169. BRENT ET AL., *supra* note 29, at 25.

170. *See generally* 33 U.S.C. §§ 1401–1445.

171. *Id.* § 1401(b).

172. *Id.* § 1402(f).

173. *Id.* § 1402(c).

174. *Id.* § 1411(a)(1).

175. *Id.* § 1411(a)(2).

176. *Id.* § 1411(b).

177. 40 C.F.R. § 227.7(c)(3) (2022).

178. *Id.* § 227.7(d)(1).

enhancement. There are also other federal laws that might be pertinent for CDR research in U.S. territorial waters, such as the Rivers and Harbors Act and Clean Water Act, as well as pertinent state laws if the research is conducted close to the shore.¹⁷⁹

Entities engaged in research, wherever it takes place in the oceans, are also required to proffer information on both the contours of research programs and results of “major programmes” (an undefined term) “by publication and dissemination.”¹⁸⁰ Researching States have an obligation to provide coastal States, if so requested, an assessment of data, samples, and research results or assistance in assessment or interpretation.¹⁸¹ Moreover, a research entity is required to ensure that research results are made available internationally “as soon as practicable.”¹⁸² However, this obligation is subject to prior agreement by the pertinent coastal State if the project is “of direct significance for the exploration and exploitation of natural resources.”¹⁸³ Part XIII also imposes an affirmative obligation to foster the flow of data, knowledge, and information, especially to developing countries, as well as to help such countries develop their technical and scientific capacities.¹⁸⁴

These requirements might be viewed by entities hoping to ultimately profit from such research as particularly onerous, as they might entail disclosure of commercially sensitive information. However, the contours of these requirements, including the nature of a coastal State’s right to participate in projects, the appropriate channels for communication with coastal States, and who has a right of access to data, have not been well defined.¹⁸⁵ This is likely to be one of the areas in which additional rules may have to be developed if widespread ocean CDR research ensues in the years to come.

Coastal States conducting ocean-based CDR MSR would also have the right to protect such operations. UNCLOS accords foreign ships a right of innocent passage through a State’s territorial waters.¹⁸⁶ However, the treaty provides that coastal States may adopt laws and regulations relating to innocent passage to protect their interests, including those pertinent to “marine scientific research”¹⁸⁷ and “the protection of navigational aids and facilities and other facilities or

179. SILVERMAN-ROATI ET AL., *supra* note 76. National legal regulation could be extremely important in other jurisdictions also. For example, Germany has restricted ocean iron fertilization activities in its waters to research, subject to stringent conditions. *The German Government Implements Additional Provisions of the London Protocol on the Prevention of Marine Pollution*, FED. MINISTRY FOR THE ENV’T, NATURE CONSERVATION, NUCLEAR SAFETY & CONSUMER PROT. (Jan. 8, 2018), <https://www.bmu.de/en/pressrelease/the-german-government-implements-additional-provisions-of-the-london-protocol-on-the-prevention-of-marine-pollution>.

180. UNCLOS, *supra* note 35, at 496.

181. *Id.* at 498–99.

182. *Id.*

183. *Id.* at 499.

184. *Id.* at 496.

185. See Emmanuella Doussis, *Marine Scientific Research: Taking Stock and Looking Ahead*, in *THE FUTURE OF THE LAW OF THE SEA* 87, 94 (Gemma Andreone ed., 2017).

186. UNCLOS, *supra* note 35, at 404–05 (“Passage is innocent so long as it is not prejudicial to the peace, good order or security of the coastal State.”).

187. *Id.* at 405.

installations.”¹⁸⁸ This might include, for example, requesting that foreign vessels avoid areas where such research is being conducted by the coastal State.¹⁸⁹

2. Exclusive Economic Zone/Continental Shelf

UNCLOS accords coastal States the right to establish an exclusive economic zone (EEZ) up to two hundred nautical miles from the baseline of the breadth of their territorial waters.¹⁹⁰ It imbues coastal States with, *inter alia*, the sovereign right to explore, exploit, conserve, and manage all natural resources within this zone.¹⁹¹ Coastal States are also accorded jurisdiction over MSR within EEZs.¹⁹²

A coastal State’s continental shelf is comprised of the seabed and subsoil of submarine areas beyond the territorial seas.¹⁹³ It extends from the natural prolongation of a State’s land to the outer edge of the continental margin, or two hundred nautical miles from the breadth of the territorial sea where the outer edge of the continental margin does not extend to this distance.¹⁹⁴ Coastal States are accorded the right to explore and exploit mineral and other non-living resources of the seabed and subsoil, as well as sedentary species.¹⁹⁵

UNCLOS requires the consent of coastal States to conduct MSR in their EEZs or on their continental shelves.¹⁹⁶ Under normal circumstances, coastal States are to accord other States, their nationals, and competent international organizations the right to conduct research in these areas “for peaceful purposes and in order to increase scientific knowledge of the marine environment for the benefit of all mankind.”¹⁹⁷ However, an entity proposing a research project in the EEZ or on a coastal State’s continental shelf is required to permit the coastal State to participate in the project¹⁹⁸ and to provide access to data and samples from the project.¹⁹⁹

In contrast to a coastal State’s virtually unfettered right to withhold consent for MSR in its territorial sea, its discretion to do so in its EEZ or on its continental shelf is limited to one of four types of projects under UNCLOS Article 246(5) implicating coastal State interests: (i) projects that are directly significant to the “exploration and exploitation” of living or non-living resources;²⁰⁰ (ii) projects that involve drilling on the continental shelf, the use of explosives, “or the introduction of harmful substances into the marine environment;”²⁰¹ (iii) projects that involve

188. *Id.*

189. ALEXANDER PROELSS & ROBERT STEENKAMP, OCEAN NETS, DELIVERABLE 2.8: REPORT ON THE FUTURE REGULATION OF OCEAN-BASED NETS 6 (2022).

190. UNCLOS, *supra* note 35, at 418–419.

191. *Id.* at 418.

192. *Id.*

193. *Id.* at 428.

194. *Id.*

195. *Id.* at 429–30.

196. *Id.* at 497.

197. *Id.*

198. *Id.* at 498–99.

199. *Id.*

200. *Id.* at 497.

201. *Id.*

construction, operation, or use of artificial islands, installations, and structures,²⁰² or (iv) projects that contain inaccurate information or involve outstanding obligations to the coastal State from a previous project.²⁰³ Moreover, a coastal State's discretion to withhold consent to MSR in cases where the research may be pertinent to exploration or exploitation of resources is circumscribed in continental shelf regions. In these areas, a coastal State is not permitted to withhold consent on this ground "outside those specific areas which coastal States may at any time publicly designate as areas in which exploitation or detailed exploratory operations focused on those areas are occurring or will occur within a reasonable period of time."²⁰⁴

At least two of the conditions outlined above might justify a coastal State's denial of a request to conduct ocean-based CDR research in these areas. First, consider a hypothetical in which an ocean-CDR startup company proposes an MSR program in a State's EEZ to determine the viability of approaches to fostering growth of organisms for purposes of effectuating carbon dioxide sequestration. This could include several of the options discussed in Section I: ocean iron fertilization (phytoplankton), ocean upwelling (phytoplankton), or seaweed cultivation (macroalgae). A coastal State might contend that this would justify withholding consent under Article 246(5) on the grounds that (i) the proposed research could be construed as "of direct significance for the exploration and exploitation of natural resources, whether living or non-living"²⁰⁵ (in these instances, living organisms in the water column); and (ii) the purpose of the MSR program would be to explore the potential for ultimate "exploitation" of these living organisms by selling carbon credits in voluntary carbon markets.²⁰⁶

However, the company proposing CDR research might contend that its proposal does not constitute "exploration or exploitation" of the coastal State's natural resources. UNCLOS doesn't define these terms in the context of MSR. However, MSR scholar Chuxiao Yu, relying on the International Seabed Authority's definitions of the terms in the context of seabed mining, suggests that "'exploitation' refers to the recovery of natural resources for commercial purposes and the production and marketing of certain products," while "'exploration' refers to research and analytic activities for the purposes of exploitation."²⁰⁷

202. *Id.*

203. *Id.*

204. *Id.*

205. *Id.* However, coastal States cannot withhold consent on these grounds on their respective continental shelves in areas other than those in which they are engaged in exploration or exploitation, or where such activities will occur in a "reasonable period of time." *Id.*

206. *Id.*; see also Petya Trendafilova, *What Are Carbon Dioxide Removal Marketplaces and How Many Are There?*, CARBON HERALD (Aug. 13, 2022), <https://carbonherald.com/carbon-dioxide-removal-marketplaces-can-they-remove-corporate-emissions/>; David Henry, *Can Carbon Markets Supercharge Nature-Based Solutions to Climate Change?*, LANDSCAPE NEWS (Apr. 1, 2022), <https://news.globallandscapesforum.org/56632/can-carbon-markets-supercharge-nature-based-solutions-to-climate-change/>.

207. Chuxiao Yu, *Implications of the UNCLOS Marine Scientific Research Regime for the Current Negotiations on Access and Benefit Sharing of Marine Genetic Resources in Areas Beyond National Jurisdiction*, 51 OCEAN DEV. & INT'L L. 2, 6 (2020).

A company proposing an OIF research project might argue, for example, that OIF does not entail the “recovery” of natural resources for commercial purposes, in the sense that the phytoplankton that might be produced in such experiments would not be extracted from the ocean or converted into products. By this analysis, the company could also contend that its research activities are not “exploration” either, because they would not ultimately lead to exploitation as defined above. This argument might be advanced by entities engaged in ocean alkalinity enhancement, seaweed sinking, or ocean upwelling or downwelling projects, none of which would involve “recovery” or production and marketing of products.

Moreover, an entity proposing to engage in ocean-based CDR MSR could argue that coastal States are encouraged to grant consent within their EEZs or on their continental shelves for MSR that would “increase scientific knowledge of the marine environment for the benefit of all mankind.”²⁰⁸ A commercial entity could contend that, while it may be profit-driven, the research on CDR approaches might help to ameliorate climate change. In turn, this could ultimately benefit “mankind,” weighing in favor of a coastal State granting consent for such research.

Unfortunately, the hypothetical company above would likely never have the opportunity to adjudicate these questions. On the one hand, UNCLOS provides that disputes concerning the application or interpretation of the treaty can be unilaterally referred by any party for binding judicial settlement, utilizing one of several different fora, including (i) the International Tribunal for the Law of the Sea (ITLOS), a new international court established by Annex VI of UNCLOS; (ii) arbitration in accordance with Annex VII; or (iii) for certain kinds of disputes, arbitration in accordance with Annex VIII.²⁰⁹ However, it also expressly exempts coastal States from engaging with such mechanisms in the case of disputes arising under a “right or discretion” under the MSR provisions of Article 246.²¹⁰ While any State can still submit disputes related to Article 246 to non-binding conciliation procedures, conciliation committees also cannot override a coastal State’s decisions made under Article 246(5).²¹¹

Another ground for coastal States to deny permission for ocean-CDR research could be under Article 246(5)(b), which allows a State to withhold consent if proposed research could entail “introduction of harmful substances into the marine environment.”²¹² This proposition is reinforced by Article 240(d), which provides that MSR must be conducted in a manner that complies, *inter alia*, with regulations for protecting and preserving marine environments.²¹³

As indicated in Part I, deployment of ocean-based CDR options could pose risks to ocean ecosystems, which in many cases would be linked to the introduction of substances into the marine environment. This could include seeding ocean regions with iron or other substances to assess ocean fertilization, introducing minerals in ocean environments to induce alkalinity, or introducing macroalgae and

208. UNCLOS, *supra* note 35, at 497.

209. *Id.* at 509–10.

210. *Id.* at 513.

211. *Id.* at 514.

212. *Id.* at 497.

213. *Id.* at 495.

supporting infrastructure into a marine environment. Moreover, a coastal State's decision to withhold consent on these grounds could also not be contested through UNCLOS's binding dispute resolution mechanism.²¹⁴

3. High Seas

Under UNCLOS, the "high seas" encompass all areas of the oceans outside of the territorial sea or exclusive economic zones of coastal States, as well as in the archipelagic waters of archipelagic States.²¹⁵ Overall, this accounts for 64% of the oceans' surface and 95% of their volume.²¹⁶

Many ocean-based CDR approaches would optimally be deployed in the high seas;²¹⁷ thus, treaty rules for MSR in these areas could be extremely important. "Freedom of scientific research" is recognized in UNCLOS as one of the rights of all States and competent international organizations on the high seas.²¹⁸ Unlike in coastal State waters, only the Flag State of a vessel conducting MSR has jurisdiction in these regions.²¹⁹ However, States and entities under their jurisdiction and control are subject to pertinent MSR provisions of Part XIII, as well as other "relevant regulations" under the treaty.²²⁰

The most pertinent regulations in this context are the substantive and procedural marine environmental protection provisions of Part XII, as well as other relevant international and regional agreements and national legislation.²²¹ All of the environmental provisions of UNCLOS are recognized as a codification of existing international legal principles,²²² making these principles also pertinent to non-parties that may engage in ocean-based CDR research, including the United States, a country that is likely to have jurisdiction over many private companies engaged in ocean-based CDR research.

Article 192 of UNCLOS, which provides the framing on the rights and obligations set forth in Part XII, imposes a broad obligation on all parties to "protect and preserve the marine environment."²²³ However, the general mandate of Article 192 is to be interpreted consistently with the rights and obligations of the parties under other provisions of UNCLOS, including those that follow in Part XII.²²⁴ Article 194 helps flesh out the substantive obligations that flow from

214. See UNCLOS, *supra* note 35, at 513.

215. *Id.* at 432.

216. PARLIAMENTARIANS FOR GLOB. ACTION, CAMPAIGN FOR THE PROTECTION OF THE OCEANS & IMPLEMENTATION OF SDG 14: THE HIGH SEAS – UNREGULATED AND UNDER ATTACK: A FACTSHEET FOR PARLIAMENTARIANS.

217. Christine Bertram, *Ocean Iron Fertilization in the Context of the Kyoto Protocol and the Post-Kyoto Process*, 38 ENERGY POL'Y 1130, 1134 (2010).

218. UNCLOS, *supra* note 35, at 432–33, 502.

219. Doussis, *supra* note 185, at 93.

220. UNCLOS, *supra* note 35, at 495.

221. Hubert, *supra* note 134, at 336.

222. Maria Gavouneli, *Protection Standards for the Marine Environment: Updating Part XII of the Law of the Sea Convention?*, in STRESS TESTING THE LAW OF THE SEA 254, 256 (Stephen Minas & Jordan Diamond eds., 2018).

223. UNCLOS, *supra* note 35, at 477.

224. Robin Warner, *Marine Snow Storms: Assessing the Environmental Risks of Ocean Fertilization*, 4 CARBON & CLIMATE L. REV. 426, 429 (2009).

Article 192. States are required to “take . . . all measures . . . that are necessary to prevent, reduce and control pollution of the marine environment from any source.”²²⁵ Moreover, under Article 194, States are required to “ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution to other States and their environment.”²²⁶ This includes protection of “rare or fragile ecosystems as well as the habitat of depleted, threatened, or endangered species and other forms of marine life.”²²⁷ The principle of prevention set forth in Article 194 is also recognized as customary international law.²²⁸

UNCLOS capaciously defines the term “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.²²⁹

As such, for example, the pumping of ocean nutrients in upwelling or downwelling experiments could be construed as the “introduction of energy” into marine environments. Should damage ensue from such activities, it could potentially give rise to liability for compensation of damaged parties.²³⁰ Similarly, the introduction of iron or minerals to enhance alkalinity would constitute the introduction of “substances” into the marine environment, again potentially giving rise to liability for harmful impacts. While some of the substances or sources of “energy” associated with ocean-based research constitute novel introductions into ocean ecosystems, the definition of “pollution of the marine environment” has been routinely subject to evolutionary interpretation by the parties.²³¹

Generally, State responsibility lies for violations of international legal principles, including breaches of multilateral treaty obligations such as those set forth in Part XII of UNCLOS.²³² These violations are grounds for a demand of full reparations for damages associated with the wrongful act, as well as cessation of the activity giving rise to responsibility and assurances of non-repetition.²³³

225. UNCLOS, *supra* note 35, at 478.

226. *Id.*

227. *Id.* at 479.

228. Alexander Proelss, *Law of the Sea and Geoengineering*, in *THE LAW OF THE SEA* 93, 108 (Nele Matz-Lück et al. eds., 2022).

229. *Id.* at 399.

230. *Id.* at 494.

231. Alan Boyle, *Further Development of the Law of the Sea Convention: Mechanisms for Change*, 54 *INT'L & COMP. L.Q.* 563, 568–69 (2005).

232. Christina Voigt, *International Environmental Responsibility and Liability*, in *THE OXFORD HANDBOOK OF INTERNATIONAL ENVIRONMENTAL LAW* 1003, 1004 (Lavanya Rajamani & Jacqueline Peel eds., 2d ed. 2021).

233. *Id.*; see also *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*, Case No. 17, Advisory Opinion of Feb. 1, 2011, 17 *ITLOS Rep.* 10, ¶ 196–97.

UNCLOS does not impose new liability rules related to damage to the marine environment,²³⁴ providing for liability “in accordance with international law.”²³⁵

A number of factors may militate against potential liability exposure in the case of ocean-based CDR research. First, neither Article 192 nor Article 194 imposes strict liability on States for pollution that may occur as a consequence of marine activities by government entities or private parties under their jurisdiction. Rather, these provisions impose an obligation of conduct—that of due diligence.²³⁶

As outlined in the International Court of Justice’s decision in the *Pulp Mills* case,²³⁷ states have an obligation to act with due diligence in terms of all activities within their respective jurisdictions and control.²³⁸ The scope of the due diligence obligation includes not only the adoption of appropriate rules and measures by States, but also the capability to effectively enforce such measures and monitor the activities of both public and private actors under their jurisdiction.²³⁹ Moreover, the International Tribunal for the Law of the Sea’s Seabed Disputes Chamber has held that a higher level of care is required for “riskier activities.”²⁴⁰ While some scholars have suggested that this proportionality test might counsel in favor of a lower level of vigilance for MSR activities,²⁴¹ an argument can be made for very stringent requirements for ocean-based CDR research given our extremely elementary understanding at this point. Also, the Seabed Disputes Chamber has noted that a State’s requisite level of diligence may change over time in the face of “new scientific or technological knowledge.”²⁴² This might elevate a State’s requisite standard of care as the understanding of the potential risks of certain CDR approaches are revealed over time during both the research stage and in subsequent instances of deployment.

A second potential limitation on liability for MSR could be the relatively high threshold for harm established under UNCLOS’s definition of “pollution.” As noted above, 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

234. Voigt, *supra* note 232, at 1009.

235. UNCLOS, *supra* note 35, at 494.

236. *In re South China Sea Arb. (Phil. v. China)*, Case No. 2013-19, Award, ¶ 944 (Perm. Ct. Arb. 2016); Akiko Takano, *Land-Based Pollution of the Sea and Due Diligence Obligations*, 60 J.L. POL’Y & GLOBALIZATION 92, 94 (2017).

237. *Pulp Mills on the River Uruguay (Arg. v. Uru.)*, Judgment, 2010 I.C.J. 14 (Apr. 20).

238. *Id.* ¶ 197.

239. *Id.*; see also Int’l L. Comm’n, Rep. on the Work of Its Fifty-Third Session, U.N. Doc. A/56/10, at 154 (2001).

240. Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, Case No. 17, Advisory Opinion of Feb. 1, 2011, 17 ITLOS Rep. 10, ¶ 117.

241. Anna-Marie Hubert, *Marine Scientific Research*, in HANDBOOK ON MARINE ENVIRONMENT PROTECTION 933, 939 (Markus Salomon & Till Markus eds., 2018).

242. Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area, 17 ITLOS Rep. at ¶ 117.

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.²⁴³

This threshold for impacts might not be reached in the case of many ocean-based CDR experiments.²⁴⁴

Finally, it could be argued that one of the categories of “pollutants” that States have an obligation to control under Article 194 is greenhouse gas emissions. As such, environmental policy expert Jesse Reynolds has contended that under Article 194 there is “a need to balance the risks to the marine environment from climate engineering research with those from climate change.”²⁴⁵ However, Article 195 of UNCLOS calls upon its parties “not to transfer, directly or indirectly, damage or hazards from one area to another or *transform one type of pollution into another*.”²⁴⁶ While Reynolds argues that the risks of greenhouse gas pollution should be weighed against the risks of pollutants associated with climate interventions such as CDR in determining State obligations under Part XII, it is not clear that Article 195 contemplates—or permits—such a balancing test.

A final potential barrier to imposing liability for damages associated with ocean-based CDR research is that it is often unclear, including under UNCLOS, whether a party can invoke the responsibility of another State when this obligation is owed to all States (*erga omnes*).²⁴⁷ In such cases, it may prove difficult to identify an individually injured State, especially where impacts are dispersed or occur in the global commons.²⁴⁸ This might particularly be the case for potential harms associated with MSR conducted on the high seas.

Furthermore, States are required to take measures to prevent, reduce, and control “intentional or accidental introduction of species, alien or new, to a particular part of the marine environment, which may cause significant and harmful changes thereto.”²⁴⁹ This provision might be particularly relevant to seaweed cultivation research given the very real potential for introducing alien or new species to ecosystems.²⁵⁰

Article 210 calls upon States to prevent, reduce, and control pollution of the marine environment by “dumping,”²⁵¹ defined as, *inter alia*, “any deliberate disposal of wastes or other matter from vessels, aircraft, platforms or other man-

243. UNCLOS, *supra* note 35, at 399 (emphasis added).

244. See Karen N. Scott, *Not an Intractable Challenge: Geoengineering MSR in ABNJ*, in *MARINE BIODIVERSITY OF AREAS BEYOND NATIONAL JURISDICTION* 189, 200 (Myron H. Nordquist & Ronán Long eds., 2021).

245. Jesse Reynolds, *Climate Engineering Field Research: The Favorable Setting of International Environmental Law*, 5 *WASH. & LEE J. ENERGY CLIMATE & ENV'T* 417, 455 (2014). Reynolds defines the term “climate engineering” to include carbon dioxide removal. *Id.* at 422; see also Justin L. Penn & Curtis Deutsch, *Avoiding Ocean Mass Extinction from Climate Warming*, 386 *SCI.* 524, 526 (2022) (“The projected impact of accelerating climate change on marine biota is profound, driving extinction risks higher and marine biological richness lower than has been seen in Earth’s history for the past tens of millions of years.”).

246. UNCLOS, *supra* note 35, at 479 (emphasis added).

247. Voigt, *supra* note 232, at 1006.

248. *Id.*

249. UNCLOS, *supra* note 35, at 479.

250. See *supra* note 79 and accompanying text.

251. UNCLOS, *supra* note 35, at 483.

made structures at sea.”²⁵² On its face, ocean-based CDR MSR involving placement in marine environments of substances such as iron or minerals to enhance alkalinity might fall under this rubric. However, UNCLOS also provides that “placement of matter for a purpose other than the mere disposal thereof” does not constitute dumping, “provided that such placement is not contrary to the aims of this Convention.”²⁵³

The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention)²⁵⁴ includes this “dumping exception” language also.²⁵⁵ The London Convention is recognized as operationalizing the dumping provisions of UNCLOS,²⁵⁶ and its parties have addressed the legality of one ocean-based CDR approach: ocean iron fertilization.

The parties to the Convention, and its Protocol,²⁵⁷ have addressed the question of whether OIF could be regulated under these instruments and under what conditions it might be permitted. In 2008, the parties passed a resolution stating that OIF activities could fall under the dumping exception to the treaty “as placement of matter for a purpose other than the mere disposal.”²⁵⁸ However, the resolution also provided that OIF activities were restricted to “legitimate scientific research”²⁵⁹ and subject to a case-by-case risk assessment.²⁶⁰ The parties to the Convention subsequently developed a risk assessment protocol for vetting OIF proposals.²⁶¹ While these resolutions were focused on OIF, it is likely that the parties to the Convention and Protocol would treat other ocean CDR options in a commensurate fashion.

252. *Id.* at 399.

253. *Id.*

254. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, Dec. 29, 1972, 1046 U.N.T.S. 138 (entered into force Aug. 30, 1975) [hereinafter London Convention].

255. *Id.* at 140.

256. David L. VanderZwaag, *Ocean Dumping and Fertilization in the Antarctic: Tangled Legal Currents, Sea of Challenges*, in SCIENCE DIPLOMACY: ANTARCTICA, SCIENCE, AND THE GOVERNANCE OF INTERNATIONAL SPACES 245, 246 (Paul Arthur Berkman et al. eds., 2011).

257. The 1996 Protocol to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, Nov. 14, 1996, 36 I.L.M. 1 (entered into force March 24, 2006) [hereinafter London Protocol], is a stand-alone treaty that establishes superseding obligations for its contracting parties. Harald Ginzky, *Marine Geoengineering*, in HANDBOOK ON MARINE ENVIRONMENTAL PROTECTION 997, 1001 (Markus Salomon & Till Markus eds., 2018). It is contemplated as a more protective treaty that will ultimately replace the London Convention. INT’L MAR. ORG. [IMO], STRATEGIC PLAN FOR THE LONDON PROTOCOL AND LONDON CONVENTION (2017). The Protocol currently has fifty-three parties. *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*, IMO, <https://www.imo.org/en/OurWork/Environment/Pages/London-Convention-Protocol.aspx> [<https://perma.cc/V4LD-JBTS>].

258. IMO, *Resolution LC-LP.1 (2008) on the Regulation of Ocean Fertilization*, at 2, LC 30/16 (Oct. 31, 2008).

259. *Id.* The resolution provided that “other activities,” presumably commercial operations, should not be permitted “given the present state of knowledge.” *Id.*

260. *Id.*

261. IMO, *Assessment Framework for Scientific Research Involving Ocean Fertilization*, LC 32/15 (Oct. 14, 2010).

Moreover, the parties to the London Protocol adopted an amendment in 2013 to provide a framework for the regulation of “marine geoengineering.”²⁶² The term “marine geoengineering” is defined broadly to encompass any “deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts, and that has the potential to result in deleterious effects, especially where those effects may be widespread, long lasting or severe.”²⁶³

Some have construed the London Convention’s resolutions on OIF and the London Protocol amendment as de facto “moratoria” on climate interventions of this nature.²⁶⁴ However, this interpretation is belied by the fact that the amendment’s preambular language expressly notes U.N. resolutions that acknowledge the importance of MSR for the well-being of marine environments and encourage additional study of OIF.²⁶⁵

While the London Protocol amendment only initially regulates OIF, it would facilitate regulation in the future of other activities that fall under the rubric of “marine geoengineering.”²⁶⁶ In the context of OIF, a permit is only to be issued by a party for an OIF operation “if it is assessed as constituting legitimate scientific research taking into account any specific placement assessment framework.”²⁶⁷ However, the amendment has not entered into force, having only been accepted by six London Protocol parties to date.²⁶⁸

Several provisions of Part XII could also be pertinent to ocean-based CDR research. Article 204 requires assessment of the “risks or effects of pollution of the marine environment,”²⁶⁹ as well as ongoing monitoring impacts of “any activities” that might result in marine pollution.²⁷⁰ States are also required to publish reports of their findings to competent international organizations, and these must made

262. See generally IMO, Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities, at 1, LC 35/15 (Oct. 18, 2013) [hereinafter Amendment to the London Protocol].

263. *Id.* at 3.

264. See Silvia Ribeiro, *Against Geoengineering*, GEOENG’G MONITOR (Nov. 1, 2018), <https://www.geoengineeringmonitor.org/2018/11/against-geoengineering/>.

265. Amendment to the London Protocol, *supra* note 262, at 1.

266. *Id.* at 1–2. In 2022, the London Convention/Protocol’s Correspondence Group on Marine Geoengineering identified four additional ocean-based geoengineering approaches for prioritized consideration for potential listing in Annex 4 of the Protocol’s marine geoengineering amendment. IMO, *Statement on Marine Geoengineering*, LC 44/17 (Oct. 2022). This includes two carbon dioxide removal options: ocean alkalinity enhancement and macroalgae cultivation. *Id.* In October, the Consultative Meeting of the Contracting Parties to the London Convention and the Meeting of the Contracting Parties to the London Protocol adopted a “Statement on Marine Geoengineering,” concurring with the Correspondence Group on the need to evaluate the approaches identified by the Group, as well as the potential adverse impacts these approaches might pose for marine environments. *Id.*

267. Amendment to the London Protocol, *supra* note 262, at 4.

268. IMO, STATUS OF IMO TREATIES 571 (2022). Amendments under the Protocol only come into force for parties who have accepted it after two-thirds of the parties have deposited instruments of acceptance. London Protocol, *supra* note 232, at 17.

269. UNCLOS, *supra* note 35, at 481.

270. *Id.*

available to all States.²⁷¹ Article 206 also requires parties to assess the impacts of “planned activities” where there is risk of “substantial pollution” or “significant or harmful change” to the marine environment.²⁷² This is consistent with the now well-recognized obligation under customary international law to engage in environmental impact assessments for activities that may cause transboundary harm, including the duty to consult potentially affected States.²⁷³

Compliance with these provisions may be particularly salutary in the context of emerging carbon dioxide removal approaches in the world’s oceans. These procedures can facilitate an early and ongoing colloquy with stakeholders, concordant with principles of responsible innovation and social license to operate. As some have recently concluded, in the context of geochemical-based CDR approaches,

[a]n opaque research effort led primarily by commercial actors, effectively isolated from stakeholders and wider publics, may struggle to secure broad-based, durable support from the public and policymakers. In contrast, co-development through principles of responsible research and innovation may provide the means by which the eventual costs, benefits, and other trade-offs of scaled-up approaches are accurately defined, broadly understood, and equitably shared.²⁷⁴

C. Regulation of Deployment of MSR Equipment or Installations

Some ocean CDR research approaches would entail the deployment of equipment or installations in ocean waters. For example, artificial upwelling or downwelling research would require the deployment of vertical pipes and other equipment, such as pumps and sources of power.²⁷⁵ This equipment might be moored to the seabed or free float above these areas.²⁷⁶ Seaweed can be cultivated in ocean environments for research purposes through several methods entailing the use of equipment, including growing kelp by suspension of assemblages of spores

271. *Id.*

272. *Id.*; see also Yoshifumi Tanaka, *The South China Sea Arbitration: Environmental Obligations Under the Law of the Sea Convention*, 27 RECIEL 90, 93–94 (2018).

273. See e.g., *Pulp Mills on the River Uruguay (Arg. v. Uru.)*, Judgment, 2010 I.C.J. 14, ¶ 204 (Apr. 20); *Certain Activities Carried Out by Nicaragua in the Border Area (Costa Rica v. Nicar.)* and *Construction of a Road in Costa Rica Along the San Juan River (Nicar. v. Costa Rica)*, Judgment, 2015 I.C.J. 665, ¶¶ 104, 153 (Dec. 16); *Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area*, Case No. 17, Advisory Opinion of Feb. 1, 2011, 17 ITLOS Rep. 10, ¶ 145; see also Neil Craik, *The Duty to Cooperate in the Customary Law of Environmental Impact Assessment*, 69 INT’L & COMPAR. L. Q. 239, 239–59 (2020).

274. Cara N. Maesano et al., *Geochemical Negative Emissions Technologies: Part II. Roadmap*, FRONTIERS CLIMATE, Sept. 9, 2022, at 1, 2.

275. WEBB ET AL., *supra* note 83, at 31.

276. *Id.*

on ropes in ocean environments attached to buoys,²⁷⁷ suspended in nets,²⁷⁸ or on free-ranging semi-autonomous vehicles.²⁷⁹

Part XIII also governs installations and equipment employed in MSR “in any area of the marine environment,” providing that they are to be governed in the same manner as the conducting of research “in any such area.”²⁸⁰ Moreover, some specific rules are set out to protect the interest of other parties in addition to research entities. Researchers are required to identify and mark their installations and equipment, as well as use internationally recognized warning signals to ensure safety at sea.²⁸¹ Research equipment and installations also must not pose obstacles to vessels in international shipping routes.²⁸² In turn, researchers are accorded the right to establish safety zones of up to five hundred meters around equipment and installations, to be respected by vessels from all other States.²⁸³

D. Biodiversity Beyond National Jurisdiction Treaty

There has been growing recognition in recent years of the need for an international body with legally binding authority to protect and preserve marine biodiversity and the marine environment in areas outside of national jurisdiction.²⁸⁴ A decade of negotiations inside the United Nations and other fora ultimately led the United Nations General Assembly to adopt a resolution in 2015 to strengthen protection of biodiversity in areas beyond national jurisdiction.²⁸⁵ The resolution established a negotiating framework for an internationally binding agreement under UNCLOS.²⁸⁶ Five negotiating sessions have ensued, and the text of the Biodiversity Beyond National Jurisdiction (BBNJ) agreement (also known as the “High Seas Treaty”) may soon be adopted.²⁸⁷

The BBNJ acknowledges the need for a comprehensive regime to enhance conservation and sustainable use of biodiversity in areas beyond national

277. Smith, *supra* note 69; Bever, *supra* note 74.

278. Bren Smith, *This “Ocean Farmer” Could Make You Hopeful About the Future of the Sea*, GRIST (Feb. 26, 2016), <https://grist.org/food/this-ocean-farmer-could-make-you-hopeful-about-the-future-of-the-sea/>.

279. *Kelp Carbon Removal Seaweed Sinking Climate Change*, CARBON ZERO (June 9, 2021), <https://carbonzero.finance/kelp-carbon-removal-seaweed-sinking-climate-change/>.

280. UNCLOS, *supra* note 35, at 502.

281. *Id.*

282. *Id.*

283. *Id.*

284. See Robin Warner, *Mitigating Human Impacts on Marine Biodiversity Beyond National Jurisdiction: Potential Benefits of the International Legally Binding Instrument*, in MARINE BIODIVERSITY OF AREAS BEYOND NATIONAL JURISDICTION 167, 169 (Myron H. Nordquist & Ronán Long eds., 2021); Robert Blasiak et al., *Negotiating the Use of Biodiversity in Marine Areas Beyond National Jurisdiction*, FRONTIERS MARINE SCI., Nov. 11, 2016, at 1, 2.

285. See generally G.A. Res. 69/292 (June 19, 2015).

286. *Id.* ¶ 1.

287. See Kristina M. Gjerde et al., Editorial, *High Seas Treaty Within Reach*, 377 SCI. 1241, 1241 (2022); Minna Epps, *Key Takeaways from Treaty Negotiations for Biodiversity Beyond National Jurisdiction (BBNJ)*, United Nations HQ, New York, IUCN (Aug. 31, 2022), <https://www.iucn.org/blog/202208/key-takeaways-treaty-negotiations-biodiversity-beyond-national-jurisdiction-bbnj-united>.

jurisdiction.²⁸⁸ It emphasizes the responsibility of all parties to comport themselves as stewards of the high seas, “caring for and ensuring responsible use of the marine environment, maintaining the integrity of ocean ecosystems and preserving the inherent value of biodiversity of areas beyond national jurisdiction.”²⁸⁹

The treaty contains several provisions focused directly on marine research. Article 6 calls for the promotion of international cooperation to facilitate MSR.²⁹⁰ Article 7 calls for promoting generation of knowledge and technological innovation through MSR in areas beyond national jurisdiction, though the focus in this section is on marine genetic resources.²⁹¹

A number of other provisions of the draft treaty could be pertinent to future ocean-based CDR MSR. BBNJ provides for the establishment of a well-managed “network of ecologically representative and connected marine protected areas.”²⁹² The overarching objective is to “[r]ehabilitate and restore biodiversity and ecosystems” and to help build resilience to stressors.²⁹³

Parties to the agreement will be required to ensure that activities within their control and conducted in protected areas comport with decisions adopted by the parties for the management of such areas.²⁹⁴ It is conceivable that the parties may choose to ban, or substantially restrict, ocean-based CDR research in some protected areas. Conversely, CDR research may be privileged in some protected areas if it is believed that it can contribute to building resilience. For example, ocean alkalinity enhancement research might be encouraged in protected areas particularly imperiled by ocean acidification,²⁹⁵ one of the concerns set forth in the treaty that should be addressed in protected areas.²⁹⁶

Under certain circumstances, the BBNJ also contemplates the requirement of an environmental impact assessment (EIA) for activities that may impact high-seas marine environments.²⁹⁷ This could obviously include ocean-based CDR research activities. Ultimately, the treaty may provide far more precise and substantive parameters for conducting EIAs than what is provided for under UNCLOS or current customary international law.²⁹⁸ This could include the establishment of global minimum standards for conducting EIAs²⁹⁹ and a requirement to submit an

288. Intergovernmental Conference on an International Legally Binding Instrument Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction, *Further Revised Draft Text of an Agreement Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction*, at 4, A/CONF.232/2022/5 (June 1, 2022) [hereinafter BBNJ].

289. *Id.* at 8.

290. *Id.*

291. *Id.* at 9.

292. *Id.* at 17.

293. *Id.*

294. *Id.* at 22.

295. *See supra* Section I.B.

296. BBNJ, *supra* note 288, at 8.

297. *Id.* at 23–34.

298. *See* ENV'T L. INST., IMPLEMENTATION OF EIA IN AREAS BEYOND NATIONAL JURISDICTION UNDER THE UN BBNJ AGREEMENT: NEXT STEPS IN EIA GUIDELINES 10 (2021).

299. BBNJ, *supra* note 288, at 23–25.

EIA to the BBNJ's Scientific and Technical Body for "input and recommendations."³⁰⁰

However, one potential incarnation of the treaty would dispense with the requirement of an initial screening by a party if it determined that a proposed activity is likely to "have less than minor or transitory effect,"³⁰¹ while another version would require evidence of "substantial pollution or of significant and harmful changes to the marine environment."³⁰² These threshold requirements might exempt many small-scale ocean CDR research experiments from EIA requirements, as they arguably would not reach the requisite levels of potential harm to justify a full-blown EIA. However, an argument can be made that the treaty's embrace of a precautionary approach³⁰³ might justify EIAs under most circumstances given the high levels of uncertainty surrounding ocean-based CDR options at this point.

CONCLUSION

Ocean-based carbon dioxide removal research is in its incipient stages. There are imposing uncertainties in terms of how these approaches will be governed at the national or international level, including whether the global community will need to develop additional legal provisions and principles to both facilitate and adequately control these emerging technologies. The United Nations Law of the Sea Convention is likely to play a substantial role in the research stage of ocean CDR approaches. However, how individual States or key UNCLOS institutions will interpret these provisions in the context of these approaches remains very unclear. This Article seeks to provide some insights into how ocean-based CDR research may, and should, be operationalized.

300. *Id.* at 25.

301. *Id.* at 25–26 (Option A).

302. *Id.* at 26 (Option B).

303. *See id.* at 8.