Centre for International
Governance Innovation

Governance of Marine Geoengineering

SPECIAL REPORT

Kerryn Brent, Wil Burns and Jeffrey McGee

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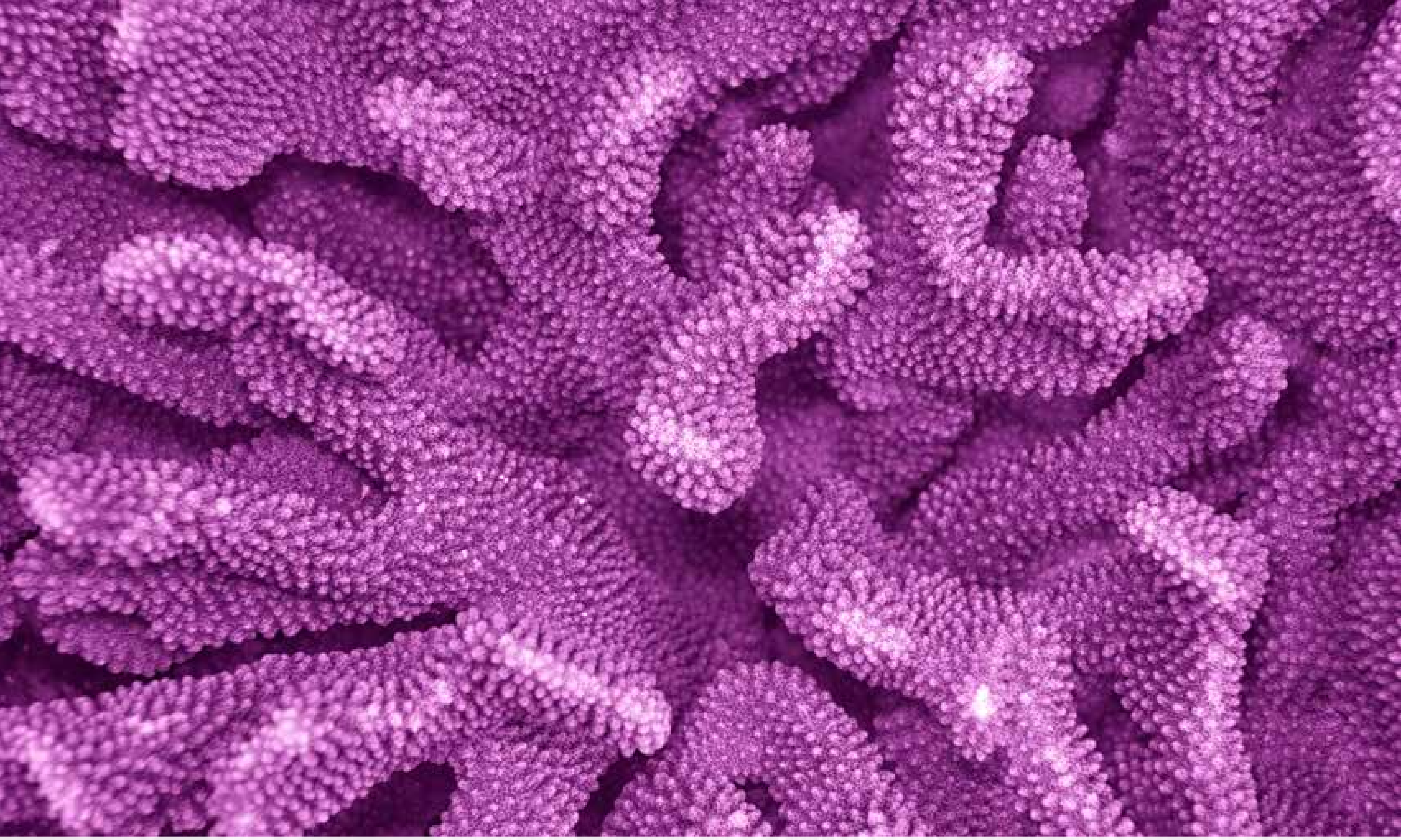
Contents



Acronyms and Abbreviations

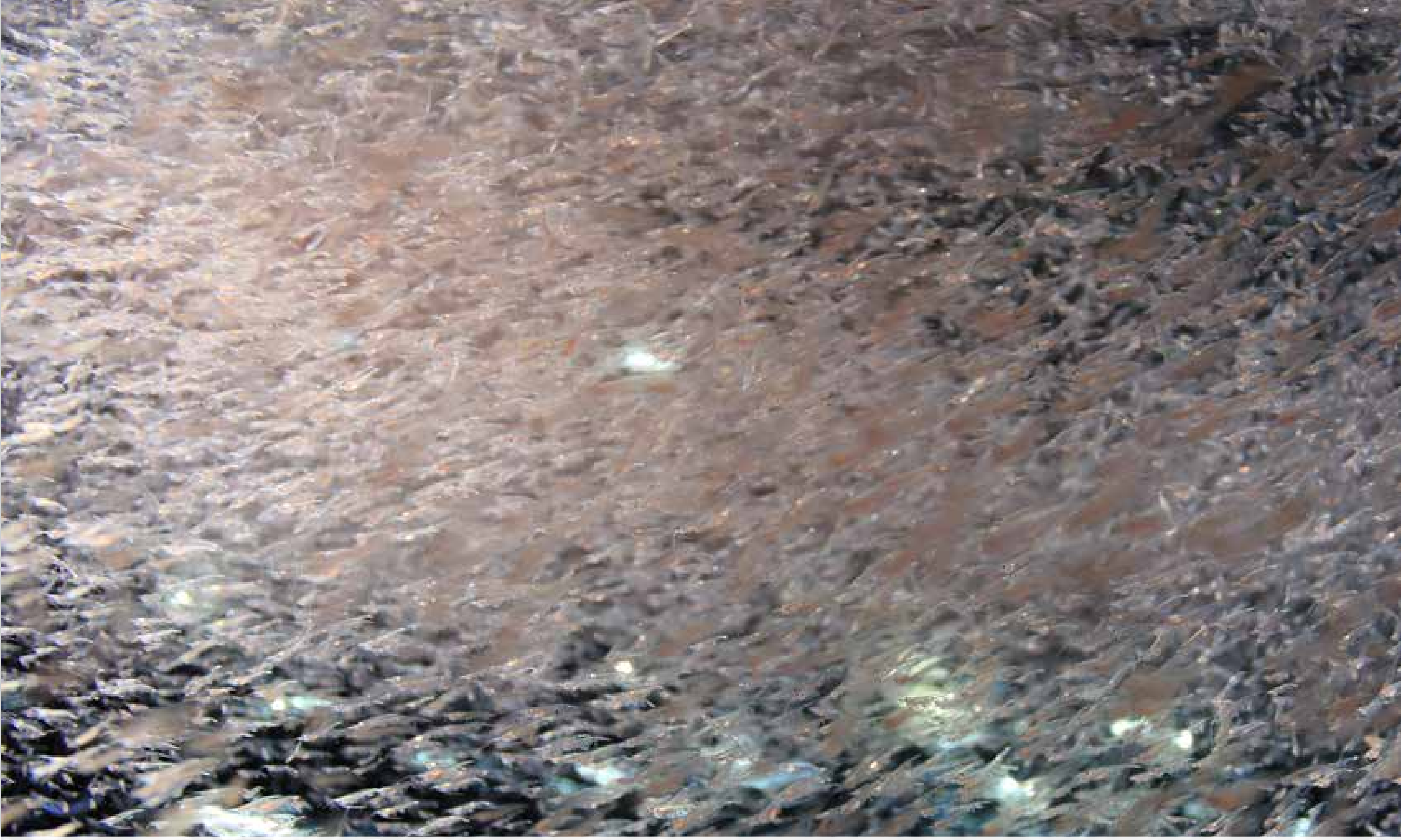
AOA	artificial ocean alkalization
BBNJ	biodiversity beyond national jurisdiction
BECCS	bioenergy with carbon capture and storage
CBD	UN Convention on Biodiversity
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CCS	carbon capture and sequestration
CDR	carbon dioxide removal
CO_2	carbon dioxide
COP	Conference of the Parties
EEZ	exclusive economic zone
EIAs	environmental impact assessments
ENMOD Convention	Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques
EPBC Act	Environment Protection and Biodiversity Conservation Act
GBR	Great Barrier Reef
GHG	greenhouse gas
HNLC	high-nitrate, low-chlorophyll
IPCC	Intergovernmental Panel on Climate Change
JARPA	Japan's Research Program in the Antarctic
LOSC	UN Convention on the Law of the Sea
MCB	marine cloud brightening

MSR	marine scientific research
NDCs	nationally determined contributions
NGOs	non-governmental organizations
OFAF	Assessment Framework for Scientific Research Involving Ocean Fertilization
OIF	ocean iron fertilization
OSPAR Convention	Convention for the Protection of the Marine Environment of the North-East Atlantic
RFMOs	regional fisheries management organizations
SRM	solar radiation management
UNESCO	UN Educational, Scientific and Cultural Organization
UNFCCC	UN Framework Convention on Climate Change
UNFSA	United Nations Fish Stocks Agreement

Executive Summary

After more than two decades of UN negotiations, global greenhouse gas (GHG) emissions continue to rise, with current projections indicating the planet is on a pathway to a temperature increase of approximately 3.2°C by 2100, well beyond what is considered a safe level. This has spurred scientific and policy interest in the possible role of solar radiation management (SRM) and carbon dioxide removal (CDR) geoengineering activities to help avert passing critical climatic thresholds, or to help societies recover if global temperatures overshoot expectations of safe levels. There are various proposals for SRM and CDR marine geoengineering, but aside from ocean iron fertilization (OIF) and marine cloud brightening (MCB), none of these options have moved beyond conceptual development and laboratory testing. Marine geoengineering proposals show significant diversity in terms of their purpose, scale of application, likely effectiveness, requisite levels of international cooperation and intensity of environmental risks. This diversity of marine geoengineering activities will likely place significant new demands upon the international law system to govern potential risks and opportunities.

International ocean law governance is comprised of a patchwork of global framework agreements, sectoral agreements and customary international law rules that have developed over time in response to disparate issues. These include maritime access, fisheries management, shipping pollution, ocean dumping and marine scientific research (MSR). This patchwork of oceans governance contains several bodies of rules that might apply in governing marine geoengineering activities. However, these bodies of rules were negotiated for different purposes, and not specifically for the governance of marine geoengineering. The extent to which this patchwork of rules might contribute to marine geoengineering governance will vary, depending on the purpose of an activity, where it is conducted, which state is responsible for it and the types of impacts it is likely to have. Applying this patchwork to a specific marine geoengineering activity is complex, and existing rules may provide only limited concrete guidance as to how an activity ought to be conducted. The 2013 amendment to the London Protocol on ocean dumping provides the most developed and specific framework for marine geoengineering governance to date. But the capacity of this amendment to bolster the capacity of international law to govern marine geoengineering activities is limited by some significant shortcomings. Negotiations are under way to establish a new global treaty on conservation of marine biodiversity in areas beyond national jurisdiction, including new rules for area-based management, environmental impact assessments (EIAs) and capacity building/technology transfer. The potential provisions of this agreement could be pertinent to marine geoengineering options. This negotiation is both an opportunity and a risk for marine geoengineering governance. A new agreement has the potential to fill key gaps in the existing patchwork of international law for marine geoengineering activities in high-seas areas. However, it is also important that this new treaty be structured in a way that is not overly restrictive, which might hinder responsible research and development of marine geoengineering in high-seas areas.



Introduction

When the Paris Agreement[1] to the United Nations Framework Convention on Climate Change[2] (UNFCCC) was adopted in 2015, many policy makers lauded the agreement, characterizing it as a "major leap for mankind,"[3] a "watershed event,"[4] and a "monumental triumph for people and our planet."[5] However, it has become increasingly clear in the ensuing years that the non-binding pledges made by the parties to effectuate the treaty's overarching objectives, may prove to be wholly inadequate to the imposing task at hand.

The Paris Agreement aims to strengthen the objectives of the UNFCCC by "[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels."[6] However, given the global community's

1 United Nations Framework Convention on Climate Change, *Paris Agreement,* 12 December 2015, Dec CP.21, 21st Sess, UN Doc FCCC/CP/2015/L.9 (entered into force 4 December 2016) [*Paris Agreement*].

2 *United Nations Conference on Environment and Development, Framework Convention on Climate Change*, 9 May 1992, 1771 UNTS 107, 31 ILM 849 (entered into force 21 March 1994) [*UNFCCC*].

3 J Vida et al, "World leaders hail Paris climate deal as 'major leap for mankind'", *The Guardian* (12 December 2015), online: <www.theguardian.com/environment/2015/dec/13/world-leaders-hail-paris-climate-deal>.

4 Steinar Andresen et al, "The Paris Agreement: Consequences for the EU and Carbon Markets?" (2016) 4:3 Politics & Governance 188.

5 "COP21: UN chief hails new climate change agreement as 'monumental triumph'", *UN News* (12 December 2015), online: <https://news.un.org/en/story/2015/12/517982-cop21-un-chief-hails-new-climate-change-agreement-monumental-triumph>.

6 *Paris Agreement*, *supra* note 1, art 2(1)(a).

growing heat-trapping emissions, and steadily increasing concentrations of long-lived GHGs in the atmosphere, recent assessments indicate that the remaining "carbon budget" to hold temperatures to below 1.5ºC may be exhausted by 2030,[7] with temperatures potentially reaching 1.5ºC by 2040 if current rates of warming continue.[8] Moreover, even the budget required to hold global temperatures to below 2ºC may be expended by 2030,[9] or, at the most, within a few decades thereafter.[10]

Indeed, Climate Analytics et al. projects that the nationally determined contributions (NDCs) made by states under the Paris Agreement put the world on track for temperature increases of 3.2°C.[11] Other contemporaneous assessments project that the current NDCs may result in global temperature increases of between 2.6°C and 3.7°C by 2100,[12] with temperatures continuing to rise for centuries beyond, and staying above Holocene level conditions for more than 10,000 years.[13]

Sobering projections of this nature have led to increasing interest in the potential role of climate geoengineering techniques to help avert passing critical climatic thresholds,[14] or to help societies recover in so-called overshoot scenarios (i.e., where global temperature overshoots expectations of safe limits).[15] Geoengineering is defined by the United Kingdom's Royal Society as "the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change."[16] There are various types of climate geoengineering proposals, most of which are still at a conceptual

7 Joeri Rogelj et al, "Paris Agreement climate proposals need a boost to keep warming well below 2°C" (2017) 534 Nature 631 at 635 (based on a 50 percent probability of not exceeding this temperature). See also Richard J Millar et al, "Emission budgets and pathways consistent with limiting warming to 1.5 °C" (2017) 10 Nature Geoscience 741 at 742; Jan C Minx et al, "Negative emissions—Part 1: Research landscape and synthesis" (2018) 13:6 Environmental Research Letters 063001 at 3 (remaining budget could be exhausted within five years).

8 MR Allen et al, "2018: Framing and Context" in V Masson-Delmotte et al, eds, *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (IPCC, 2018) 81 [IPCC, *Global Warming of 1.5°C*], online: <www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter1_Low_Res.pdf>. But see Yangyang Xu et al, "Global warming will happen faster than we think" (2018) 564 Nature 30 at 31 (concluding that we could reach 1.5°C by 2030).

9 Rogelj et al, *supra* note 7 at 635.

10 Philip Goodwin et al, "Pathways to 1.5°C and 2°C warming based on observational and geological constraints" (2018) 11 Nature Geoscience 102 at 104. However, it should be emphasized that there is a very wide range of plausible future emissions scenarios consistent with meeting either the 1.5°C or 2°C target. See Zeke Hausfather, "Analysis: How much 'carbon budget' is left to limit global warming to 1.5C?" *CarbonBrief* (9 April 2018), online: <www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c> ("Recent studies suggest the remaining carbon budget to limit warming to 'well below' 1.5C might have already been exceeded by emissions to-date, or might be as large as 15 more years of emissions at our current rate"); Adrian E Raftery et al, "Less than 2°C warming by 2100 unlikely" (2017) 7 Nature Climate Change 637; Edward Comryn-Platt et al, "Carbon budgets for 1.5 and 2°C targets lowered by natural wetland and permafrost feedbacks" (2017) 11 Nature Geoscience 568; Glen P Peters, "The 'best available science' to inform 1.5°C policy choices" (2016) 6 Nature Climate Change 646.

11 Climate Action Tracker, "The highway to Paris", online: <https://climateactiontracker.org/>.

12 Calum Brown, "Achievement of Paris Climate Goals unlikely due to time lags in the land system" (2019) 9 Nature Climate Change 203 at 206; Rob Bellamy, "Incentivize negative emissions responsibly" (2018) 3 Nature Energy; Raftery et al, *supra* note 10, 637–39; Rogelj et al, *supra* note 7 at 634. It should be emphasized that the Paris Agreement does provide for a "global stocktake" every five years "to assess the collective progress towards achieving the purpose of this Agreement and its long-term goals," with an eye to enhancing domestic and international commitments to meet the agreement's overarching objectives, if necessary. See *Paris Agreement*, *supra* note 1, art 14. While this provision could help the parties to avoid passing the 2°C threshold, this would require substantially strengthened commitments. See Wolfgang Obergassel et al, "Phoenix from the Ashes—An Analysis of the Paris Agreement to the United Nations Framework Convention on Climate Change", Wuppertal Institute for Climate, Environment and Energy (January 2016) at 45, online: <http://wupperinst.org/uploads/tx_wupperinst/Paris_Results.pdf>. The world's remaining "carbon budget" to avert passing the 2°C threshold may also be far lower than many current estimates, given uncertainties about many critical parameters. See Glen Peters, "The 'Best Available Science' to Inform 1.5°C Policy Choices" (2016) 6:7 Nature Climate Change 646.

13 Peter U Clark et al, "Consequences of Twenty-First Century Policy for Multi-Millennial Climate and Sea-Level Change" (2016) 6 Nature Climate Change 360 at 361; Gregory Trencher, "Climate Change: What Happens After 2100?", *Our World* (16 November 2011), online: <http://ourworld.unu.edu/en/climate-change-what-happens-after-2100>. In a recent assessment, Will Steffen et al. have also concluded that biogeophysical feedbacks associated with climate change could ultimately elevate temperatures to as much as 4 or 5°C above pre-industrial levels, and raise sea levels by 10 to 60 metres. Will Steffen et al, "Trajectories of the Earth System in the Anthropocene" (2018) 115:33 Proceedings of the National Academy of Sciences (PNAS) 8252, Supplementary Information at 4.

14 Mark G Lawrence, "Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals" (2018) 9:3734 Nature Communications 1; Detlef P van Vuuren et al, "Alternative pathways to the 1.5°C target reduce the need for negative emission technologies" (2018) 8 Nature Climate Change 391; Douglas G MacMartin, Katharine L Ricke & David W Keith, "Solar geoengineering as part of an overall strategy for meeting the 1.5°C Paris target" (2018) 376:2119 Philosophical Transactions of the Royal Society.

15 "Temperature overshoot" is defined as a period of time in which global temperature increases over pre-industrial levels exceed prescribed targets, such as 2°C or 1.5°C. See KL Ricke et al, "Constraints on global temperature target overshoot" (2017) 7:14743 Scientific Reports at 2. A number of studies have emphasized the potentially critical role of CDR/negative emissions technologies under overshoot scenarios. See Oliver Geden & Andreas Löschel, "Define limits for temperature overshoot targets" (2017) 10 Nature Geoscience 881; CD Jones et al, "Simulating the Earth system response to negative emissions" (2016) 11:095012 Environmental Research Letters; Christian Azar et al, "Meeting global temperature targets—the role of bioenergy with carbon capture and storage" (2016) 8:03400 Environmental Research Letters at 3.

16 The Royal Society, *Geoengineering the climate: Science, governance and uncertainty* (London, UK: The Royal Society, 2009) at 11.

or modelling stage. However, within scientific and policy literatures, climate geoengineering technologies are usually divided into two broad categories, that is, SRM and CDR approaches.[17]

Most SRM techniques focus on reducing the amount of solar radiation absorbed by the earth (currently pegged at approximately 235 watts per square metre[18]) by an amount sufficient to offset the increased trapping of infrared radiation by rising levels of GHGs.[19] The most widely discussed and actively investigated SRM option to date is sulfur aerosol injection.[20] This method seeks to enhance planetary albedo (the surface reflectivity of the sun's radiation)[21] through the injection of a gas such as sulfur dioxide (or another gas that will ultimately react chemically) in the stratosphere to form sulfate aerosols. The high reflectivity of aerosols causes a negative forcing that could ultimately substantially reduce projected temperature increases under the Intergovernmental Panel on Climate Change's (IPCC's) Representative Concentration Pathway.[22] Other frequently discussed SRM options include MCB[23] and space-based options.[24]

CDR options, also often referred to as negative emissions technologies, seek to remove and sequester carbon dioxide (CO_2) from the atmosphere, either by enhancing natural terrestrial and ocean sinks for carbon, or deploying chemical engineering to remove CO_2 from the atmosphere.[25] This, in turn, can increase the amount of long-wave radiation emitted by the earth back to space, reducing radiative forcing and thus exerting a cooling effect.[26]

Many analysts now believe that large-scale deployment of CDR options may be critical to achieve the temperature target range of the Paris Agreement.[27] Indeed, 87 percent of the IPCC's Fifth Assessment scenarios consistent with achieving the 2ºC climate stabilization target (with more than a 50 percent likelihood) assume widespread utilization

17 William CG Burns, "Geoengineering the Climate: An Overview of Solar Radiation Management Options" (2012) 46 Tulsa L Rev 283 at 286. There is also increasing characterization of SRM options, such as "albedo modification," including in the two most recent assessment reports of the IPCC. See Mark G Lawrence & Paul J Crutzen, "Was breaking the taboo on research on climate engineering via albedo modification a moral hazard, or a moral imperative?" (2016) 5 Earth's Future 136. It should also be emphasized that some approaches denominated as "geoengineering," including some CDR options, are closely akin to technologies for industrial carbon management, such as carbon capture and sequestration or land use, land-use change and forestry, and thus might not be classified by everyone as "climate geoengineering." See John Virgoe, "International Governance of a Possible Geoengineering Intervention to Combat Climate Change" (2009) 95 Climatic Change 103.

18 JT Kiehl & Kevin E Trenberth, "Earth's Annual Global Mean Energy Budget" (1997) 78:2 Bull American Meteorological Society 197.

19 Michael C MacCracken, "Beyond Mitigation: Potential Options for Counter-Balancing the Climatic and Environmental Consequences of the Rising Concentrations of Greenhouse Gases" (2009) World Bank Policy Research Working Paper 4938 at 15. Balancing positive global mean radiative forcing of +4 W/m_2, projected with a doubling of CO_2 from pre-industrial levels, would require reducing solar radiative forcing by approximately 1.8 percent; see Royal Society, *supra* note 16 at 23. While most SRM options focus on reducing the amount of incoming short-wave solar radiation, one approach, cirrus cloud thinning, seeks to increase outgoing long-wave radiation by reducing the optical death of cirrus clouds by injecting ice nuclei into regions of cirrus cloud formation, which can induce a transition from homogeneous to heterogeneous freezing. See Jón Egill Kristjánsson et al, "The hydrological cycle response to cirrus cloud thinning" (2015) 42 Geophysical Research Letters 10,807.

20 MacMartin, Ricke & Keith, *supra* note 14 at 2; Wil CG Burns, "Solar Radiation Management and its Implications for Intergenerational Equity" in Wil CG Burns & Andrew L Strauss, eds, *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks* (New York: Cambridge University Press, 2013) 208 [Burns, "SRM & Intergenerational Equity"].

21 "Albedo is the fraction of incident sunlight that is reflected." Albedo is measured on a 0–1 scale. If a surface absorbs all incoming sunlight, its albedo is 0; if it is perfectly reflecting, its albedo is 1. See Arctic Coastal Ice Processes, "Albedo," online: <www.arcticice.org/albedo.htm>.

22 Yosuke Arino et al, "Estimating option values of solar radiation management assuming that climate sensitivity is uncertain" (2016) 113 PNAS 5886; Andy Jones et al, "A comparison of the climate impacts of geoengineering by stratospheric SO2 injection and by brightening of marine stratocumulus cloud" (2011) 12:2 Atmospheric Science Letters 176, 178–80. For further details about MCB, see the second section of this report, "MCB."

23 K Alterskjær & JE Kristjánsson, "The sign of the radiative forcing from marine cloud brightening depends on both particle size and injection amount" (2013) 40:1 Geophysical Research Letters 210; John Latham et al, "Marine cloud brightening" (2012) 370:1974 Philosophical Transactions Royal Society A 4217.

24 Colin R McInnes, "Planetary Macro-Engineering Using Orbiting Solar Reflectors" in Viorel Badescu, RB Cathcart & RD Schuiling, eds, *Macro-Engineering: A Challenge for the Future* (Dordrecht, Netherlands, Springer, 2006) 215; R Bewick, JP Sanchez & CR McInnes, "The feasibility of using an L1 positioned dust cloud as a method of space-based geoengineering" (2012) 49:7 Advances in Space Research 1212. Space-based approaches all seek to modify the earth's energy balance in terms of incoming solar radiation through approaches such as deployment of a "space parasol," large metallic reflectors, clouds of small spacecraft orbited near the inner Lagrange point, or an artificial planetary ring of passive scattering particles. See FJT Salazar, CR McInnes & OC Winter, "Intervening in Earth's climate system through space-based solar reflectors" (2016) 58:1 Advances in Space Research 17.

25 Timothy Lenton, "The Global Potential for Carbon Dioxide Removal" in Roy Harrison & Ron Hester, eds, *Geoengineering of the Climate System* (London, UK: Royal Society of Chemistry, 2014) 53.

26 TM Lenton & NE Vaughan, "The Radiative Forcing Potential of Different Climate Geoengineering Options" (2009) 9 Atmospheric Chemistry & Physics 5539.

27 E Kriegler et al, "Pathways limiting warming to 1.5°C: a tale of turning around in no time?" (2018) 376:2119 Philosophical Transactions Royal Society at 1; Sabine Fuss et al, "Negative emissions—Part 2: Costs, potentials and side effects" (2018) 13:6 Environmental Research Letters at 2; Bellamy, *supra* note 12 at 532.

of CDR technologies.[28] The vast majority of these scenarios contemplate deployment of one CDR option, bioenergy with carbon capture and storage (BECCS),[29] a process by which biomass is converted to heat, electricity, or liquid or gas fuels, coupled with the capture of CO_2 and storage in geological or other reservoirs.[30] Other frequently discussed CDR technologies include direct air capture,[31] biochar,[32] enhanced mineral weathering,[33] reforestation/afforestation[34] and soil carbon enhancement.[35]

As our understanding of the potential risks associated with the most privileged negative emissions technologies, including large-scale deployment of BECCS, as well as the most widely discussed SRM option, sulfur aerosol injection, have deepened,[36] interest in other geoengineering approaches has also increased. Indeed, many commentators contend that the optimal approach, at least in the context of CDR options, may be adoption of a portfolio of approaches, all deployed at relatively modest scales.[37]

This has included increasing discussion of the potential role of marine-based processes.[38] As defined by the parties to the London Protocol to the Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, marine geoengineering means "a deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/or its impacts."[39]

The world's oceans are a logical cynosure for geoengineering research, as they cover 71 percent of the planet's area, currently remove 25 percent of anthropogenic CO_2 emissions and have great potential to remove and store much more.[40]

28 Ottmar Edenhofer et al, "Climate Change 2014: Mitigation of Climate Change Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change" (2014) at 14–15; Espen Moe & Jo-Kristian S Røttereng, "The post-carbon society: Rethinking the international governance of negative emissions" (2018) 44 Energy Research & Social Science 199. It should be emphasized that there are scenarios that avoid the passing of the 2°C threshold, while foregoing or minimizing the use of CDR options. See Detlef P van Vuuren et al, "Alternative pathways to the 1.5°C target reduce the need for negative emission technologies" (2018) 8 Nature Climate Change 391; Johan Rockström et al, "A roadmap for rapid decarbonization" (2017) 355 Science 1269.

29 Bellamy, *supra* note 12 at 532; Wil Burns & Simon Nicholson, "Bioenergy with carbon capture and sequestration with storage (BECCS): the prospects and challenges of an emerging climate response" (2017) 7:2 J Environmental Studies & Sciences 527.

30 Mathias Fridahl, "Introduction" in Mathias Fridahl, ed, *Bioenergy with Carbon Capture and Storage: From global potentials to domestic realities* (Brussels: European Liberal Forum, 2018).

31 AA Okesola et al, "Direct Air Capture: A Review of Carbon Dioxide Capture from the Air" (2018) 413 Materials Science & Engineering, Conference 1 at 1–4; Jere Elfving, Cyril Bajamundi & Juho Kauppinen, "Characterization and Performance of Direct Air Capture Sorbent" (2017) 114 Energy Procedia 6087; Klaus Lackner, "The thermodynamics of direct air capture of carbon dioxide" (2013) 50 Energy 38.

32 C Werner et al, "Biogeochemical potential of biomass pyrolysis systems for limiting global warming to 1.5°C" (2018) 13 Environmental Research Letters 044036; S Mia et al, "Long-Term Aging of Biochar: A Molecular Understanding with Agricultural and Environmental Implications" (2017) 141 Advances in Agronomy 1. Biochar involves conversion of biomass, including crop residues, non-commercial wood and wood waste, manure, solid waste, non-food energy crops, construction scraps, yard trimmings, methane digester residues or grasses, to a more stable form that can facilitate long-term storage of carbon. This is effectuated either by medium-temperature pyrolysis, or high-temperature gasification processes. See "The European Transdisciplinary Assessment of Climate Engineering (EuTRACE): Removing Greenhouse Gases from the Atmosphere and Reflecting Sunlight away from Earth" in Stefan Schäfer et al, eds, *Final report of the FP7 CSA project EuTRACE* (2015) at 31.

33 Christiana Dietzen et al, "Effectiveness of enhanced mineral weathering as a carbon sequestration tool and alternative to agricultural lime: An incubation experiment" (2018) 74 International J Greenhouse Gas Control 251; Lyla L Taylor et al, "Simulating carbon capture by enhanced weathering with croplands: an overview of key processes highlighting areas of future model development" (2017) 13:4 Biology 20160868.

34 Derek Martin et al, "Carbon Dioxide Removal Options: A Literature Review Identifying Carbon Removal Potentials and Costs" (submitted in partial fulfillment of the requirements for the degree of master of science (Natural Resources and Environment, University of Michigan, 2017) at 18–31.

35 United Nations Environment Programme (UNEP), *Emissions Gap Report* 61-2 (2017), online: <https://wedocs.unep.org/bitstream/handle/20.500.11822/22070/EGR_2017.pdf>; Pete Smith, "Soil carbon sequestration and biochar as negative emission technologies" (2016) 22:3 Global Change Biology 1315.

36 Risks associated with BECCS include potentially massive demands for land, with serious implications for food security, large water demands, huge increased appropriation of nitrogen and potential adverse impacts on biodiversity. See Mathilde Fajardy et al, "BECCS deployment: a reality check" (2019) Grantham Institute Briefing Paper No 28 at 5–8; RC Henry et al, "Food supply and bioenergy production within the global cropland planetary boundary" (2018) 13:3 PLOS ONE e0194695 at 1–17; Burns & Nicholson, *supra* note 29 at 529–30; S Kartha & K Dooley, "The risks of relying on tomorrow's 'negative emissions' to guide today's mitigation action" (2016) Stockholm Environment Institute Working Paper No 2016-08; Phil Williamson, "Emissions reduction: scrutinize CO_2 removal methods" (2016) 530:7589 Nature 153. Potential risks associated with SRM include potential declines in food production associated with changes in precipitation patterns, depletion of the ozone layer and rapid climatic changes should the use of such technologies be suddenly terminated. See Katherine Dagon & Daniel Schrag, "Exploring the Effects of Solar Radiation Management on Water Cycling in a Coupled Land–Atmosphere Model" (2016) 29 J Climate 2635; Burns, "SRM & Intergenerational Equity", *supra* note 20; Simone Tilmes, R Müller & R Salawitch, "The sensitivity of polar ozone depletion to proposed geoengineering schemes" (2008) 320:5880 Science 1201.

37 Fajardy et al, *supra* note 36 at 3; Minx et al, *supra* note 7 at 3.

38 The judiciousness of conducting an assessment of the potential risks and benefits of an array of climate geoengineering approaches was emphasized by the IPCC in its special report on the implications of temperature increases of 1.5°C. In their Summary for Policymakers, the drafters of the report emphasized, at least in the context of CDR options, that "[f]easibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at very large scale." IPCC, *Global Warming of 1.5°C, supra* note 8, SPM-23.

39 Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities, *Report of the Thirty-Fifth Consultative Meeting and the Eighth Meeting of the Contracting Parties*, UNEP, Res LP.4(8), Annex 4, LC 35/15 (2013) [Res LP.4(8)].

40 Jean-Pierre Gattuso et al, "Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems" (2018) Frontiers in Marine Science, DOI:<10.3389/fmars.2018.00337>; Greg Rau, "Enhancing the Ocean's Role in CO_2 Mitigation" in Bill Freedman, ed, *Global Environmental Change* (New York: SpringerLink, 2014) 817.

A turn toward marine geoengineering activities will place significant new demands upon the international law system to provide governance of the potential risks and opportunities. However, the rules of international law that will most likely be called on to provide governance of marine geoengineering have mostly developed in response to issues of quite different type and scale. It is therefore important and timely to assess the current capacity of the international law system to provide governance of marine geoengineering and what changes might be required.

This report thus proceeds as follows. The second section provides an extensive survey of the different types of marine geoengineering proposals that have appeared in the scientific literature and the few that have been the subject of field testing. This section details the substance of these proposals and highlights some of the environmental and social risks that have been identified. The third section provides analysis of various rules of international law that might be relevant to marine geoengineering. This section details the key oceans regimes that might be called upon to govern proposals on marine geoengineering activity, including the London Convention/London Protocol treaties on marine dumping, the 1982 United Nations Convention on the Law of the Sea (LOSC)[41] and customary international law rules relating to transboundary harm. The fourth section analyzes an amendment to the London Protocol, which arguably represents the most advanced attempt at marine geoengineering governance to date, but which has yet to come into force. The fifth section looks at a recent LOSC negotiation process on high seas biological diversity that may provide a new venue for governance of marine geoengineering. The final section concludes with a summary of key findings and discussion of areas for reform of the international law system that might assist in meeting future demands for governing marine geoengineering.

41 *United Nations Convention on the Law of the Sea*, 10 December 1982, 1833 UNTS 3 (entered into force 16 November 1994) [*LOSC*].

Potential Ocean-based Geoengineering Options

As discussed above, the oceans have significant potential as sites for geoengineering research, field testing and possible implementation. There have been numerous proposals for both SRM and CDR marine geoengineering. The following provides an overview of the more prominent marine geoengineering proposals.

SRM Proposals

MCB

Low-level marine stratiform clouds cover approximately 25 percent of ocean surfaces, and usually have albedos of 0.3 to 0.7, which exert a substantial cooling effect in terms of the earth's radiative balance.[42] MCB is a geoengineering approach that seeks to disperse sea salt particles into maritime clouds. Sea salt particles are a major source of cloud condensation nuclei, which in turn enhance cloud droplet number concentrations, reducing cloud droplet size. This results in an increase in droplet surface, and thus albedo.[43] This approach could also

42 John Latham et al, "Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds" (2008) 366:1882 Philosophical Transactions Royal Society A [Latham et al, "Global temperature stabilization"].

43 Ben Parkes, Alan Gadian & John Latham, "The Effects of Marine Cloud Brightening on Seasonal Polar Temperatures and the Meridional Heat Flux" (2012) International Scholarly Research Notices, Article ID 142872 at 1; J Feitcher & T Leisner, "Climate engineering: A critical review of approaches to modify the global energy balance" (2009) 176:1 European Physical J Special Topics 87.

enhance the longevity of such maritime clouds, potentially enhancing their cooling capacity.[44]

By way of example, one proponent of MCB has proposed that it could be accomplished through the deployment of up to 1,500 remote-controlled, wind-powered "albedo yachts." It is anticipated these vessels would be capable of generating sufficient electricity through turbines dragged in the water to create a mist of seawater, which could in turn be lofted 1,000 metres into the atmosphere to help create maritime clouds.[45]

Several studies have concluded that MCB deployed at a large scale could offset the radiative effective from a doubling of atmospheric CO_2,[46] while other research has projected a more modest reduction of 35 percent of current radiative forcing.[47] However, to date, the potential effectiveness of this option has only been assessed with global scale models, which have poor spatial resolution. This precludes assessment on the scale of individual clouds.[48] Moreover, some studies have found that MCB could even reduce albedo under some circumstances,[49] emphasizing the need for substantial additional research.[50]

Deployment of MCB could also pose several risks to both ocean ecosystems and terrestrial landmasses. The reduction of available light and ocean temperature associated with MCB could potentially alter carbon uptake of oceans by changing seawater chemistry and phytoplankton production, which could in turn affect other biogeochemical cycles and ocean ecology, including fisheries and other aspects of marine food webs.[51] While it's possible that this might not significantly affect total biological productivity, there is a risk that it could have significant impacts on the vertical distribution of productivity, and alter other factors important to the function of marine ecosystems, such as the horizontal transport of ocean nutrients.[52]

Moreover, depending on the scale of use, MCB could also have serious impacts on global precipitation patterns. While MCB might not have profound impacts on aggregate global precipitation,[53] several studies have projected that deployment could result in "sharp decreases" of precipitation in a number of regions, including in South America, where it could have detrimental impacts on the Amazon rainforest.[54] Regional cooling projected in some

44 PW Boyd & CMG Vivian, eds, "High-Level Review of a Wide Range of Proposed Marine Geoengineering Techniques" (2019) GESAMP Reports & Studies No 98; John Latham et al, "Marine cloud brightening: regional applications" (2014) 372:2031 Philosophical Transactions Royal Society A at 2.

45 Stephen Salter, Graham Sortino & John Latham, "Sea-going hardware for the cloud albedo method of reversing global warming" (2008) 366:1882 Philosophical Transactions Royal Society A 3989; Christopher Mims, "'Albedo Yachts' and Marine Clouds: A Cure for Climate Change?", *Scientific American* (21 October 2009).

46 Cao Long et al, "Geoengineering: Basic science and ongoing research efforts in China" (2015) 6:3–4 Advances in Climate Change Research 188; Latham et al, "Global temperature stabilization", *supra* note 42 at 3371.

47 G Bala et al, "Albedo enhancement of marine clouds to counteract global warming: Impacts on the hydrological cycle" (2011) 37:5–6 Climate Dynamics 915.

48 H Korhonen, KS Carslaw & S Romakkaniemi, "Enhancement of marine cloud albedo via controlled sea spray injections: a global model study of the influence of emission rates, microphysics and transport" (2010) 10 Atmospheric Chemistry & Physics 735.

49 Alan Robock et al, "Studying geoengineering with natural and anthropogenic analogs" (2013) 121 Climatic Change 445; David Keith & Peter Irvine, "The Science and Technology of Solar Geoengineering: A Compact Summary" in *Governance of the Deployment of Solar Geoengineering: Harvard Project on Climate Agreements* (November 2018) at 3; L Ahlmet al, "Marine cloud brightening — as effective without clouds" (2017) 17 Atmospheric Chemistry & Physics 13071. Moreover, MCB experiments usually assume uniform distribution of emitted sea salt in ocean grid boxes. However, this fails to take into account sub-grid aerosol coagulation within sea-spray plumes. One study incorporating this factor into simulations concluded that it reduces the Cloud Droplet Nuclear Concentrations (and the resulting radiative effect) by about 50 percent over emission regions, with variations ranging from 10 to 90 percent depending on meteorological conditions. See GS Stuart et al, "Reduced efficacy of MCB geoengineering due to in-plume aerosol coagulation: parameterization and global implications" (2013) 13 Atmospheric Chemistry & Physics 10385.

50 Mark G Lawrence et al, "Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals" (2018) 9 Nature Communications, art 3734 at 10; Camilla W Stjern et al, "Response to MCB in a multi-model ensemble" (2018) 18 Atmospheric Chemistry & Physics 621; Stephen H Salter et al, "Engineering Ideas for Brighter Clouds" (2014) 38 Issues Science & Technology 131.

51 Antti-Ilari Partanen et al, "Impacts of sea spray geoengineering on ocean biogeochemistry" (2016) 43:14 Geophysical Research Letters 7600.

52 *Ibid*; Nick J Hardman-Mountford et al, "Impacts of light shading and nutrient enrichment geo-engineering approaches on the productivity of a stratified, oligotrophic ocean ecosystem" (2013) 10:89 J Royal Society Interface.

53 Kari Alterskjær et al, "Sea-salt injections into the low-latitude marine boundary layer? The transient response in three Earth system models" (2013) 118:21 J Geophysical Research: Atmospheres 12,195.

54 Bala et al, *supra* note 47 at 2. See also A Jones & JM Haywood, "Sea-spray geoengineering in the HadGEM2-ES earth-system model: radiative impact and climate response" (2012) 12 Atmospheric Chemistry & Physics 10887.

modelling studies could also have impacts on the West African monsoon and El Niño Southern Oscillation.[55] MCB could also result in changes in soil moisture content, manifested in notable areas of drying in South America and the southern United States, while increasing soil moisture in central Africa and India.[56]

Microbubbles/Foam

As far back as 1965, a President's Science Advisory Committee in the United States suggested that the impending threat of climate change could be addressed by "spreading very small reflecting particles over large oceanic areas" to enhance ocean albedo.[57] In 2011, Russell Seitz expanded upon this concept, concluding that the generation of reflective microbubbles over a portion of the more than 300 million square kilometres of fresh and salt water on the earth could potentially offset all current radiative forcing associated with anthropogenic emissions of CO_2, methane, nitrogen dioxide and halocarbons.[58] He suggested that these "hydrosols" could be produced by methods such as expansion of air through vortex nozzles, mechanical shakers or ultrasonic transducers.[59] Julian Evans et al.[60] and Julia Crook et al.[61] have also suggested that increasing ocean albedo through creation of surface bubbles or foam could have salutary impacts on Arctic ice and temperatures. An experiment conducted as part of the Geoengineering Model Intercomparison Project Testbed also concluded that this approach could effectuate a substantial reduction in projected global mean surface temperatures.[62]

A more interventionist approach in sea surface albedo modification has been proposed by Leslie Field et al.[63] Their research suggests that the placement of sheet-like or granular materials, such as hollow glass microspheres on Arctic ocean surfaces, could effectuate surface ice albedo modification in the region and help tamp down projected temperature increases.[64] The researchers concluded that the use of this glass microspheres method could increase Arctic ice volumes between 0.5 and one percent per year,[65] as well as substantially reducing temperatures in the region.[66]

However, very little research on these approaches has ensued to date,[67] and issues abound in terms of their potential effectiveness and cost.[68] Moreover, some researchers have raised concerns about potential risks associated with large-scale deployment of these options. These could include the potential to exacerbate ocean acidification by increasing the efficiency of CO_2 absorption in the oceans, potential environmental impacts associated with artificial surfactants, potential impacts on oceanic species through temperature effects and reduction of sunlight, and potential changes in regional precipitation patterns.[69]

CDR Proposals

OIF

The world's oceans sequester approximately one-third of anthropogenic CO_2 emissions,[70] with about 80 percent of all atmospheric carbon ending up in

55 Lynn M Russell et al, "Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan" (2012) 41:4 Ambio 350.

56 Jones & Haywood, *supra* note 54 at 10893.

57 President's Science Advisory Committee, *Restoring the Quality of Our Environment: Report of the Environmental Pollution Panel* 127 (November 1965), online: <www.documentcloud.org/documents/3227654-PSAC-1965-Restoring-the-Quality-of-Our-Environment.html>.

58 Russell Seitz, "Bright water: hydrosols, water conservation and climate change" (2011) 105 Climatic Change 365 at 371.

59 *Ibid* at 366.

60 JRG Evans et al, "Can oceanic foams limit global warming?" (2010) 42 Climate Research 155.

61 Julia A Crook, Lawrence S Jackson & Piers M Forster, "Can increasing albedo of existing ship wakes reduce climate change?" (2016) 121:4 JGR: Atmospheres 1549.

62 Corey J Gabriel et al, "The G4Foam Experiment: global climate impacts of regional ocean albedo modification" (2017) 17 Atmospheric Chemistry & Physics 595 at 602 (dispersal of highly reflective microbubble "foam" could reduce projected global mean land temperatures from an IPCC RCP6.0 scenario by 0.51–0.70 Kelvin).

63 L Field et al, "Increasing Arctic Sea Ice Albedo Using Localized Reversible Geoengineering" (2018) 6:6 Earth's Future 882 at 884.

64 *Ibid*.

65 *Ibid* at 896.

66 *Ibid*.

67 National Research Council, *Climate Intervention: Reflecting Sunlight to Cool Earth* (Washington, DC: National Academies Press, 2015) at 129.

68 Ivana Cvijanovic, Ken Caldeira & Douglas G MacMartin, "Impacts of ocean albedo alteration on Arctic sea ice restoration and Northern Hemisphere climate" (2015) 10:4 Environmental Research Letters at 7; Robert L Olson, "Soft Geoengineering: A Gentler Approach to Addressing Climate Change" (2012) 54:5 Environment: Science & Policy for Sustainable Development 29 at 31.

69 Alan Robock, "Bubble, bubble, toil and trouble: An editorial comment" (2011) 105 Climatic Change 383; Gabriel et al, *supra* note 62 at 606–08; Field et al, *supra* note 63 at 900.

70 Laurent Bopp et al, "The Ocean: A Carbon Pump", Ocean-Climate.org at 12, online: <www.ocean-climate.org/wp-content/uploads/2015/03/ocean-carbon-pump_ScientificItems_BD-2.pdf>; Field et al, *supra* note 63.

the oceans at some point in its life cycle.[71] The role of oceans as carbon sinks is primarily attributable to two processes. First, the solubility pump drives absorption of atmospheric carbon due to the partial pressure differential between the ocean and the atmosphere.[72] This can facilitate storage of CO_2 in the oceans over a centennial time scale.[73]

The second process, and the one most pertinent to OIF, is the biological pump. The starting point for this process is the fixation of dissolved inorganic CO_2 in shallow ocean waters by phytoplankton in the process of photosynthesis, converting the CO_2 into an organic form.[74] 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 sediments (i.e., ocean floor).[75] Carbon sinking to the level of sediments can be sequestered for decades to centuries, or even longer.[76]

In the 1980s, oceanographer John Martin advanced the "iron hypothesis," contending that phytoplankton growth in regions such as the Southern (Antarctic) Ocean and equatorial Pacific are limited by iron deficiencies, obviating the ability of these organisms to utilize excess nitrate/phosphate.[77] By implication, this iron deficiency reduces the amount of carbon that can be exported via the biological pump.[78] In support of this proposition, researchers contend that 30 percent of the 80 ppm CO_2 drawdown during the last glacial maxima may have been attributable to iron-driven enhancement of phytoplankton productivity.[79]

The iron hypothesis stimulated substantial interest in the past few decades in the geoengineering approach known as OIF. OIF seeks to stimulate net phytoplankton growth through dispersal of iron[80] in surface waters in areas characterized by high-nitrate, low-chlorophyll (HNLC) conditions.[81] OIF is one of the few ocean-based geoengineering approaches that has moved beyond conceptual development and modelling to the stage of field testing.[82] There have been 15 field OIF experiments conducted to date, although some of these were for non-geoengineering purposes.[83]

Some early assessments projected that OIF might be able to offset as much as 25 percent of the world's annual carbon emissions.[84] However, additional research has resulted in more refined estimates of the overall efficiency of phytoplankton uptake in response to iron seeding declining.[85] As a consequence, many recent analyses have concluded that deployment of OIF, even at very

71 Howard Herzog, Ken Caldeira & John Reilly, "An Issue of Permanence: Assessing the Effectiveness of Temporary Carbon Storage" (2003) 59:3 Climatic Change 293 at 302. It has been estimated that atmospheric concentrations of CO_2 would be one-third higher absent ocean storage of carbon. See Richard Sanders et al, "The Biological Carbon Pump in the North Atlantic" 129(B) Progress in Oceanography 200.

72 Louis A Legendre et al, "The microbial carbon pump concept: Potential biogeochemical significance in the globally changing ocean" (2009) 134 Progress in Oceanography 432.

73 Stephen A Rackley, "Ocean storage" in *Carbon Capture and Storage*, 1st ed (Oxford, UK: Butterworth-Heinemann, 2010), ch 12.

74 Stephen A Rackley, "Ocean storage" in *Carbon Capture and Storage*, 2nd ed (Oxford, UK: Butterworth-Heinemann, 2017), ch 20; PM Williams, H Oeschger & P Kinney, "Natural Radiocarbon Activity of the Dissolved Organic Carbon in the Northeast Pacific Ocean" (1969) 224 Nature 256. Approximately half of carbon fixation via photosynthesis is attributable to phytoplankton. See Sallie W Chisholm et al, "Dis-Crediting Ocean Fertilization" (2001) 294:5541 Science 309. This is true despite the fact that marine phytoplankton comprise less than one percent of the earth's total photosynthetic biomass. See CL De La Rocha & U Passow, "The Biological Pump" in Heinrich D Holland & Karl K Turekian, eds, *Treatise on Geochemistry*, 2nd ed, vol 8 (Amsterdam: Elsevier, 2004) 93.

75 Andy Ridgwell, "Evolution of the ocean's 'biological pump'" (2011) 108:40 PNAS 16485 at 16485; Jennie Dixon, "Iron Fertilization: A Scientific Review with International Policy Recommendations" (2009) 32:2 Environs 321 at 324–25.

76 Victor Smetacek et al, "Deep carbon export from a Southern Ocean iron-fertilized diatom bloom" (2012) 487 Nature 313.

77 JH Martin et al, "Testing the iron hypothesis in ecosystems of the equatorial Pacific Ocean" (1994) 371 Nature 123; John H Martin, "Glacial-Interglacial CO_2 Change: The Iron Hypothesis" (1990) 5:1 Paleoceanography 1.

78 De La Rocha & Passow, *supra* note 74 at 87.

79 PW Boyd et al, "Mesoscale Iron Enrichment Experiments 1993-2005: Synthesis and Future Directions" (2007) 315 Science 612.

80 To date, the most widely discussed form of iron to utilize in OIF is ferrous sulfate, with other options including iron lignosite or solid forms of iron. See KH Coale, "Iron Fertilization" in Steve A Thorpe & Karl K Turekian, *Encyclopedia of Ocean Sciences,* 1st ed (Amsterdam: Elsevier Science, 2001).

81 Ken O Busseler et al, "Ocean Iron Fertilization — Moving Forward in a Sea of Uncertainty" (2008) 319 Science 162; Phillip W Boyd et al, "A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization" (2000) 407 Nature 695. Approximately 20 percent of the world's oceans are classified as HNLC. See Jonathan William Pitchford & John Brindley, "Iron limitation, grazing pressure and oceanic high nutrient-low chlorophyll (HNLC) regions" (1999) 21:3 J Plankton Research 525. HNLC regions are predominantly in the subarctic Pacific, large regions of the eastern equatorial Pacific and the Southern Ocean. See Coale, *supra* note 80 at 333. The Southern Ocean is the largest HNLC region of the global ocean. See Stéphane Blain et al, "Effect of natural iron fertilization on carbon sequestration in the Southern Ocean" (2007) 446 Nature 1070.

82 Jeffrey McGee, Kerryn Brent & Wil Burns, "Geoengineering the oceans: an emerging frontier in international climate change governance" (2018) 10:1 Austl J Maritime & Ocean Affairs 67.

83 *Ibid*.

84 Hugh Powell, "Fertilizing the ocean with iron" (2008) 46:1 Oceanus 4.

85 United Nations Educational, Scientific and Cultural Organization & Intergovernmental Oceanographic Commission, *Ocean Fertilization: A Scientific Summary for Policy Makers* (2010).

large scales, might only sequester between less than a gigaton or a few gigatons of CO_2 annually.[86]

OIF could also pose substantial environmental and social risks. Fertilization could substantially alter ecological community composition in seeded areas.[87] The designed floristic shift to production of larger, bloom-forming phytoplankton could result in fundamental alteration of the base of the food web and alter the biogeochemical function of marine communities.[88]

Fertilization could also rob substantial expanses of downstream ecosystems of critical nutrients, and thus decrease primary production in those areas.[89] This could negatively impact production of marine resources such as fish in downstream regions, with potentially negative impacts on livelihoods.[90] Moreover, it could result in a net decline in phytoplankton productivity, and thus negatively impact the global carbon budget.[91] Other potential impacts of OIF could include proliferation of toxic algal blooms that could threaten ocean ecosystems[92] and the exacerbation of ocean acidification.[93]

There have also been proposals to stimulate ocean productivity through macronutrient fertilization. For example, in ocean regions where the limiting nutrient is nitrogen, the addition of nitrogen-rich urea might stimulate higher phytoplankton biomass.[94] However, there are also serious potential risks to assess in this context, including the potential for creating hypoxic or anoxic environments that could threaten marine species,[95] declines in phytoplankton diversity,[96] and potential for eutrophication and production of toxin-producing dinoflagellates.[97]

Artificial Upwelling/Downwelling

Artificial upwelling seeks to stimulate primary production in marine environments by drawing nutrient-rich water from beneath the photic zone to the surface.[98] As is the case with OIF, stimulation of phytoplankton production could lead to a drawdown of atmospheric CO_2 through the sinking of a portion of particulate organic carbon to the ocean floor, and sequestration for decades or centuries.[99] It might also produce co-benefits, including increases in fish production and cooling of coral reefs.[100]

86 The Royal Society, *Greenhouse Gas Removal* (2018) ("upper limit for ocean iron fertilisation is a CO_2 sink of not more than 3.7 $GtCO_2$ annually" at 44), online: <https://royalsociety.org/~/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf>; David P Keller, "Marine Climate Engineering" in M Salmon & T Markus, eds, *Handbook on Marine Environmental Protection* 261 (sequestration potential of only a few gigatons of CO_2 annually, even with fertilization of the entire Southern Ocean, at 230); Aaron L Strong et al, "Ocean Fertilization: Science, Policy, and Commerce" (2009) 22:3 Oceanography 236 (citing studies projecting CO_2 uptake with OIF of 0.9–1.5 GtC/year, at 244).

87 Caitlin G McCormack et al, "Key impacts of climate engineering on biodiversity and ecosystems, with priorities for future research" (2016) 13 J Integrative Environmental Science 103 at 115.

88 Strong et al, *supra* note 86 at 256; Michelle Allsopp et al, "A scientific critique of oceanic iron fertilization as a climate change mitigation strategy" (2007) Greenpeace Research Laboratories Technical Note 07/2007 at 11.

89 Christine Bertram, "Ocean iron fertilization in the context of the Kyoto protocol and the post-Kyoto process" (2010) 38 Energy Policy 1130 at 1133; John J Cullen & Philip W Boyd, "Predicting and verifying the intended and unintended consequences of large-scale ocean iron fertilization" (2008) 364 Marine Ocean Ecology 295 at 298.

90 Anand Gnanadesikan et al, "Effects of patch ocean fertilization on atmospheric carbon dioxide and biological production" (2003) 17:2 Global Biogeochemical Cycles, art 1050 at 19–10; Bertram, *supra* note 89 at 1133.

91 Strong et al, *supra* note 86 at 244.

92 Randall S Abate & Andrew B Greenlee, "Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change, and the International Environmental Law Framework" (2010) 27 Pace Environmental L Rev 555 at 567; Ian SF Jones, "Contrasting micro- and macro-nutrient nourishment of the ocean" (2011) 425 Marine Ecology Progress Series 281 at 291; Bertram, *supra* note 89 at 1132.

93 Andreas Oschlies et al, "Side effects and accounting aspects of hypothetical large-scale Southern Ocean iron fertilization" (2010) 7 Biogeoscience 4017 (OIF could reduce pH in the Southern Ocean an additional 0.15 units compared to current projections by 2110, at 4026).

94 Uday Bhan Singh & AS Ahluwalia, "Microalgae: a promising tool for carbon sequestration" (2013) 18 Mitigation & Adaptation Strategies Global Change 73 at 79; Patricia Glibert et al, "Ocean iron fertilization for carbon credits poses high ecological risks" (2008) 56 Marine Pollution Bull 1049 at 1051.

95 Julia Mayo-Ramsay, "Environmental, legal and social implications of ocean urea fertilization: Sulu sea example" (2010) 34 Marine Policy 831 at 833; Glibert et al, *supra* note 94 at 1051.

96 Glibert et al, *supra* note 94 at 1051.

97 Secretariat of the Convention on Biological Diversity, "Scientific Synthesis of the Impacts of Ocean Fertilization on Marine Biodiversity" (2009) CBD Technical Series No 45 at 31.

98 Susie J Bauman et al, "Augmenting the Biological Pump: The Shortcomings of Geoengineered Upwelling" (2015) 27:3 Oceanography at 17; Andrew Yool, "Low efficiency of nutrient translocation for enhancing oceanic uptake of carbon dioxide" (2009) 114:C8 J Geophysical Research (Oceans) at 2–3.

99 Yiwen Pan et al, "Achieving Highly Efficient Atmospheric CO_2 Uptake by Artificial Upwelling" (2018) 10 Sustainability, art 664 at 1; Phillip Williamson et al, "Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance" (2017) 90 Process Safety & Environmental Protection 475 at 479.

100 Boyd & Vivian, *supra* note 44, at 61.

A range of devices has been proposed to facilitate the upwelling process, including salt fountains,[101] airlift pumps[102] and wave-powered systems.[103]

Research to date has indicated that ocean upwelling, even at large-scale deployment, would yield relatively modest benefits in terms of carbon uptake by the oceans, probably less than one gigaton annually.[104] Some studies have even concluded that upwelling could result in a net *increase* in atmospheric concentrations of CO_2.[105] Moreover, should upwelling be stopped at some point, it could result in a rapid net increase in global temperatures. This is because additional heat uptake of the planet associated with artificial upwelling would be reversed with the termination of deployment on a decadal time scale, with the extra heat making its way back to the sea surface.[106] For example, Andreas Oschlies et al. conducted a simulated experiment of artificial upwelling and concluded that temperatures could be 0.03°C, 0.07°C and 0.23°C higher than under a control experiment's conditions, when upwelling is ceased after 10, 20 and 50 years, respectively.[107]

Ocean upwelling could also pose risks to ocean ecosystems. The drawdown of CO_2 into marine environments could exacerbate ocean acidification,[108] potentially decreasing ocean pH by 0.15 units beyond present acidification projections.[109] Artificial upwelling could also substantially restructure ocean ecosystems, including favouring larger phytoplankton, such as diatoms,[110] and resulting in a shift from oligotrophic (nutrient-poor) to eutrophic (nutrient-rich) species.[111]

By contrast, ocean downwelling proposals would seek to increase the rate of CO_2 transfer to deep ocean regions by enhancing the transport of carbon-rich cold water into the deep ocean, a process known as the "solubility pump." To do so, downwelling options focus on approaches that increase downwelling currents, primarily by utilizing pumps that cool surface waters.[112] However, several studies have concluded that this approach would entail high costs and have a minimal impact on atmospheric concentrations of CO_2.[113]

Ocean Alkalinity/Ocean Liming

A number of researchers have proposed adding lime (in the form of calcium oxide, calcium hydroxide, or calcium carbonate),[114] or silicate minerals such

101 The perpetual salt fountain would seek to induce nutrient upwelling by inserting a pipe connecting deep seawater and surface seawater, then filling the pipe with low-salinity deep seawater. Because the salinity of water inside the pipe would be lower than the outside, it would create a buoyant force via convective motion that would drive nutrients to the upper levels of the ocean. See Shigenao Maruyama et al, "Artificial Upwelling of Deep Seawater Using the Perpetual Salt Fountain for Cultivation of Ocean Desert" (2004) 60:4 J Oceanography 563. See also H Stommel et al, "An oceanographical curiosity: the perpetual salt fountain" (1956) 3:2 Deep Sea Research 152. This option would likely be viable only in certain regions, including the Northern Pacific Ocean, and some areas of the tropics and sub-tropics. See Dahai Zhang, "Reviews of power supply and environmental energy conversions for artificial upwelling" (2016) 56 Renewable & Sustainable Energy Rev 659 at 667.

102 An airlift pump is powered by compressed gas, usually air, which is injected into the lower part of a pipe that transports a liquid that utilizes fluid pressure to facilitate moving liquid in ascendant air flows in the same direction as the air. See Wei Fan, "Experimental study on the performance of an air-lift pump for artificial upwelling" (2013) 59 Ocean Engineering 47 at 48. Researchers have mapped out a conceptual airlift pump system to upwell deep ocean water, using a submerged vertical pipe and introducing compressed air into the pipe near the upper end. See NK Liang & HK Peng, "A study of air-lift artificial upwelling" (2005) 32 Ocean Engineering 731. See also Qicheng Meng et al, "A simplified CFD model for air-lift artificial upwelling" (2013) 72 Ocean Engineering 267.

103 A wave-powered pump utilizes a buoy and a flapper valve that opens and closes inside the pipe. The hingeing is designed to open and close at opposite phases of the wave cycle, causing water to rise upward. See Kern E Kenyon, "Upwelling by a Wave Pump" (2007) 63 J Oceanography 327. See also Wei Fan et al, "Experimental study on the performance of a wave pump for artificial upwelling" (2016) 113 Ocean Engineering 192.

104 Andreas Oschlies et al, "Climate engineering by artificial ocean upwelling: Channeling the sorcerer's apprentice" (2010) 37 Geophysical Research Letters L04701 at 4; Philippe Ciais et al, "Carbon and Other Biogeochemical Cycles" in IPCC, *Climate Change 2013: The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the IPCC 550; Pan et al, *supra* note 99 at 1.

105 Pan et al, *supra* note 99 at 2; S Dutreuil et al, "Impact of enhanced vertical mixing on marine biogeochemistry: lessons for geo-engineering and natural variability" (2009) 6 Biogeosciences 901 at 908.

106 Oschlies et al, *supra* note 104 at 4; David P Keller, Ellias Y Feng & Andreas Ochlies, "Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario" (2014) 5 Nature Communications, art 3304, 8.

107 Oschlies et al, *supra* note 104 at 4.

108 James E Lovelock & Chris G Rapley, "Ocean pipes could help the Earth to cure itself" (2007) 449 Nature 403.

109 Bauman et al, *supra* note 98 at 21.

110 L Zarauz et al, "Changes in plankton size structure and composition, during the generation of a phytoplankton bloom, in the central Cantabrian Sea" (2009) 31:2 J Plankton Research 193.

111 Bauman et al, *supra* note 98 at 21.

112 S Zhou & PC Flynn, "Geoengineering Downwelling Ocean Currents: A Cost Assessment" (2005) 71 Climatic Change 203 at 206–13.

113 Lenton & Vaughan, *supra* note 26 at 5553; The Royal Society, *Greenhouse Gas Removal* (2018) at 65, online: <https://royalsociety.org/~/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf>.

114 Gemma Cripps et al, "Biological impacts of enhanced alkalinity in Carcinus maenas" (2013) 71 Marine Pollution Bull 190 at 191. Calcium carbonate has been suggested as the optimal mineral because of its ready availability at the scales, which would be required for widescale deployment of ocean alkalinity processes.

as olivine,[115] to ocean surfaces. This approach is usually referred to as artificial ocean alkalization (AOA), or "enhanced ocean alkalinity." Oceanic dissolution of these minerals would increase total alkalinity.[116] This would, in turn, result in chemical transformation of CO_2, and storage in the ocean in the form of bicarbonate and carbonate ions.[117] For example, the dissolution of one mole of calcium carbonate is accompanied by the uptake of one mole of CO_2.[118] AOA would accelerate processes that would otherwise remove CO_2 from the atmosphere on time scales of up to thousands of years.[119]

A flotilla of ships could be deployed to distribute finely ground limestone in selected parts of the oceans,[120] or limestone could be dissolved and pumped to the ocean where local water supplies are readily available.[121] An alternative option to enhance ocean alkalinity would be through dissolution of carbonate materials exposed to flue gas CO_2 and seawater. Research suggests that contacting carbonate materials with seawater and flue gases would increase alkalinity in the effluent discharged back to the ocean.[122] In the case of silicate minerals, such as olivine, grains could be scattered by vessels in the open ocean, or crushed olivine could be scattered in coastal waters, taking advantage of high abrasion of materials in these zones.[123]

There is a wide range of estimates for the potential sequestration capacity associated with AOA. Tim Lenton and Nem Vaughan concluded that AOA using limestone could produce a modest drawdown of CO_2 of 30 ppm relative to a baseline of 430 ppm.[124] Other studies, however, concluded that CO_2 drawdown with lime-based mineral dispersal could be much more effective, with drawdown ranges from 166 to 450 ppm by 2100.[125] Peter Köhler et al. projected that olivine-based AOA could compensate for about nine percent of anthropogenic CO_2 emissions.[126] However, all of these projections should be approached with great caution, as AOA research to date has not advanced beyond desktop techno-economic assessment, or bench-scale laboratory work.[127] AOA could also help to reduce the growing threat of ocean acidification,[128] providing a potentially very important co-benefit.

There would also be some substantial logistical and economic challenges associated with large-scale deployment of AOA. AOA operations might require increasing the global production of lime by 23 times,[129] in the case of olivine.[130] Substantial energy requirements associated with production of lime from limestone, as well as associated CO_2 emissions, may make this process impractical.[131] Mining, transport and discharge of quicklime could cost between US$0.5 and US$2.8 trillion annually, equivalent to between 0.7 and 4.0 percent of GDP annually[132] or $72 to $125 per ton of sequestered carbon.[133] Olivine dissolution in oceans

115 Lennart T Bach et al, "CO_2 Removal With Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-benefits for Marine Pelagic Ecosystems" (2019) 1 Frontiers in Climate art 7; P Köhler et al, "Geoengineering impact of open ocean dissolution of olivine on atmospheric CO_2 surface ocean pH and marine biology" (2013) 8 Environmental Research Letters 014009; J Hartmann et al, "Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification" (2013) 51 Rev Geophysics 113.

116 Miriam Ferrer González & Tatiana Ilyina, "Impacts of artificial ocean alkalization on the carbon cycle and climate in Earth system simulations" (2016) 43 Geophysical Research Letters 6493.

117 Phil Renforth & Gideon Henderson, "Assessing ocean alkalinity for carbon sequestration" (2017) 55 Rev Geophysics 636 at 637.

118 LDD Harvey, "Mitigating the atmospheric CO_2 increase and ocean acidification by adding limestone powder to upwelling regions" (2008) 113 J Geophysical Research C04028 at 2.

119 D Archer, "Fate of fossil fuel CO_2 in geologic time" (2005) 110 J Geophysical Research C09S05 at 3.

120 Lenton & Vaughan, *supra* note 26 at 5553.

121 Haroon S Kheshgi, "Sequestering Atmospheric Carbon Dioxide By Increasing Ocean Alkalinity" (1995) 20:9 Energy 915 at 917.

122 Phil Renforth, "The negative emission potential of alkaline materials" (2018) 10 Nature Communications 1 at 2; GH Rau & K Caldeira, "Enhanced carbonate dissolution: A means of sequestering waste CO_2 as ocean bicarbonate" (1999) 40:17 Energy Conversion & Management 1803.

123 Jasper Griffioen, "Enhanced weathering of olivine in seawater: The efficiency as revealed by thermodynamic scenario analysis" (2017) 575 Science Total Environment 536.

124 Lenton & Vaughan, *supra* note 26 at 5553.

125 Ellias Feng et al, "Could artificial ocean alkalization protect tropical coral ecosystems from ocean acidification?" (2016) 11:7 Environmental Research Letters 074008 at 9.

126 Peter Köhler et al, "Geoengineering impact of open ocean dissolution of olivine on atmospheric CO_2, surface ocean pH and marine biology" (2013) 8:1 Environmental Research Letters 014009 at 8.

127 Stefano Caserini et al, "Affordable CO_2 negative emission through hydrogen from biomass, ocean liming, and CO_2 storage" (2019) Mitigation & Adaptation Stategies; Renforth & Henderson, *supra* note 117 at 32.

128 Harvey, *supra* note 118 (application of 4 gigatons of limestone per year beginning in 2020 could "restore about 20% of the difference between the minimum pH and preindustrial pH by 2220 and restore about 40% of the difference by 2500" at 20); Tatiana Ilyina et al, "Assessing the potential of calcium-based ocean alkalization to mitigate rising atmospheric CO_2 and ocean acidification" (2013) 40 Geophysical Research Letters 5909; Boyd & Vivian, *supra* note 44 at 64.

129 Ilyina et al, *supra* note 128 at 5911.

130 González & Ilyina, *supra* note 116 at 6494.

131 Renforth & Henderson, *supra* note 117 at 3.

132 François S Paquay & Richard E Zeebe, "Assessing possible consequences of ocean liming on ocean pH, atmospheric CO_2 concentration and associated costs" (2013) 17 Intl J Greenhouse Gas Control 183 at 187.

133 P Renforth et al, "Engineering challenges of ocean liming" (2013) 60 Energy 442 at 448.

could also be extremely costly, given the need to finely grind the mineral, although costs could be reduced by application in more accessible coastal and shelf environments.[134] Estimates of costs associated with using silicate rocks to achieve a 50 ppm drawdown of CO_2 could be in the range of US$60 to US$600 trillion.[135] To put this number in perspective, global GDP in 2019 is projected to be over US$88 trillion.[136]

Finally, AOA would pose a host of potential risks to ocean ecosystems. The process could potentially disadvantage marine organisms that are not able to concentrate carbon within their cells under conditions of increased alkalinity.[137] AOA could also cause spontaneous precipitation of calcium hydroxide. This might adversely impact coral reefs, because they are sensitive to high levels of turbidity.[138] The addition of non-carbon alkaline minerals to the oceans could also alter primary and second production, thereby increasing contaminant accumulation in food chains via the release of minerals such as cadmium, nickel, chromium, iron and silicon.[139]

Blue Carbon

The term "blue carbon" refers to carbon captured by phytoplankton, as well as marine coastal macrophytes, including mangroves, salt marshes, seagrass and seaweed assemblages.[140] Macroalgae is usually not included under the rubric of blue carbon, because most grows on rocks, where burial is precluded.[141] However, some researchers have contended that it should be included under the blue carbon rubric. The rationale is that some macroalgae grow on sandy sediments, with burial rates for carbon of 0.4 percent of net primary productivity. Moreover, there are substantial amounts of production export of particulate organic and dissolved organic carbon.[142] The current natural blue carbon sink is characterized as "huge," perhaps 20 to 50 percent of the optimistic projections for the sequestration potential of ocean fertilization, and 18 percent of ocean carbon sequestration in sediments.[143]

There has been growing interest in the potential role of enhancing blue carbon sinks to effectuate atmospheric CDR. Recent research has indicated that it may be possible to more than double current rates of sequestration through restoration and creation of coastal ecosystems.[144] Moreover, there is serious concern about declining rates of carbon sequestration in many of these ecosystems, due to both climate change and other anthropogenic stressors.[145]

There is substantial potential to expand kelp forests, seaweed beds and mangroves, including in deeper waters.[146] Beyond the potential carbon sequestration benefits that could flow from taking these measures, there is also the potential for substantial co-benefits, such as improved wastewater treatment[147] and alternatives to fossil fuels for energy production,[148] including providing feedstocks

134 Francesc Montserrat et al, "Olivine Dissolution in Seawater: Implications for CO_2 Sequestration through Enhanced Weathering in Coastal Environments" (2017) 51 Environmental Science & Technology 3960 at 3961.

135 Lyla L Taylor et al, "Enhanced weathering strategies for stabilizing climate and averting ocean acidification" (2016) 6 Nature Climate Change 402 at 406.

136 World Population Review, "GDP Ranked by Country 2019", online: <http://worldpopulationreview.com/countries/countries-by-gdp/>.

137 Caserini et al, *supra* note 127; Gideon Henderson et al, "Decreasing Atmospheric CO_2 by Increasing Ocean Alkalinity" (2008) University of Oxford Department of Earth Sciences and the James Martin 21st Century Ocean Institute at 14.

138 Feng et al, *supra* note 125 at 7.

139 Gattuso et al, *supra* note 40 at 11; David P Edwards et al, "Climate change mitigation: potential benefits and pitfalls of enhanced rock weathering in tropical agriculture" (2017) 13:4 Biology Letters, art 337 at 4.

140 Francisco Arena & Fátima Vaz-Pinto, "Marine Algae as Carbon Sinks and Allies to Combat Global Warming" in Leonel Pereira & JM Neto, eds, *Marine Algae: Biodiversity, Taxonomy, Environmental Assessment and Biotechnology* (Boca Raton, FL: CRC Press, 2014) 178 at 183; NOAA, National Ocean Service, "What is Blue Carbon?", online: <https://oceanservice.noaa.gov/facts/bluecarbon.html>.

141 CM Duarte et al, "The role of coastal plant communities for climate change mitigation and adaptation" (2013) 3 Nature Climate Change 961 at 961–62.

142 Dorte Krause-Jensen & Carlos M Duarte, "Substantial role of macroalgae in marine carbon sequestration" (2016) 9 Nature Geoscience 737.

143 Sophia C Johannessen & Robie W Macdonald, "Geoengineering with seagrasses: is credit due where credit is given?" (2016) 11 Environmental Research Letters 113001 at 1.

144 National Academy of Sciences, *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda* (2018) at 32, online: <http://nap.edu/25259>.

145 *Ibid*; Alexander Pérez et al, "Factors influencing organic carbon accumulation in mangrove ecosystems" (2018) 14 Biology Letters 20180237 at 1–5; Elizabeth Mcleod et al, "A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2" (2011) 9:10 Frontiers in Ecology & Environment 552 at 556.

146 Ik Kyo Chung et al, "Installing kelp forests/seaweed beds for mitigation and adaptation against global warming: Korean Project Overview" (2013) 70:5 ICES J Marine Science 1038; Calvyn FA Sondak et al, "Carbon dioxide mitigation potential of seaweed aquaculture beds (SABs)" (2017) 29:5 J Applied Psychology 2363 at 2368.

147 SP Shukla et al, "Atmospheric Carbon Sequestration Through Microalgae: Status, Prospects, and Challenges" in JS Singh & G Seneviratne, eds, *Agro-Environmental Sustainability* (Amsterdam: Springer Nature, 2017) 219 at 230.

148 Kai Ling Yu et al, "Recent developments on algal biochar production and characterization" (2017) 246 Biosource Technology 2; Diana Moreira & José CM Pires, "Atmospheric CO_2 capture by algae: Negative carbon dioxide emission path" (2016) 215 Bioresource Technology 371 at 376.

for the BECCS process that would avoid or lessen dependence on terrestrial bioenergy crops.[149]

However, there are many challenges to enhancing sequestration through blue carbon strategies, including the high financial cost of some options,[150] as well as ecological constraints to expanding the scope of blue carbon sources, especially in open-ocean environments.[151] Enhancing blue carbon processes may also pose risks to ocean ecosystems, including alteration of ocean surface albedo and potential negative impacts on marine ecosystems associated with ocean temperature changes,[152] and potential production of toxins and algal blooms that could negatively impact ocean ecosystems.[153]

As discussed above, marine geoengineering proposals will likely place new demands upon the international law system to manage its risks and opportunities. The following section therefore examines how current international law might govern ocean geoengineering research, field testing and eventual deployment. It looks at what current rules exist that might apply to ocean geoengineering and what changes in rules might be needed.

149 Colin M Beal et al, "Integrating Algae with Bioenergy Carbon Capture and Storage (ABECCS) Increases Sustainability" (2018) 6 Earth's Future 524; Charles H Greene et al, "Geoengineering, marine microalgae, and climate stabilization in the 21st century" (2016) 5 Earth's Future 278 at 279–80; Andrew J Cole et al, "Using CO_2 to enhance carbon capture and biomass applications of freshwater microalgae" (2014) 6:6 Global Change Biology: Bioenergy 637.

150 B Bharathiraja et al, "Aquatic biomass (algae) as a future feed stock for bio-refineries: A review on cultivation, processing and products" (2015) 47 Renewable & Sustainable Energy Rev 634 at 637–38; Beal et al, *supra* note 149 at 533.

151 Rackley, *supra* note 74 at 538.

152 Antoine de Ramon N'Yeurt et al, "Negative Carbon via Ocean Afforestation" (2012) 90:6 Process Safety & Environmental Protection 467 at 472.

153 Marc Y Menetrez, "An Overview of Algae Biofuel Production and Potential Environmental Impact" (2012) 46:13 Environmental Science & Technology 7073 at 7079.

International Law and Marine Geoengineering

The discussion above outlines a range of potential marine geoengineering proposals. The proposals have important differences in terms of purpose (i.e., CDR, SRM or both), scale of application, likely effectiveness, international cooperation required and the intensity of environmental and social risk. It is also important to keep in mind that aside from OIF and MCB, most marine geoengineering proposals have not yet moved beyond the lab-based stage of conceptual development and modelling. It would likely take a decade or more of further research and development before these options could be deployed at significant scale.

It is also likely that any approaches that might ultimately be adopted will look quite different from those currently in circulation in the scientific literature. The following analysis of international law relevant to marine geoengineering must therefore partly consider the extent to which the international law system will be able to adapt to govern the risks and opportunities presented by technologies that can, at the moment, only be pictured in the abstract.

International Law and the Oceans

There are various rules of international law potentially relevant to the research, field testing and implementation of marine geoengineering. The world's oceans are governed by a network of international agreements to which various states have consented to be bound. At the outset, we can consider agreements that are wide-ranging or global in scope in terms of the geographic scale of their operation and types of issues covered. These global agreements have a wide scale of application and provide general rules and principles for how states should conduct activities in the world's oceans. Two primary examples are the LOSC and the 1992 United Nations Convention on Biological Diversity (CBD).[154] Moving downwards in scale, various sectoral agreements govern specific marine environmental and resource use issues, such as the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention),[155] or activities in specific regions, such the 1959 Antarctic Treaty System, various regional seas conventions and regional fisheries management organizations (RFMOs). Finally, in parallel with all these international agreements are rules of customary international law. These rules establish binding legal rights and obligations for states concerning activities conducted within or affecting the world's oceans, such as the duty to prevent activities from causing significant transboundary harm and harm to areas beyond the national jurisdiction of states, such as the high seas.[156] Viewed together, framework agreements, sectoral agreements and customary international law form a legal patchwork for oceans governance that has arisen in response to issues such as maritime access, fisheries access and management, sea-bed mining, shipping pollution, undersea cables and MSR.

This patchwork is, however, incomplete and contains notable holes. States have yet to develop robust international laws to govern some key marine environmental issues such as biodiversity conservation,[157] marine bioprospecting (i.e., the exploitation of marine genetic resources),[158] ocean acidification and the impacts of climate change on the marine environment.[159] Sectoral agreements often have limited membership, based on state interest in the issue the agreement seeks to govern. The capacity of regional agreements to contribute to oceans governance is further limited to specific geographical regions. Framework agreements and customary international law establish general rules that apply to most or all states, but are often difficult to interpret and apply to specific scenarios. They may be particularly difficult to apply to new or novel problems that were not anticipated at the time the agreement was formed. There are also limited mechanisms to monitor and enforce state compliance with rules in framework and sectoral agreements, which often apply to conduct in high-seas areas that are difficult and expensive to observe. Significant weaknesses therefore exist in international law that limit its capacity to govern certain marine environmental issues and activities.

The aim of this section is to help guide geoengineering researchers to assess the extent to which this patchwork of treaty and customary international law rules, as they are currently formulated, can govern the research, field testing and implementation of marine geoengineering. It considers the extent to which existing rules of international law provide substantive and procedural obligations relevant to marine geoengineering, including whether states may engage in marine geoengineering activities, and rules concerning how such activities ought to be conducted. This analysis seeks to inform governance scholars and policy makers on gaps and limitations in the current legal framework with a view to further developing international law for the governance of marine geoengineering activities.

This section takes an integrated approach to analyzing international law relevant to the research, field testing and implementation of marine geoengineering. To avoid the problem of compartmentalizing that may arise from separately considering each of the international law regimes that might be implicated by marine geoengineering, or by separately analyzing the application of international law to each individual proposal, this section instead seeks to provide a synthetic analysis anchored around the following four questions:

- → What is the purpose of the marine geoengineering activity?
- → Where will the marine geoengineering activity be conducted and by whom?
- → What are the likely impacts of the activity?
- → Can a state or other actor be held liable if marine geoengineering activities inflict damage?

These questions reflect the fact that marine geoengineering activities may be conducted

154 *Convention on Biological Diversity*, 5 June 1992, 1760 UNTS 79 (entered into force 29 December 1993) [*CBD*].

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

156 *Legality of the Threat or Use of Nuclear Weapons Case*, Advisory Opinion, [1996] ICJ Rep 226 at 241–42 [*Threat or Use of Nuclear Weapons*].

157 See Robin M Warner, "Conserving Marine Biodiversity in Areas Beyond National Jurisdiction: Co-Evolution and Interaction with the Law of the Sea" in Donald R Rothwell et al, eds, *The Oxford Handbook of the Law of the Sea* (Oxford, UK: Oxford University Press, 2015).

158 See Joanna Mossop, "Marine Bioprospecting" in Rothwell et al, *supra* note 157 at 825.

159 See Tim Stephens, "Warming Waters and Souring Seas: Climate Change and Ocean Acidification" in Rothwell et al, *supra* note 157 at 777; Robin Warner, "Oceans in Transition: Incorporating Climate-Change Impacts into Environmental Impact Assessment for Marine Areas Beyond National Jurisdiction" (2018) 45:31 Ecology LQ 31 at 36–48.

by different actors, in different locations and for different purposes. They also reflect the fact that different proposals are also likely to present different types and magnitudes of risk.

What Is the Purpose of the Marine Geoengineering Activity?

The purpose of a marine geoengineering activity is significant because different purposes may require the application of different rules of international law. Marine geoengineering activities can be conducted for three broad purposes: scientific research, to respond to climate change and associated impacts, and to enhance marine productivity. Of course, some marine geoengineering activities might be conducted with one purpose in mind but have co-benefits. For example, ocean fertilization can be conducted primarily to enhance marine productivity and enhance fish stocks; however, it may also have a co-benefit of drawing down CO_2. Similarly, enhanced kelp farming may be proposed to increase the CO_2 uptake of existing carbon sinks, but might also boost kelp stocks for food, agriculture or pharmaceutical purposes.[160]

Research Activities

To encourage understanding of the natural world, international agreements often distinguish scientific research activities from non-research activities. They commonly provide specific rules on scientific research activities that might be relevant to marine geoengineering research. Various sectoral regimes contain provisions for scientific research.[161] However, the most detailed and generally applicable rules of this type are contained in Part XIII of the LOSC, which establishes rules to promote and guide the conduct of MSR activities.[162]

The LOSC doesn't have a specific definition of activities that fall within MSR, and there is no commonly accepted definition of "scientific research" in international law that might otherwise be used to interpret this term.[163] However, MSR is commonly construed as "any form of *scientific* investigation, fundamental or applied, concerned with the marine environment."[164] According to Tim Stephens and Don Rothwell, MSR includes research activities for which the object of study is the ocean and marine environment, such as "physical oceanography, marine chemistry and biology, scientific ocean drilling and coring, geological and geophysical research and other activities that have a scientific purpose."[165] Rules under Part XIII of the LOSC will therefore apply to marine geoengineering research activities that involve *in situ* research in the marine environment, especially where that research will enhance knowledge of the marine environment.[166] This would include research activities to assess marine conditions for engaging in a marine geoengineering activity (for example, assessing water temperature and nutrient density for ocean fertilization or marine upwelling), or the testing of delivery mechanisms.[167] The definition of MSR under the LOSC does not distinguish between research conducted purely to enhance scientific knowledge, or research for applied and/or commercial purposes, such as the exploitation of natural resources. Marine geoengineering field tests, such as the placement of ferrous sulphate for OIF or lime for ocean alkalinity enhancement, will likely also qualify as MSR.

However, not all marine geoengineering research activities will qualify as MSR. Research activities may fall outside the scope of Part XIII if they are not conducted in the ocean, and/or do not primarily aim to enhance understanding of the marine environment. For example, marine geoengineering research conducted in a laboratory would be beyond the scope of the LOSC. Another example would be SRM research activities conducted *over* the ocean. These would arguably not constitute MSR if their objective

160 See Chung et al, *supra* note 146; Tim Flannery, *Sunlight and Seaweed: An Argument for How to Feed, Power and Clean up the World* (Melbourne: Text Publishing, 2017).

161 See e.g. *Convention for the Protection of the Marine Environment of the North-East Atlantic*, 22 September 1992, 32 ILM 1068, art 8 (entered into force 25 March 1998) [*OSPAR Convention*]; *Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean*, 16 February 1976, 15 ILM 290, art 13 (entered into force 12 February 1978) [*Barcelona Convention*]; *Convention for the Protection of the Natural Resources and Environment of the South Pacific Region*, 25 November 1986, 26 ILM 38, art 17 (entered into force 22 August 1990) [*Noumea Convention*].

162 *LOSC*, *supra* note 41.

163 For further discussion of this issue in the context of whaling, see Brendan Gogarty & Peter Lawrence, "The ICJ Whaling Case: missed opportunity to advance the rule of law in resolving science-related disputes in global commons?" (2017) 77:1 Heidelberg J Intl L 165.

164 Patricia Birnie, "Law of the Sea and Ocean Resources: Implications for Marine Scientific Research" (1996) 10:2 Intl J Marine & Coastal L 229 at 241–42 [emphasis added].

165 Tim Stephens & Donald R Rothwell, "Marine Scientific Research" in Rothwell et al, *supra* note 157, 559 at 562.

166 See Alexander Proelss & Chang Hong, "Ocean Upwelling and International Law" (2012) 43:4 Ocean Development & Intl L 371 at 373. Proelss and Hong suggest that large-scale deployment activities aimed at delivering negative emissions or enhancing marine productivity are not MRS, as the objective of these activities is not to increase knowledge of the marine environment.

167 See also *ibid*.

would be to understand atmospheric conditions and not potential impacts of SRM on the marine environment.[168] MCB experiments that aim to assess the creation and albedo effects of seawater particles in low-lying clouds therefore would not qualify as MSR.[169]

The LOSC provides states with a general right to conduct MSR,[170] but this right depends on where an activity will be conducted. A state may conduct MSR in their territorial waters[171] and exclusive economic zone (EEZ),[172] in accordance with their own domestic laws. However, if states wish to conduct MSR in the territorial waters or EEZ of another coastal state, they must first obtain that state's permission.[173] In accordance with principles of state sovereignty, coastal states have the exclusive right to decide whether to allow other states to conduct MSR in their territorial waters. However, under normal circumstances, coastal states should permit MSR activities in their respective EEZs.[174] This is in keeping with the general obligation that states have under the LOSC to promote and facilitate MSR.[175] In addition, all states have the right to conduct MSR in high-seas areas.[176] These are areas beyond the national jurisdiction of states (i.e., beyond the 200-nautical mile limit of EEZs) and make up nearly 60 percent of the world's oceans.[177] States therefore have a general right to conduct marine geoengineering research activities across a large part of the world's oceans.

However, the right of a state to conduct MSR in these areas is qualified by several important obligations. MSR must be conducted for peaceful purposes and employ "appropriate scientific methods."[178] The LOSC, again, does not elaborate on what appropriate scientific methods might be, but a similar issue was considered by the International Court of Justice in the 2014 *Whaling in the Antarctic* case.[179] This case involved a dispute between Australia and Japan under the 1946 International Convention for the Regulation of Whaling,[180] rather than the LOSC. Australia alleged that Japan's Research Program in the Antarctic (JARPA II) was a guise for commercial whaling, which is prohibited by a moratorium on such operations. The International Court of Justice therefore had to determine whether scientific research was the actual purpose of JARPA II. The court held that such a determination "does not turn on the intentions of individual government officials, but rather on whether the design and implementation of a programme are reasonable in relation to achieving the stated research objectives....The research objectives alone must be sufficient to justify the programme as designed and implemented."[181] The court used the objectives of the JARPA II program as the standard against which it assessed the program's design and implementation. In approaching the issue this way, the court thereby avoided providing a specific definition of the meaning of scientific research.

A court or tribunal could take a similar approach to determining whether the methods of a marine geoengineering research program are "appropriate" under the LOSC. However, such an approach would not be comprehensive. The LOSC provides states with little guidance as to what appropriate scientific methods would be in the context of a specific marine geoengineering research activity, beyond ensuring that they are reasonable in light of the activity's stated research objectives. In practice, states might therefore have quite wide discretion in how they interpret and apply this obligation to marine geoengineering research.

In December 2018, Japan announced that due to the ongoing criticism of its whaling program, it was withdrawing from the International Convention for the Regulation of Whaling and would recommence commercial whaling.[182] The Japanese whaling

168 See Stephens & Rothwell, *supra* note 165 at 562.

169 See e.g. Marine Cloud Brightening Project, online: <www.mcbproject.org/about.html>.

170 *LOSC*, *supra* note 41, art 238.

171 *Ibid*, art 245.

172 *Ibid*, art 246.

173 *Ibid*, arts 245–46.

174 *Ibid*.

175 *Ibid*, art 239.

176 *Ibid*, art 257.

177 Katherine Zischka et al, "Marine Biodiversity Beyond National Jurisdiction—Australia's Continuing Role" (2018) Australian Committee for the IUCN 1, online: <http://aciucn.org.au/index.php/publications/2018-marine-bbnj/>.

178 *LOSC*, *supra* note 41, art 240(b).

179 *Whaling in the Antarctic* (*Australia v Japan; New Zealand Intervening*) [2014] ICJ Rep 226 [*Whaling in the Antarctic*].

180 *International Convention for the Regulation of Whaling*, 2 December 1946, 161 UNTS 72 (entered into force 10 November 1948).

181 *Whaling in the Antarctic*, *supra* note 179 at 97. The court held that the design and implementation of the JARPA II whaling program was not reasonable in relation to the program's stated objectives, and that the killing of whales therefore was not for the purpose of scientific research (at 227).

182 Justin McCurry & Matthew Weaver, "Japan confirms it will quit IWC to resume commercial whaling", *The Guardian* (26 December 2018), online: <www.theguardian.com/environment/2018/dec/26/japan-confirms-it-will-quit-iwc-to-resume-commercial-whaling>.

example shows that the international law system has had significant difficulty policing the distinction between scientific research and other types of activity. This is important to bear in mind in considering the prospects of the international law system governing research on marine geoengineering.

Moreover, if a marine geoengineering research activity qualifies as MSR, the state responsible for it must also satisfy numerous rules that are designed to protect the sovereign rights and interests of other states, and also promote cooperation between states regarding MSR. States have a general obligation to ensure that research activities do not unjustifiably interfere with other legitimate uses of the sea.[183] More specifically, states must prevent any installations or equipment they use for MSR from interfering with shipping routes, and ensure they are fitted with adequate warning signals to prevent accidents.[184] This provision would be particularly relevant to upwelling and downwelling research projects that might involve the installation of large vertical pipes in the ocean.

States also have specific reporting requirements if they intend to conduct MSR within the EEZ or on the continental shelf of another state. They must provide the relevant coastal state with information regarding the intended research activity, including its geographic location, research objectives and methods.[185] The researching state must also provide the coastal state with the opportunity to participate in the project, and a copy of the research results and data if requested.[186] Moreover, the researching state must also ensure that results of any such research are made internationally available as soon as possible.[187]

These rules could provide a de facto assessment framework for marine geoengineering research activities by providing a coastal state with the opportunity to obtain and consider information relating to a proposed activity. By requiring the state to make results available to the international community, these rules could also promote research transparency and dissemination of results. However, these rules do not apply to activities conducted by a state within its own territorial sea, EEZ, or in high-seas areas.

MSR activities must also comply with the same rules for environmental protection and pollution control as all other activities.[188] These rules are set out under Part XII of the LOSC and include a general obligation (based on customary international law) to protect and preserve the marine environment,[189] and more specific obligations to prevent, reduce and control pollution.[190] (These obligations are examined in greater detail below.) However, what is significant for marine geoengineering research is that the LOSC does not provide separate environmental protection standards or rules for MSR. The environmental protection obligations in Part XII of the LOSC will apply equally to marine geoengineering research activities and to full-scale deployment activities. A one-size-fits-all approach to marine environmental protection may be desirable from a conservation standpoint; however, it may not be appropriate for facilitating responsible marine geoengineering research. For example, the approach in Part XII of the LOSC would not allow for the environmental impacts of a marine geoengineering research activity to be weighed against the risks of not conducting such research in the face of the impacts of anthropogenic climate change.

The rules for MSR under the LOSC largely focus on balancing the rights of coastal states against the need to develop better scientific knowledge of the world's oceans and marine environment. This is unsurprising, given that the first rules for MSR were developed in response to concerns by some developing country coastal states that developed country researching states might abuse freedoms to conduct MSR to facilitate exploitation of natural resources and infringe on their sovereign rights.[191] However, this focus on state sovereign rights has resulted in rules of international law that vary between different areas and provide no substantive guidance on how marine geoengineering research should be conducted within a state's own jurisdiction, or in high-seas areas.

183 *LOSC*, *supra* note 41, art 240.

184 *Ibid*, arts 261–62.

185 *Ibid*, art 248.

186 *Ibid*, art 249.

187 *Ibid*.

188 *Ibid*, art 240(d).

189 *Ibid*, art 192.

190 *Ibid*, art 194.

191 See Emmanuella Doussis, "Marine Scientific Research: Taking Stock and Looking Ahead" in Gemma Andreone, ed, *The Future of the Law of the Sea: Bridging Gaps between National, Individual and Common Interests* (Amsterdam: Springer Nature, 2017) 87 at 87–90.

Marine Geoengineering to Address Climate Change

Marine geoengineering activities are primarily being proposed to address climate change. Some proposals aim to address climate change at a global level (i.e., ocean fertilization by reducing the level of CO_2 in the atmosphere). Others, such as MCB, might also be used to address the impacts of climate change at a regional or local level.[192] It is therefore surprising that geoengineering proposals are currently not explicitly governed by international climate change law. In 2016, CIGI published a special report on geoengineering and the Paris Agreement by Neil Craik and Wil Burns.[193] This report found that key provisions of the UNFCCC and the Paris Agreement could arguably be interpreted to include CDR proposals. The following draws on key findings of that report and considers them in the specific context of marine geoengineering.

According to Craik and Burns, parties to the Paris Agreement may include emissions reductions attendant on deployment of CDR technologies as part of their NDCs on emissions reduction.[194] The Paris Agreement does not mandate legally binding emissions reduction targets by individual parties, but is rather based on parties making non-binding NDCs to reduce emissions. Article 4 establishes a general goal for all states to reach peak GHG emissions as soon as possible, and to establish a balance between global GHG emissions and sinks by 2050. Under article 5, states also have a general obligation to enhance domestic GHG sinks and reservoirs. However, it is up to the parties to determine what actions they will take to meet these obligations and communicate them to other states through NDCs.

As mentioned above, NDCs are not legally binding; however, states have an "obligation of conduct" to establish domestic measures to try and meet their respective NDCs.[195] According to Craik and Burns, the definition of "sinks" and "reservoirs" under the UNFCCC is arguably broad enough to include the removal and storage of CO_2 by CDR technologies.[196] This is not to say that the Paris Agreement expressly requires states to develop and implement CDR technologies. It does mean, however, that states have scope to integrate marine CDR proposals into their respective NDCs.[197] This scope is unlikely to extend to marine SRM proposals, as they do not seek to limit GHG emissions.[198]

The Paris Agreement does not, however, provide more specific rules for the governance of CDR technologies. There are currently no limits on the extent to which states might incorporate CDR into their NDCs.[199] According to Natalya Gallo, David Victor and Lisa Levin, 27 states have included blue carbon in their NDCs, including "ocean carbon storage and protection, replantation or management of mangroves, salt marshes, sea grass beds, or other marine ecosystems."[200] States have otherwise not expressly included CDR in their NDCs.[201] However, without clear guidelines, there is a risk that states might be too ambitious in relying on CDR technologies that have yet to be adequately researched, developed and/or implemented at scale.[202] Craik and Burns also warn that states could use promises of future CDR deployment to justify otherwise "unambitious emission reduction actions" in their NDCs.[203] The UNFCCC contains general principles that could mediate this, such as sustainable development[204] and precaution,[205] but does not extend these principles beyond general understanding in international law or provide further guidance on how they should be interpreted to apply in the context of marine geoengineering technologies. Furthermore, while the Paris Agreement implicitly suggests that CDR will have an important role to play in delivering negative emissions, it does not otherwise provide a framework to govern marine geoengineering activities for this purpose.

192 See case study below regarding MCB proposals to protect the Great Barrier Reef. For a more detailed analysis, see Jan McDonald et al, "Governing geoengineering research for the Great Barrier Reef" (2019) 19:7 Climate Policy 801.

193 A Neil Craik & William CG Burns, "Climate Engineering under the Paris Agreement: A Legal and Policy Primer" CIGI, Special Report, 1 November 2016.

194 *Ibid* at 1.

195 Jonathan Pickering et al, "Global Climate Governance Between Hard and Soft Law: Can the Paris Agreement's 'Crème Brûlée' Approach Enhance Ecological Reflexivity?" (2018) 31:1 J Envtl L 1 at 14.

196 Craik & Burns, *supra* note 193 at 6–7.

197 *Ibid* at 6.

198 *Ibid* at 8.

199 *Ibid* at 6–7.

200 Natalya D Gallo, David G Victor & Lisa A Levin, "Ocean commitments under the Paris Agreement" (2017) 7 Nature Climate Change 833 at 833–34.

201 Jesse L Reynolds, "International Law" in Michael B Gerrard & Tracy Hester, eds, *Climate Engineering and the Law: Regulation and Liability for Solar Radiation Management and Carbon Dioxide Removal* (Cambridge, UK: Cambridge University Press, 2018) 57 at 60.

202 Craik & Burns, *supra* note 193 at 7.

203 *Ibid*.

204 *UNFCCC*, *supra* note 2, art (3)(4).

205 *Ibid*, art (3)(3).

Marine Geoengineering to Enhance Marine Productivity

Some researchers have also suggested that ocean fertilization and marine upwelling approaches might be used to increase the abundance of fish stocks.[206] This raises questions about the extent to which international fisheries law might apply to marine geoengineering activities, even in cases where fisheries enhancement is not a specific objective. This body of international law governs the exploitation of marine living resources. It is made up of numerous treaties and international organizations, including the LOSC, the 1995 United Nations Fish Stocks Agreement (UNFSA)[207] and 14 RFMOs.[208] These agreements establish fishing rights[209] and/or conservation and management principles to prevent overexploitation of fish stocks.[210] Generally speaking, these agreements and organizations establish rules for fishing activities and industries, rather than rules for activities that aim to stimulate or enhance marine productivity per se. However, this does not mean that marine geoengineering activities are beyond the scope of international fisheries law.

Marine geoengineering for enhancing marine productivity (OIF, for example) may fall within the scope of marine living resources that are governed under the LOSC. This treaty establishes general rights and obligations concerning the exploitation of marine living resources by states in territorial waters, EEZs and in high-seas areas. Coastal states have the exclusive sovereign right to exploit natural resources (including fish stocks) within their respective territorial seas and EEZs.[211] They must also establish proper conservation and management measures to ensure that living resources within their EEZs are not overexploited.[212] Article 61(3) of the LOSC states that these "measures shall also be designed to *maintain or restore* populations of harvested species at levels which can produce the maximum sustainable yield."[213] There is no definition of the term "restore" in the LOSC, but it does not seem untenable to construe it to include marine geoengineering activities that might boost fish-stock populations. However, activities aimed at enhancing marine productivity are still subject to other obligations under the LOSC, including obligations on states to protect and preserve the marine environment (see "International Law on Environmental Harm," below).

Marine geoengineering activities will likely be of interest to international fisheries governance bodies that have adopted an ecosystem-based approach to fisheries management. This is a holistic approach to fisheries management that considers the effect an activity will have on an ecosystem as a whole, rather than just focusing on the impact it will have on a single species.[214] According to E. K. Pikitch et al., the purpose of this approach is to "sustain healthy marine ecosystems and the fisheries they support."[215] The ecosystem-based approach has been adopted by the UNFSA[216] and several other RFMOs.[217] While this approach is generally directed at the impacts of fishing activities on marine ecosystems, it could extend to include the impacts of marine geoengineering activities to enhance marine productivity. For example, under the UNFSA, parties have an obligation to "assess the impacts of fishing, *other human activities* and

206 See e.g. Randall S Abate, "Ocean Iron Fertilization and Indigenous Peoples' Right to Food: Leveraging International and Domestic Law Protections to Enhance Access to Salmon in the Pacific Northwest" (2016) 20 UCLA J Intl L & Foreign Aff 45; Proelss & Hong, *supra* note 166 at 372.

207 *United Nations Agreement for Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks*, 4 December 1995, 2156 UNTS 3 (entered into force 11 December 2001) [*UNFSA*].

208 There are 14 separate RFMOs that primarily aim to achieve "long-term conservation and sustainable use of the fish stocks under their management." See Rosemary Rayfuse, "Regional Fisheries Management Organizations" in Rothwell et al, *supra* note 157, 559 at 562. These RFMOs are the International Commission for the Conservation of Atlantic Tunas; the Indian Ocean Tuna Commission; the Western and Central Pacific Fisheries Commission; the Inter-American Tropical Tuna Commission; the Commission for the Conservation of Southern Bluefin Tuna; the North-East Atlantic Fisheries Commission; the Northwest Atlantic Fisheries Organization; the North Atlantic Salmon Conservation Organization; the South Pacific Regional Fisheries Management Organization; the Commission on the Conservation of Antarctic Marine Living Resources; the General Fisheries Commission for the Mediterranean; the South Indian Ocean Fisheries Agreement; and the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea.

209 See e.g. *LOSC*, *supra* note 41, arts 51, 61–70.

210 See e.g. *UNFSA*, *supra* note 207, art 5; *Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean*, 5 September 2000, 2275 UNTS 43, art 5 (entered into force 19 June 2004); *Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean*, 14 November 2009 [2012] ATS 28, art 3 (entered into force 24 August 2012).

211 *LOSC*, *supra* note 41, arts 2, 56.

212 *Ibid*, art 61(2).

213 *UNFSA*, *supra* note 207 [emphasis added] contains a similar obligation to "restore" fish populations under article 5(e).

214 EK Pikitch et al, "Ecosystem-Based Fishery Management" (2004) 305:5682 Science 346.

215 *Ibid* at 346.

216 *United Nations Agreement for Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks*, 4 December 1995, 2156 UNTS 3 (entered into force 11 December 2001).

217 See Robin Warner, Kristina Gjerde & David Freestone, "Regional governance for fisheries and biodiversity" in Serge M Garcia, Jake Rice & Anthony Charles, eds, *Governance of Marine Fisheries and Biodiversity Conservation: Interaction and Coevolution* (Oxford, UK: Wiley-Blackwell, 2014) 211.

environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks."[218] A further example is the 1980 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which governs marine living resources south of the Antarctic convergence. The CCAMLR requires that any marine harvesting and associated activities align with conservation principles that maintain ecological relationships between harvested, dependant and related populations,[219] and also prevent or minimize the risk of changes in the marine ecosystem "which are not potentially reversible over two or three decades, taking into account…the effects of associated activities [to harvesting] on the marine ecosystem and of the effects of environmental change."[220]

These ecosystem-based management provisions of the UNFSA and CCAMLR are broad in scope and may therefore be wide enough to include marine geoengineering activities. The provisions under the CCAMLR will likely only apply to marine geoengineering activities with the express purpose of enhancing harvestable stocks (i.e., fish species, krill). The provisions under the UNFSA are, however, likely to apply to any marine geoengineering activity that may impact on target stocks, regardless of whether marine productivity enhancement is the primary purpose of the activity. States may therefore have a general obligation under such treaties to consider the impacts of marine geoengineering activities, such as ocean fertilization and ocean upwelling, on the ocean ecosystem as a whole, and not just the capacity of these techniques to enhance the population of a single harvestable species.

As a stand-alone legal principle, ecosystem-based management is, however, unlikely to provide states with specific obligations relevant to marine geoengineering activities. States may have a general obligation to consider the impacts of a proposed activity on the ecosystem as a whole, but this general obligation does not mandate specific EIA procedures. It also does not provide clear guidance on how the potential benefits of marine geoengineering activities (such as enhancing the numbers of one species, and the lessening of climate change risk, including on marine species) should be weighed against potentially negative impacts on the marine ecosystem (such as the risk of an OIF activity fundamentally altering the base of the food web and "nutrient robbing"). RFMOs that adopt the principle of ecosystem-based management may still wish to consider proposed marine geoengineering activities that fall within their respective jurisdictions, especially if they are intended to enhance the numbers of harvestable fish stocks. RFMOs may also have the capacity to develop future conservation and management measures for marine geoengineering proposals such as ocean fertilization and upwelling to enhance marine productivity.[221]

The purposes of marine geoengineering activities are therefore very important in determining which existing rules of international law might apply. Marine geoengineering activities aimed at CDR and SRM offer the more straightforward case. However, the above analysis shows that such activities may have multiple purposes, which will trigger the application of rules of international law from disparate issue areas (such as MSR and fisheries management) that are not usually associated with climate change.

Where Will the Activity Be Conducted and by Whom?

Location

States will have different rights and obligations regarding marine geoengineering research, field-testing and deployment activities, depending on where it will be conducted. As indicated above, under the LOSC, states have different rights and obligations depending on whether the activity will be conducted within internal waters, territorial waters, an EEZ or the high seas.

Marine Geoengineering in Coastal Waters

Coastal states have exclusive sovereignty over the waters, airspace, seabed and subsoil of their internal waters and territorial sea, which typically extends up to a limit of 12 nautical miles, measured

218 *UNFSA*, *supra* note 207, art 5(d) [emphasis added].

219 *Convention on the Conservation of Antarctic Marine Living Resources,* 20 May 1980, 1329 UNTS 47, art II(3)(b) (entered into force 7 April 1982) [*CCAMLR*].

220 *Ibid*, art II(3)(c).

221 The commission has a wide mandate to adopt new conservation measures for activities "associated" with harvesting that may more broadly impact on the Antarctic marine ecosystem. See e.g. *CCAMLR*, *supra* note 219, art IX(2)(i).

from their coastal baseline.[222] States wishing to conduct marine geoengineering activities within a coastal state's internal waters or territorial sea will therefore need permission from that coastal state. Moreover, as these areas are part of the sovereign territory of the coastal state, marine geoengineering activities in internal waters and the territorial sea will be subject to the jurisdiction of the coastal state's domestic environmental and resource management laws. These may include laws and regulations related to marine spatial planning with designated use zoning, environmental protection and planning, pollution abatement and EIAs.[223]

For example, states that are party to the London Convention and/or London Protocol should already have detailed legislation in place implementing their obligations to prevent marine pollution from ocean dumping under these agreements.[224] This domestic legislation will be particularly relevant to marine geoengineering activities that require placement of matter into the ocean (i.e., OIF, alkalinity enhancement, ocean sunshields). Some states also have specific domestic legislation governing weather modification and cloud seeding activities that may be relevant to MCB proposals.[225]

It is beyond the scope of this report to provide a detailed analysis of how domestic law might apply to marine geoengineering across all states. Instead, the following Australian case study[226] illustrates how domestic law might provide a de facto governance framework for marine geoengineering activities carried out within internal waters, territorial sea or an EEZ.

Case Study: MCB Proposals for the Great Barrier Reef

> In 2017 and 2018, the Australian national government and Queensland state government allocated approximately AU$2million for feasibility studies of local/regional-scale marine geoengineering for the Great Barrier Reef (GBR).[227] The GBR is the largest coral reef system in the world and a UNESCO [UN Educational, Scientific and Cultural Organization] World Heritage site. In 2016 and 2017, the reef experienced two severe bleaching events that resulted in damage across two-thirds of the reef.[228] The frequency and severity of coral bleaching events will continue to increase as a result of climate change.[229] MCB has been proposed as a potential means of reducing sea surface temperatures on the reef and limiting UV exposure to prevent coral bleaching events.[230]
>
> Australia does not have domestic laws that explicitly govern geoengineering research, field testing or deployment. However, Australia's primary national environmental legislation, the Environment Protection and Biodiversity Act 1999 (Cth) (EPBC Act), provides for a limited development approval and EIA process that might act as the starting point for governance of MCB on the GBR. The difficulty is that the EPBC Act applies only in a limited range of circumstances. To trigger operation of the act, the federal environment minister must first assess whether the MCB proposal would have a "significant impact" upon a matter of "national environmental significance."[231] The GBR is listed under the World Heritage Convention,[232] and is

222 *LOSC*, *supra* note 41, arts 2, 3. The normal baseline is measured from the low waterline along the coast, unless otherwise provided for in the LOSC (art 5). For example, different rules apply for islands or atolls with fringing reefs (art 6), states with deeply indented coastlines of a fringe of islands (art 7), river mouths (art 9), bays (art 10), ports (art 11), roadsteads (art 12), low-tide elevations (art 13), states that have opposite or adjacent coastlines (art 15), and baselines for archipelagic states (art 47).

223 For an overview of these rules in the context of Canada, the United States and Australia, see Neil Craik, Jason Blackstock & Anna-Maria Hubert, "Regulating Geoengineering Research through Domestic Environmental Protection Frameworks: Reflections on the Recent Canadian Ocean Fertilization Case" (2013) 7:2 Carbon & Climate L Rev 117; Albert C Lin, "US Law" in Gerrard & Hester, *supra* note 201 at 154; Kerryn Brent et al, "Carbon Dioxide Removal (CDR) Geoengineering" (2018) 92:10 Austl LJ 830.

224 For example, Australia implements these obligations through the *Environment Protection (Sea Dumping) Act 1981* (Cth). Canada implements these obligations through the *Canadian Environmental Protection Act, 1999*, SC 1999, c 33, Part 7, Division 3. The United States is a party only to the London Convention, and implements its obligations through the *Marine Protection, Research, and Sanctuaries Act of 1972*, 33 USC §§ 1401–1445 (1972).

225 For example, in the United States there are laws at the federal level that require advance reporting and notification of weather modification activities. See *Weather Modification Reporting Act 1972*, 15 USC §§ 330–330e (1972). Similar legislation also exists in Canada. See *Weather Modification Information Act*, RSC 1985, c W-5.

226 For more detailed analysis, see McDonald et al, *supra* note 192.

227 "Boosting coral abundance on the Great Barrier Reef", Small Business Innovation Recipients, Advance Queensland (2018).

228 "Two-thirds of the Great Barrier Reef hit by back-to-back mass coral bleaching", ARC Center of Excellence Coral Reef Studies, online: <www.coralcoe.org.au/media-releases/two-thirds-of-great-barrier-reef-hit-by-back-to-back-mass-coral-bleaching>.

229 See Lesley Hughes et al, "Lethal consequences: climate change impacts on the Great Barrier Reef" (2018) Climate Council, online: <www.climatecouncil.org.au/resources/climate-change-great-barrier-reef/>.

230 Marine Cloud Brightening for the Great Barrier Reef, online: <www.savingthegreatbarrierreef.org/>.

231 *Environment Protection and Biodiversity Conservation Act 1999* (Cth), ss 12, 18, 23, 24B, 75 [*EPBC Act*].

232 *Convention Concerning the Protection of the World Cultural and Natural Heritage*, 16 November 1972, 1037 UNTS 151 (entered into force 17 December 1975).

specifically identified under the EPBC Act as a matter of "national environmental significance."[233] However, the degree of risk posed to the natural and social environment of the GBR by MCB proposals may be influenced by the type and scale of the activity. This will include whether the proposal is directed at research, field testing or implementation. The minister has broad executive discretion to decide the significance of the impact.[234] It is quite possible that the minister may decide that small-scale research and/or field testing of MCB has (as a standalone activity) an insignificant risk of impact upon the GBR, such that it will not trigger the wider environmental assessment and development approval provisions of the EPBC Act. This national environmental legislation might therefore fail to assess the wider ecological and social risks of SRM research that the proposal may involve.

Marine Geoengineering in EEZs

Coastal states have sovereign rights in their respective EEZs, which extend up to 200 nautical miles from their baseline.[235] These sovereign rights include the right to explore, exploit, conserve and manage natural resources in the water column, seabed and sub-soil.[236] According to Jesse Reynolds, marine CDR activities that utilize the capacity of the ocean to store CO_2 may be considered exploitation of a "natural resource."[237] If so, coastal states would have the exclusive right to engage in (or license others to engage in) marine CDR activities within their respective EEZs.[238]

Coastal states also have jurisdiction to enact laws to protect and preserve the marine environment in their EEZ, and other states are required to comply with any such domestic laws.[239] Coastal states also have jurisdiction to enact laws relating to installations, structures and MSR.[240] States wishing to conduct marine geoengineering activities in an EEZ must therefore determine whether marine geoengineering activities are permitted and subject to an approval process under the domestic laws of the relevant coastal state.[241]

Marine Geoengineering in Areas Beyond National Jurisdiction

The high seas exist beyond the territorial waters and EEZ of individual states, and are therefore open to access by all states.[242] On the high seas, all states enjoy freedom of navigation, the right to conduct scientific research, and the right to construct artificial islands and installations.[243] The domestic laws of states do not generally apply in this area, except to the extent that ships are bound by the domestic laws of their flag state.[244] However, marine geoengineering activities on the high seas are subject to duties and obligations that all state parties have under the LOSC, including to protect and preserve the marine environment, obligations relating to scientific research and the construction of research installations (Part XIII).

Other international agreements and regimes also establish rules relating to activities in the high seas. As mentioned above, various RFMOs establish rules relating to certain high-seas areas for the management of fisheries. Regional seas agreements also provide states with additional substantive and procedural obligations for the protection of the marine environment of the high seas. Key examples include the OSPAR Convention for the North-East Atlantic and Arctic region,[245] the Noumea Convention for the South Pacific,[246] the Barcelona Convention for the Mediterranean Sea[247] and the Lima Convention for the South-East Pacific.[248] These regional seas agreements contain rules potentially applicable to marine geoengineering activities, including broad rules for environmental protection, prevention of pollution from airborne sources, application of the precautionary

233 *EPBC Act*, *supra* note 231, ss 12, 24B.

234 McDonald et al, *supra* note 192 at 6.

235 *LOSC*, *supra* note 41, art 57.

236 *Ibid*, art 56(1)(a).

237 Reynolds, *supra* note 201 at 76.

238 *Ibid* at 81.

239 LOSC, *supra* note 41, art 56(b)(iii), 58(3).

240 *Ibid*, art 56(b)(i), 56(b)(ii).

241 For example, under Australian domestic law, the dumping of material in Australia's EEZ is subject to a permit process, and ocean fertilization activities are unlikely to be approved. *Environmental Protection (Sea Dumping) Act 1981* (Cth) 4, 10A. For further discussion, see Brent et al, *supra* note 223.

242 *LOSC*, *supra* note 41, art 87.

243 *Ibid*.

244 For further explanation, see Reynolds, *supra* note 201 at 80.

245 *OSPAR Convention*, *supra* note 161.

246 *Noumea Convention*, *supra* note 161.

247 *Barcelona Convention*, *supra* note 161.

248 *Convention for the Protection of the Marine Environment and Coastal Area of the South-East Pacific*, 12 November 1981 (entered into force 19 May 1986) [*Lima Convention*].

principle, control of pollution from marine dumping, EIA and the prevention of transboundary harm. State parties to regional seas agreements will therefore have additional obligations under international law, if they wish to conduct marine geoengineering activities within the relevant high-seas areas.

As stated above, due to its low iron content, the Southern Ocean has been the site of many of the OIF experiments carried out over the last two decades (see "OIF," above). Interestingly, OIF and other marine geoengineering activities in the Southern Ocean may trigger rules under the Antarctic Treaty System.[249] The 1991 Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol) establishes a framework for environmental protection of the Antarctic continent and the Southern Ocean below 60° south latitude.[250] The Madrid Protocol is aimed at comprehensive protection of the Antarctic environment and its ecosystems and so designates it as a "natural reserve, devoted to peace and science."[251] The protocol contains fundamental principles for environmental protection, including an obligation to limit activities from having adverse impacts on "the Antarctic environment and dependent and associated ecosystems."[252] More specifically, parties to the Madrid Protocol must prevent their activities from negatively affecting Antarctic climate and weather patterns, air and water quality, fauna and flora populations, and threatened species.[253] States within the Madrid Protocol also have an obligation to avoid "significant changes in the atmospheric, terrestrial (including aquatic), glacial or marine environment."[254] Marine geoengineering activities may be incompatible with these principles, especially if they will significantly alter the Antarctic marine environment.

The Madrid Protocol also establishes detailed procedures for EIA. The general obligation to conduct an EIA is set out in article 8, with more detailed rules set out in Annex 1. All activities having more than a "minor or transitory impact" must undergo at least an initial environmental assessment[255] or a comprehensive EIA.[256] The Committee for Environmental Protection established under the Madrid Protocol[257] receives and considers environmental assessments submitted by a state, and then makes recommendations. However, it is the Antarctic Treaty Consultative Parties Meeting, held yearly under the 1959 Antarctic Treaty, that ultimately decides on whether an activity may proceed and, if so, under what conditions.[258]

As discussed above, the CCAMLR is the treaty within the Antarctic Treaty system that governs marine living resources in the Southern Ocean. The CCAMLR utilizes an ecosystem-based management approach to decision making that may be relevant to future OIF activities in the Southern Ocean. In terms of location, the jurisdiction of the CCAMLR extends north (beyond the jurisdiction of the Madrid Protocol) to the Antarctic convergence,[259] which sits roughly at latitude 55° south.[260] Thus, the CCAMLR may have extended geographical relevance to future OIF activities in the Southern Ocean, in particular for large-scale field testing or deployment.

Membership in Key International Agreements

In addition to where a marine geoengineering activity will be conducted, it is also important to consider who is planning to conduct it. Rules of customary international law are generally binding on all states. However, this is not the case for international agreements. Under the doctrine of state sovereignty, states must consent to be bound by international agreements by ratifying, accepting or otherwise expressing consent.[261] The overall capacity of an international agreement to govern marine geoengineering activities therefore depends on which states have consented to be bound by it.

Rules of international law generally do not directly create obligations for non-state actors such as individuals or corporations. However, to uphold their

249 The primary treaty in this system is the *Antarctic Treaty*, 1 December 1959, 402 UNTS 72 (entered into force 23 June 1961).

250 *Protocol on Environmental Protection to the Antarctic Treaty*, 4 October 1991, [1998] ATS 6, art 3 (entered into force 14 January 1998) [*Madrid Protocol*].

251 *Ibid*, art 2.

252 *Ibid*, art 3(2)(a).

253 *Ibid*, art 2(b)(i)(ii)(iv)(v).

254 *Ibid*, art 2(b)(iii).

255 *Ibid* at Annex 1, art 2.

256 *Ibid* at Annex 1, art 3.

257 *Ibid*, art 11.

258 *Madrid Protocol*, *supra* note 250 at Annex 1, arts 3(5), 4.

259 *CCAMLR*, *supra* note 219, art 1(1).

260 Antarctic Convergence, Australian Antarctic Division, online: <www.antarctica.gov.au/about-antarctica/environment/geography/antarctic-convergence>.

261 *Vienna Convention on the Law of Treaties*, 23 May 1969, 1155 UNTS 331, art 11 (entered into force 27 January 1980).

obligations under international law, states may be required to enact relevant domestic legislation that applies to individuals and corporations under their jurisdiction and control. For example, states must enact and enforce domestic laws to uphold their obligation to prevent transboundary harm under customary international law (see "The 'No-Harm Rule'," below). States parties to the LOSC also have an obligation to adopt and enforce domestic laws to protect and preserve the marine environment.[262] Thus, international law may still be relevant to marine geoengineering activities conducted by individual researchers and corporations.

The following figures illustrate the extent to which states are party to the key international agreements that are most relevant to marine geoengineering. Figure 1 shows membership of the global framework-style agreements: the LOSC, UNFSA, CBD, UNFCCC and the Paris Agreement. Figure 2 shows the following sectoral agreements: the London Convention,[263] London Protocol,[264] Madrid Protocol, CCAMLR, OSPAR, Noumea Convention, Barcelona Convention, Lima Convention, Espoo Convention[265] and ENMOD Convention.[266] Both tables show how many states in total have ratified or assented to the agreements and which key states have ratified or assented.[267] The denomination as "key states" refers to those where geoengineering research is being or has been conducted or proposed, as well as other states that have significant scientific and technical capacity to engage in geoengineering activities in the future.

262 Examples include *LOSC*, *supra* note 41, art 210 (prevention of pollution from marine dumping); art 211 (prevention of marine pollution from vessels); art 212 (pollution from or through the atmosphere). The LOSC also provides states with corresponding duties to enforce domestic laws in arts 213–22.

263 *London Convention*, *supra* note 155.

264 *1996 Protocol to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*, 7 November 1996, [2006] ATS 11 (entered into force 24 March 2006) [*London Protocol*].

265 *Convention on Environmental Impact Assessment in a Transboundary Context*, 25 February 1991, 1989 UNTS 309 (entered into force 10 September 1997) [*Espoo Convention*].

266 *Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques*, 10 December 1976, 1108 UNTS 151 (entered into force 5 October 1978) [*ENMOD Convention*].

267 As of October 21, 2019.

Figure 1: Global Agreements

	LOSC	UNFSA	CBD	UNFCCC	Paris Agreement
Total parties	168	90	196	197	181
Australia	✓	✓	✓	✓	✓
Canada	✓	✓	✓	✓	✓
Chile	✓	✓	✓	✓	✓
China	✓	×	✓	✓	✓
France	✓	✓	✓	✓	✓
Germany	✓	✓	✓	✓	✓
India	✓	✓	✓	✓	✓
Indonesia	✓	✓	✓	✓	✓
Japan	✓	✓	✓	✓	✓
Malaysia	✓	×	✓	✓	✓
New Zealand	✓	✓	✓	✓	✓
Philippines	✓	✓	✓	✓	✓
Russian Federation	✓	✓	✓	✓	×
South Africa	✓	✓	✓	✓	✓
South Korea	✓	✓	✓	✓	✓
Switzerland	✓	×	✓	✓	✓
United Kingdom	✓	✓	✓	✓	✓
United States	×	✓	×	✓	✓*

Source: Authors.

*The Trump administration announced in 2016 that the United States would withdraw from the Paris Agreement. Under article 28 of the Paris Agreement, the earliest the United States could give official notification of its intention to withdraw was November 4, 2019; and the soonest the withdrawal notice can take effect is one year after the notification has been received by the Depositary.

Figure 2: Sectoral Agreements

	London Convention	London Protocol	Madrid Protocol	CCAMLR	OSPAR Convention	Noumea Convention	Barcelona Convention	Lima Convention	Espoo Convention	ENMOD Convention
Total parties	87	53	40	30	16	12	22	5	45	78
Australia	✓	✓	✓	✓	×	✓	×	×	×	✓
Canada	✓	✓	✓	✓	×	×	×	×	✓	✓
Chile	✓	✓	✓	✓	×	×	×	×	×	✓
China	✓	✓	✓	✓	×	×	×	×	×	✓
France	✓	✓	✓	✓	✓	✓	✓	×	✓	×
Germany	✓	✓	✓	✓	✓	×	×	×	✓	✓
India	×	×	✓	✓	×	×	×	×	×	✓
Indonesia	×	×	×	×	×	×	×	×	×	×
Japan	✓	✓	✓	×	×	×	×	×	×	✓
Malaysia	×	×	✓	×	×	×	×	×	×	×
New Zealand	✓	✓	✓	✓	×	✓	×	×	×	✓
Philippines	✓	✓	×	×	×	×	×	×	×	×
Russian Federation	✓	×	✓	✓	×	×	×	×	×	✓
South Africa	✓	✓	✓	×	×	×	×	×	×	×
South Korea	✓	✓	✓	✓	×	×	×	×	×	✓
Switzerland	✓	✓	✓	×	✓	×	×	×	✓	✓
United Kingdom	✓	✓	✓	✓	✓	×	×	×	✓	✓
United States	✓	×	✓	✓	×	✓	×	×	×	✓

Source: Authors.

Global framework-type agreements that establish rules relevant to marine geoengineering activities legally bind more states than sectoral agreements. For example, all the key states for marine geoengineering, except the United States, are parties to both the LOSC and the CBD. All key states for marine geoengineering are also parties to the UNFCCC and most are also parties to the Paris Agreement. These agreements establish rights and obligations potentially relevant to marine geoengineering, but, being part of framework agreements, these rights and obligations tend to be broad and general in nature. Thus, the global framework agreements relevant to marine geoengineering activities have very good breadth of participation, but arguably suffer from a lack of depth or specificity of obligations.

In contrast, by their very nature, the sectoral agreements relevant to marine geoengineering will have fewer state parties. However, these agreements typically provide state parties with more specific and detailed obligations. A notable example is the Espoo Convention, which establishes detailed rules for transboundary EIAs. The rules of the Espoo Convention are relevant to marine geoengineering activities likely to have transboundary impacts on the territory of other states. However, apart from Canada, only European states have ratified or assented to the Espoo Convention. This significantly restricts the Espoo Convention's capacity to govern marine geoengineering activities. Regional seas agreements similarly bind only a small number of key states. Thus, while sectoral agreements contain rules potentially relevant to marine geoengineering activities, their capacity to contribute to international governance is constrained by the relatively small number of states that have consented to be bound by them. The greater depth of obligation in sectoral agreements relevant to marine geoengineering activities is offset by their reduced breadth of participation.

This section demonstrates that scientists and policy makers cannot take a one-size-fits-all approach when considering how existing rules of international law might apply to marine geoengineering. It is important for scientists and policy makers to pay attention to the location of a proposed marine geoengineering activity and identify the state responsible for it. This is because the relevant rules of international law vary significantly depending on these two parameters. These differences may be exacerbated further, depending on the likely impacts of a marine geoengineering activity, which are considered below.

What Are the Likely Environmental Impacts of the Marine Geoengineering Activity?

The above two sections have considered how marine geoengineering activities might give rise to different obligations under international law depending on the purpose of the activity, where the activity is going to be conducted and which state is responsible for it. In addition to these considerations, further rules of international law may be relevant to marine geoengineering activities depending on the nature and severity of environmental risks and impacts they present. There are numerous rules contained in international agreements and in customary international law that may be triggered by activities that pose risks of environmental harm. Some rules are only invoked by risks that are transboundary in nature: that is, likely to harm the territory of another state or an area beyond the jurisdiction of the states, such as the high seas. Other rules exist under international law that may be triggered regardless of whether the activity presents risks that are transboundary in nature. These include rules to protect and preserve the marine environment, rules for the protection of biodiversity and rules to control specific sources of marine environmental pollution.

As illustrated in the first section of this report, marine geoengineering activities may present numerous risks of environmental harm. These risks will vary depending on the specific proposal (i.e., OIF, AOA, blue carbon enhancement, upwelling/downwelling, MCB and microbubbles) as well as the scale at which it is to be conducted. Large-scale field testing and full-scale deployment will likely present different types of risks and/or a greater severity of risk than small-scale research activities. A key issue in identifying and analyzing relevant rules of international law is whether a marine geoengineering activity presents risks of transboundary harm. Large-scale activities and activities conducted in the high seas are more likely to present such risks, and therefore trigger rules relating to transboundary harm. By contrast, small-scale activities conducted within a state's territorial waters or EEZ might pose negligible (if any) risk of transboundary harm. It is therefore important to separately consider both categories of rules. This section begins by examining rules that can only be triggered by marine geoengineering activities that present risks of transboundary impacts. It then considers rules that may be triggered regardless of whether a marine geoengineering activity risks having transboundary impacts.

International Law on Transboundary Environmental Impacts

The ENMOD Convention

The ENMOD Convention[268] contains rules potentially applicable to transboundary harm from geoengineering activities. ENMOD is essentially a

268 *ENMOD Convention*, *supra* note 266.

Cold War-era arms control agreement negotiated in response to attempts by great powers to weaponize environmental modification techniques such as cloud seeding and large-scale use of defoliants.[269]

The phrase "environmental modification techniques" is broadly defined in ENMOD as "any technique for changing — through the deliberate manipulation of natural processes — the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space."[270]

Marine geoengineering proposals such as MCB, microbubbles, OIF, AOA, artificial upwelling/downwelling and blue carbon activities could therefore fall within the scope of this definition, and potentially be governed by the rules within the ENMOD Convention.[271]

A central feature of ENMOD is a partial prohibition on environmental modification techniques. The prohibition is partial in that it only applies to techniques that have "widespread, long-lasting or severe effects" on other states.[272] The prohibition is also partial in that the environmental modification technique must be carried out for a "military or other hostile purpose."[273] That is, the prohibited environmental modification techniques are those intended to cause destruction, damage or injury to another state.[274] Peaceful environmental modification is not prohibited. In fact, the ENMOD Convention recognizes that environmental modification techniques for peaceful purposes could play an important role in protecting the global environment.[275]

In the context of marine geoengineering, the partial prohibition on environmental modification under ENMOD will not apply to activities conducted for peaceful purposes, such as seeking to ameliorate the effects of climate change or marine productivity enhancement.[276] ENMOD will therefore not likely govern states' marine geoengineering activities, so long as they are conducted for peaceful purposes. This means that ENMOD will only have the capacity to govern risks of transboundary harm to other states in very limited circumstances. It is therefore important to consider whether rules of customary international law can respond more widely to risks of transboundary harm from marine geoengineering activities.

The 'No-Harm Rule'

Marine geoengineering activities may trigger longstanding rules of customary international law if they have the potential to cause harm to the territory of other states, or to global common areas. Prominent examples include the potential for OIF to rob nutrients and decrease primary production in downstream regions, and the risk that large-scale MCB might decrease precipitation in different regions of the globe (see "MCB," above). These rules are also relevant to marine geoengineering activities conducted in high-seas areas, as they are likely to have impacts beyond the sovereign territory of an individual state. Under customary international law, all states have an obligation to prevent activities under their jurisdiction and control from causing significant harm to the territory of other states and areas beyond the individual jurisdiction and control of states, such as the high seas.[277] This rule is often referred to as the "no-harm" rule. It has been incorporated into binding international agreements, including the CBD[278] and the UNFCCC,[279] and is a fundamental principle of international environmental law.[280]

This rule can only be triggered by marine geoengineering activities that present a risk of

269 See James Rodger Fleming, "The pathological history of weather and climate modification: Three cycles of promise and hype" (2006) 37:1 Historical Studies in Physical & Biological Sciences 3.

270 *ENMOD Convention*, *supra* note 266, art II.

271 See Reynolds, *supra* note 201 at 102.

272 *ENMOD Convention*, *supra* note 266, art I(1).

273 *Ibid*.

274 *Ibid*.

275 *ENMOD Convention*, *supra* note 266 ("Realizing that the use of environmental modification techniques for peaceful purposes could improve the interrelationship of man and nature and contribute to the preservation and improvement of the environment for the benefit of present and future generations" at Preamble). See also Kerryn Brent, Jeffrey McGee & Jan McDonald, "The governance of geoengineering: an emerging challenge for international and domestic legal systems?" (2015) 24:1 J L, Information & Science 1 at 9; Reynolds, *supra* note 201 at 102.

276 See Brent, McGee & McDonald, *supra* note 275.

277 *Threat or Use of Nuclear Weapons, supra* note 156 at 29. The no-harm rule was first recognized in *Trail Smelter (United States v Canada)* (Awards) (1938 and 1941) 3 Reports of International Arbitral Awards 1905. These rules have also been reformulated in non-binding multilateral declarations: *Declaration of the United Nations Conference on the Human Environment,* UN Doc A/CONF/48/14/REV.1 (16 June 1972) Principle 21; *Declaration of the United Nations Conference on Environment and Development,* UN Doc A/CONF.151/26/Rev. 1(3–14 June 1992) Principle 2.

278 *CBD*, *supra* note 154, art 3.

279 *UNFCCC*, *supra* note 2 at Preamble.

280 See Philippe Sands & Jacqueline Peel, *Principles of International Environmental Law*, 3rd ed (Cambridge, UK: Cambridge University Press, 2012) at 191.

"significant" transboundary harm.[281] There is no set legal definition of this threshold, but it is commonly understood to mean that the harm must be more than "detectable," but need not reach the level of "serious" or "substantial."[282] Potentially relevant factors for assessing severity of harm for marine geoengineering activities may include the vulnerability of the environment likely to be affected, the physical and/or temporal scale over which impacts are likely to be felt, and the irreversibility of the impacts.[283] The no-harm rule is therefore more likely to apply to large-scale field tests and full-scale deployment activities than to small-scale research activities.

If a marine geoengineering activity poses a risk of significant transboundary harm, the state(s) responsible for the activity will have to satisfy several different obligations. First and foremost, states have a substantive obligation of "due diligence" to use all means at their disposal to prevent significant transboundary harm and harm to the global commons.[284] Exactly what this obligation should entail will depend on the marine geoengineering activity being proposed, but at a basic level states must enact and vigilantly enforce domestic laws to uphold this obligation.[285] They must also ensure that they are capable of enforcing these rules against public and private actors.[286] The Seabed Disputes Chamber of the International Tribunal for the Law of the Sea has suggested that "the precautionary approach is also an integral part of the general obligation of due diligence."[287] It would therefore be prudent for states responsible for marine geoengineering activities to adopt a precautionary approach. This means that if there is insufficient scientific evidence as to the specific scope or nature of potential negative impacts from marine geoengineering activities, states will still have an obligation to prevent significant transboundary harm, so long as there are "plausible indications of potential risks."[288] How this is to be translated in practice in unclear, but at least in theory it means that the no-harm rule may have some capacity to govern marine geoengineering activities, despite scientific uncertainty as to the precise nature or scope of their impacts.

The no-harm rule also provides states with procedural obligations that complement the substantive obligation of prevention. States have a preliminary obligation to ascertain whether a marine geoengineering activity poses a risk of significant transboundary harm or harm to the global commons.[289] States can satisfy this obligation by conducting a preliminary risk assessment of proposed marine geoengineering activities.[290] Customary international law does not, however, prescribe what the parameters of such an assessment should be, so states have wide latitude in how they interpret this obligation.[291] Furthermore, this obligation only applies to detectable risks, and is unlikely to address unforeseeable risks that might arise from marine geoengineering activities.

If the preliminary risk assessment indicates that a marine geoengineering activity may present a risk of significant transboundary harm, the state responsible for the activity must then conduct a transboundary EIA.[292] The content of the EIA must reflect the nature and magnitude of the specific marine geoengineering proposal, and take into account potentially adverse environmental impacts.[293] It must also be conducted prior to the commencement of a marine geoengineering activity.[294] In the case of marine geoengineering research, it may be prudent for states, as part of the EIA process, to consider whether alternative, less risky options may achieve the same

281 *Pulp Mills on the River Uruguay (Argentina v Uruguay)* [2010] ICJ Rep 14 at 101 [*Pulp Mills*].

282 International Law Commission, "Draft articles on Prevention of Transboundary Harm from Hazardous Activities, with commentaries" (2001) II:2 YB International Law Commission at 152.

283 Kerryn Brent, "The Certain Activities case: what implications for the no-harm rule?" (2017) 20:1 Asia Pac J Envt L 28 at 53; David Reichwein et al, "State Responsibility for Environmental Harm from Climate Engineering" (2015) 5 Climate L 142.

284 *Pulp Mills*, *supra* note 281 at 101.

285 *Ibid* at 197; *Activities in the Area* (Advisory Opinion), (2011) Case No 17 at 115 (International Tribunal for the Law of the Sea) [*Activities in the Area*].

286 *Ibid*. See also *The South China Sea Arbitration (Philippines v China)* (Awards), (2016) Case No 2013-19 at 964–66, 973–75 (Permanent Court of Arbitration). This decision was in the context of the general obligation to protect and preserve the marine environment of the high seas under the LOSC, article 192, which codifies the no-harm rule.

287 *Activities in the Area*, *supra* note 285 at 128, 131.

288 *Ibid* at 135.

289 Brent, *supra* note 283 at 53.

290 *Activities in the Area*, *supra* note 285 at 154.

291 Brent, *supra* note 283 at 53–54.

292 *Activities in the Area, supra* note 285 at 104. See also *Pulp Mills*, *supra* note 281, which indicates that the duty to conduct an EIA is not just a fundamental part of the no-harm rule, but a separate obligation under customary international law (at 204).

293 *Pulp Mills*, *supra* note 281 at 205; *Activities in the Area*, *supra* note 285 at 104.

294 *Pulp Mills*, *supra* note 281 at 205.

results, but this is not necessarily a *legal* requirement.[295] The Espoo Convention establishes more comprehensive guidelines for transboundary EIAs, including obligations to involve the general public of the affected state in the process.[296] However, as noted above, the Espoo Convention binds only a small number of states.

Under customary international law, states have wide discretion to determine what the content of a transboundary EIA should be for a specific marine geoengineering activity.[297] If the EIA affirms the risk of significant transboundary harm, the state responsible for the marine geoengineering activity then has an obligation to notify and consult with potentially affected states.[298] Customary international law does not specify which states and/or international organizations a proponent state should notify and consult with if a marine geoengineering activity poses a risk of harm to an area beyond national jurisdiction of states, such as the marine environment of the high seas. Depending on the nature of the risk, international agreements may provide further guidance on who to notify with regard to risks of harm beyond national jurisdiction. For example, the LOSC and the CBD provide further guidance on who to notify regarding risks of harm to the marine environment and biodiversity, respectively.[299] However, these provisions only relate to "imminent" risks of harm and may therefore be of limited use for harm stemming from planned activities.

The no-harm rule provides states with several obligations for marine geoengineering activities that are likely to have transboundary impacts. The main advantage of this rule is that it is legally binding and enforceable against all states. However, states have a considerable amount of discretion in how they decide to interpret their obligations under this rule in the context of marine geoengineering activities. A further limitation is that the no-harm rule can only be triggered by risks of harm above the threshold level of "significant." It is therefore unlikely to substantially contribute to marine geoengineering governance in the near term, as small-scale research activities are unlikely to meet this threshold. Other rules of international law may, however, be relevant to small-scale activities and activities unlikely to have significant transboundary impacts

International Law on Environmental Harm

There are numerous rules in international agreements that build on obligations under customary international law that do not necessarily require harm to cross territorial boundaries. These rules are instead triggered by risks of environmental harm per se and are therefore more likely to play a role in governing marine geoengineering activities in the near term. The most prominent are obligations to protect and preserve the marine environment under the LOSC; obligations directed at conserving biological diversity under the CBD; and obligations to protect the marine environment from pollution as a result of marine dumping activities under the London Convention and Protocol. As noted above, other international agreements also contain environmental protection provisions potentially relevant to marine geoengineering activities. These include the Madrid Protocol to the Antarctic Treaty, RFMOs and regional seas agreements. However, due to the limited number of parties and the geographical scope of these agreements, they are not examined further in this section. The following sections analyze rules under the LOSC, CBD and the London Protocol and Convention that may be invoked by marine geoengineering activities that pose risks of harm to the marine environment.

Marine Environmental Protection Rules under the LOSC

Marine geoengineering activities that risk harming the marine environment may give rise to obligations under Part XII of the LOSC, which establishes rules for the protection and preservation of the marine environment. Under article 192, states have a general obligation to protect and preserve the marine environment, and other articles in this part expand on this obligation. Part XII of the LOSC essentially codifies existing obligations under customary international law, with the key difference that it applies to marine geoengineering activities that are conducted in, or impact on, the territory of the state responsible for them, as well as activities that may have transboundary consequences or that are conducted in high-seas areas.[300] Unlike the no-harm

295 See Anna-Maria Hubert & David Reichwein, "An Exploration of a Code of Conduct for Responsible Scientific Research involving Geoengineering: Introduction, Draft Articles and Commentaries" (2015) IASS, Potsdam Institute for Science, Innovation and Society, University of Oxford, draft art 14; Neil Craik, "International Law and Geoengineering: Do Emerging Technologies Require Special Rules?" (2015) 5:2–4 Climate L 111 at 132–33.

296 *Espoo Convention, supra* note 265, art 2.

297 *Pulp Mills, supra* note 281 at 205.

298 *Activities in the Area, supra* note 285 at 104–68.

299 *LOSC, supra* note 41, art 198; CBD, *supra* note 154, art 14(1)(d).

300 Patricia Birnie, Alan Boyle & Catherine Redgwell, *International Law and the Environment,* 3rd ed (Oxford, UK: Oxford University Press, 2009) at 387.

rule, article 192 also does not prescribe a threshold level of harm, and is therefore of greater relevance to small-scale research and field-testing activities.

Articles 194, 195 and 196 of the LOSC provide more detailed provisions for the prevention of marine pollution, including the obligation to take all measures necessary to "prevent, reduce and control pollution of the marine environment from any source."[301] This obligation includes taking measures to minimize the release of toxic, harmful and noxious substances into the ocean.[302] States also have obligations to prevent, reduce and control pollution of the marine environment from the use of technology.[303] The capacity of these provisions to contribute to marine geoengineering governance hinges on the definition of marine pollution, that is, "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."[304]

This definition is broad and has the potential to apply to a wide range of impacts on the marine environment from marine geoengineering activities, including impacts on marine ecology.[305] According to Alan Boyle, the definition includes the ocean's uptake of atmospheric CO_2 emissions and consequential ocean acidification.[306] It could therefore be argued that marine CDR proposals qualify as a source of marine pollution, regardless of any other impacts they might have on the marine environment.

It is important to keep in mind that the definition of "marine pollution" under the LOSC is restricted to activities that *introduce* substances into the ocean that will likely have a deleterious effect.[307] OIF and AOA will likely satisfy this requirement, as they will directly introduce substances into the water column. However, it is less clear whether other marine geoengineering proposals will meet this requirement. MCB may indirectly result in the deposition of salt particles on the surface of the ocean,[308] but this deposition alone may not present a risk of "deleterious effects," especially given that the salt particles would originate from the same water column. MCB may therefore fall outside the scope of this definition.[309] As noted above in the section entitled "Microbubbles/Foam," some microbubble SRM techniques may involve placing materials, such as glass microspheres, on the surface of the ocean, but other techniques may use vortex nozzles or other means to create bubbles or foam without introducing matter. Ocean upwelling would involve the transfer of water and nutrients within the ocean. The ocean pipes are more likely to be considered "equipment" or "installations" rather than a "substance," and during scientific research phases would be governed by specific rules under articles 258–262 of the LOSC.[310] It is therefore uncertain whether obligations under articles 194, 195 and 196 (pertinent to marine pollution) will apply to all marine geoengineering proposals.[311]

The LOSC does, however, establish procedural obligations that will apply to all marine geoengineering activities, in order to protect and preserve the marine environment. All states have a duty to cooperate with other states to protect and preserve the marine environment,[312] and to notify other states and international organizations if there is an imminent danger of harm to the marine environment.[313] States must also conduct an EIA for activities that may cause "substantial pollution" or "significant and harmful changes to the marine environment,"[314] and states have ongoing monitoring obligations.[315]

301 *LOSC*, *supra* note 41, art 194(1) [emphasis added].

302 *Ibid*, art 194(3).

303 *Ibid*, art 196.

304 *Ibid*, art 1(4).

305 For further discussion, see Reynolds, *supra* note 201 at 76; Karen N Scott, "International Law in the Anthropocene: Responding to the Geoengineering Challenge" (2013) 34 Michigan J Intl L 309 at 335–36 [Scott, "International Law in the Anthropocene"]; Harald Ginzky, "Marine Geo-Engineering" in Markus Salomon & Till Markus, eds, *Handbook on Marine Environment Protection: Science, Impacts and Sustainable Management* (Amsterdam: Springer, 2018) 997 at 1000.

306 Alan Boyle, "Law of the Sea Perspectives on Climate Change" (2012) 27 Intl J Marine & Coastal L 831 at 832–33.

307 Karen N Scott, "Mind the Gap: Marine Geoengineering and the Law of the Sea" in Robert C Beckman et al, eds, *High Seas Governance: Gaps and Challenges* (Leiden: Brill Neijhoff, 2019) 33 at 45 [Scott, "Mind the Gap"].

308 Boyd & Vivian, *supra* note 44 at 23.

309 See also Scott, "Mind the Gap", *supra* note 307 at 45. Scott similarly queries whether blue carbon enhancement, such as macroalgal afforestation, could be classified as "pollution."

310 See Proelss & Hong, *supra* note 166 at 373–75.

311 Scott, "Mind the Gap", *supra* note 307 at 45.

312 *LOSC*, *supra* note 41, art 197.

313 *Ibid*, art 198.

314 *Ibid*, art 206.

315 *Ibid*, art 204.

However, as with the duty to conduct an EIA under customary international law, this obligation is very general, and the LOSC does not prescribe what the scope or content of an EIA should be for marine geoengineering activities. In particular, the LOSC does not provide any mechanisms to assess the risk of harm that might result from *not* developing marine geoengineering activities to reduce the impacts of climate change on the marine environment.[316]

The CBD

The CBD provides states with obligations to conserve biological diversity, enable sustainable use of its components, and the fair and equitable sharing of genetic resources.[317] The CBD's definition of "biological diversity" includes terrestrial, marine and other aquatic ecosystems.[318] Marine geoengineering activities likely to impact on marine biodiversity and marine ecosystems will therefore fall within the scope of this agreement. All the marine geoengineering proposals examined in this report have the potential to impact on marine biodiversity. For example, OIF could alter the base of the marine food web; OIF and ocean upwelling could exacerbate ocean acidification and thereby impact on marine ecosystems; AOA could alter primary and secondary production if non-carbon alkaline materials are added to the ocean (see "OIF," above). Even MCB, which is to be conducted in the atmosphere above the ocean's surface, could impact marine ecology and food webs by altering the ocean's carbon uptake. Rules under the CBD do not differentiate between marine geoengineering research activities, field testing or full-scale deployment. They also apply to marine geoengineering activities carried out within the territorial jurisdiction of a state, or in areas beyond state jurisdiction, such as the high seas.[319] The CBD is therefore likely to be broadly applicable to most marine geoengineering activities.

Although broadly applicable, the CBD creates few specific obligations relevant to marine geoengineering activities. The CBD reiterates the duty to prevent transboundary harm under customary international law.[320] It obliges states to identify activities "which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity."[321] States have a general duty to cooperate with one another and relevant international organizations to conserve biological diversity.[322] The CBD also establishes rules regarding EIAs.[323] States must notify other states if an activity in their jurisdiction and control poses a risk of imminent or grave danger to biodiversity in the territory of another state or in areas beyond national jurisdiction.[324]

Aside from this obligation, the rules regarding impact assessment merely require states to establish appropriate EIA procedures in their own domestic laws. However, the CBD does not stipulate what the content or parameters of an EIA should be, and provides little guidance on what would be appropriate for marine geoengineering activities.[325] Therefore, obligations established under the CBD are expressed in very general terms, and their capacity to contribute to marine geoengineering governance is limited by frequent use of qualifying language.[326]

The CBD has attempted to establish additional rules pertinent to geoengineering activities. In 2008, the CBD Conference of the Parties (COP) adopted a non-binding decision (decision IX/16) requesting states to "ensure that ocean fertilization activities do not take place until there is adequate scientific basis on which to justify such activities."[327] The exceptions to this request are "small-scale scientific research studies in coastal waters."[328] In 2010, the parties to the CBD adopted another non-binding COP decision (decision X/33), this time for geoengineering activities more generally. This decision "invites" states to ensure that "no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the

316 See also Scott, "Mind the Gap", *supra* note 307 at 44.

317 *CBD*, *supra* note 154, art 1.

318 *Ibid*, art 2.

319 *Ibid*, art 4. See also Ginzky, *supra* note 305 at 1007.

320 *CBD*, *supra* note 154, art 3.

321 *Ibid*, art 7(c).

322 *Ibid*, art 5.

323 *Ibid*, art 14.

324 *Ibid*, art 14(d).

325 See also Ginzky, *supra* note 305 at 1007.

326 Reynolds, *supra* note 201 at 96.

327 *Decisions adopted by the Conference of the Parties to the Convention on Biological Diversity at its Ninth Meeting*, UNEP Dec IX/16, s C ("Biodiversity and climate change"), UN Doc UNEP/CBD/COP/9/29 (2008) [CBD, "Biodiversity and Climate Change"], online: <www.cbd.int/doc/decisions/cop-09/full/cop-09-dec-en.pdf>. See also McGee, Brent & Burns, *supra* note 82.

328 CBD, "Biodiversity and Climate Change", *supra* note 327.

exception of small scale scientific research studies that would be conducted in a controlled setting."[329]

Decision X/33 was reaffirmed by the CBD COP in 2012[330] and again in 2016.[331] The 2016 decision noted the need for more research to better understand the impacts of geoengineering on "biodiversity and ecosystem functions and services,"[332] but this should not be interpreted as negating decision X/33, which essentially encouraged states not to engage in geoengineering activities, marine-based or otherwise, that might significantly affect biodiversity. Whether a marine geoengineering activity should be prohibited under this decision is therefore going to be a question of scale. Activities would need to be conducted at a large enough scale to affect biodiversity.[333]

These COP decisions are non-binding, which means that state parties to the CBD are not legally required to comply with them. They are nevertheless persuasive.[334] As noted above in Figure 2, the CBD has near-universal membership. According to Harald Ginzky, these decisions therefore "represent the political will of almost all States worldwide."[335] The widespread support for these decisions, however, needs to be weighed against the use of hortatory and qualified language.[336] As noted by Reynolds, the 2010 decision "merely 'invites' states to 'consider the guidance'" provided by the decision.[337] These decisions do not provide states with clear, concrete obligations concerning geoengineering activities, and therefore only enhance the capacity of the CBD to govern marine geoengineering activities by a small degree.

The London Convention and London Protocol

The London Convention and London Protocol are two separate agreements that form an international regime to govern the dumping of wastes at sea. States have general obligations to prevent, reduce and control pollution from dumping activities under the LOSC.[338] The London Convention and Protocol complement the LOSC by providing more detailed and specific obligations in this regard. The London Convention was negotiated in 1972 and aims to control sources of marine environmental pollution, especially from the dumping of waste and other matter at sea.[339] The London Protocol was negotiated in 1996 with the intention that it would succeed and replace the London Convention.[340] Its objectives are more ambitious than the Convention's, being to protect and preserve the marine environment from all sources of pollution, and eliminate pollution from dumping activities.[341] Unlike the Convention, the London Protocol explicitly adopts a precautionary approach.[342] Both agreements apply to activities conducted within a state's territorial sea, EEZ and on the high seas.[343] The London Convention and Protocol are therefore both potentially relevant to marine geoengineering research, field testing and deployment activities that introduce substances into the ocean, such as OIF and AOA.

Before continuing, it is important to note that in 2013, parties to the London Protocol adopted a resolution to amend the Protocol to specifically govern marine geoengineering.[344] This amendment has yet to enter into force and therefore is not yet legally binding on parties. For this reason, it is considered separately below. Aside from this amendment, the London Convention and Protocol apply only to marine geoengineering activities that qualify as "dumping." Under both agreements, dumping means the deliberate disposal of waste *or other matter* into the sea "from vessels, aircraft, platforms or other

329 CBD, UNEP, 10th Meeting of the Conference of the Parties to the Convention on Biological Diversity, Dec X/33 (2010) at para 8(w).

330 CBD, UNEP, 11th Meeting of the Conference of the Parties to the Convention on Biological Diversity, Dec XI/20 (2012) at para 1.

331 CBD, UNEP, 13th Meeting of the Conference of the Parties to the Convention on Biological Diversity, Dec XIII/14 (2016) at para 1.

332 *Ibid* at para 5.

333 Reynolds, *supra* note 201 at 98–99.

334 Scott, "International Law in the Anthropocene", *supra* note 305 at 333.

335 Ginzky, *supra* note 305 at 1008.

336 Scott, "International Law in the Anthropocene", *supra* note 305 at 332; Reynolds, *supra* note 201 at 99.

337 Reynolds, *supra* note 201 at 99.

338 *LOSC*, *supra* note 41, art 210.

339 *London Convention*, *supra* note 155, art II.

340 See *Strategic Plan for the London Protocol and London Convention,* IMO (2017) at 1, online: <www.imo.org/en/OurWork/Environment/LCLP/Documents/Strategic%20Plan%20leaflet_final_web.pdf>. A number of states that were party to the London Convention have since signed and ratified the London Protocol. However, there are still a number of states that have not done so. These two agreements therefore continue to operate concurrently, with parties to both agreements bound to follow the stricter provisions of the London Protocol.

341 *London Protocol*, *supra* note 264, art 2.

342 *Ibid*, art 3(1). In 1991, parties to the London Convention did, however, agree to be "guided" by a precautionary approach when implementing their obligations. See *The Application of a Precautionary Approach in Environmental Protection within the Framework of the London Dumping Convention* (1991) Res LDC.44(14).

343 *London Convention*, *supra* note 155, art III(3); *London Protocol*, *supra* note 264, art 1.7. Neither agreement applies to activities within the internal waters of a state.

344 Res LP.4(8), *supra* note 39.

man-made structures at sea."[345] It also includes the deliberate disposal at sea of "vessels, aircraft, platforms or other man-made structures."[346] If matter is placed into the ocean for a purpose other than mere disposal, it is not considered dumping so long as it is not contrary to the aims of the Convention/Protocol.[347] This definition of dumping encompasses marine geoengineering activities conducted from a wide variety of structures and installations within or near the ocean, but only if the activity involves deliberately introducing matter into the ocean.[348]

This requirement restricts the capacity of the London Convention and Protocol to govern marine geoengineering activities and presents similar challenges to the definition of pollution under the LOSC.[349] OIF and AOA will satisfy this requirement, as these proposals involve the deliberate introduction of matter (i.e., iron or calcium carbonate) into the ocean. Marine geoengineering activities that do not deliberately introduce matter into the ocean, such as MCB, ocean upwelling/downwelling and certain microbubble techniques, will likely fall outside the scope of this definition, preventing the London Convention and Protocol from governing them.[350]

Importantly, in 2008, the parties to the London Convention and Protocol decided that OIF activities are not dumping so long as they are for the purpose of legitimate scientific research.[351] However, OIF activities for a purpose other than legitimate scientific research, including activities that generate direct financial gains,[352] will be considered contrary to the aims of the London Convention and Protocol and therefore will be considered dumping. In 2010, parties adopted a non-binding assessment framework to help determine whether a proposed OIF activity is legitimate scientific research.[353] The parties have not adopted a similar framework specifically for AOA. However, AOA similarly involves placement of matter into the ocean for a purpose other than mere disposal. Large-scale field tests and full-scale deployment activities will almost undoubtedly qualify as dumping because they are likely to present risks of harm to the marine environment. Small-scale research activities may be exempt from this definition if they do not present risks to the marine environment.

If a marine geoengineering activity qualifies as dumping, it will be subjected to different rules under the London Convention and the London Protocol. The Convention adopts a "positive list" approach to regulating dumping activities in that it specifically lists substances that are prohibited from being dumped, or that require a special permit to be dumped.[354] Other substances may be dumped subject to a general permit.[355] The substances proposed for OIF and AOA are not specifically listed, and therefore may be allowed via a general permit.[356] As such, the London Convention is largely permissive of marine geoengineering activities.

On the other hand, the London Protocol takes a much more restrictive approach to dumping activities. It adopts a "reverse list" approach, which means that it prohibits the dumping of all substances, except those specifically listed.[357] This list notably does not include the substances likely to be used in OIF or AOA activities.[358] As a result, large-scale OIF and AOA activities are most likely prohibited under the London Protocol. Smaller-scale research activities may be permitted, so long as they do not risk harming the marine environment. As noted above, parties have affirmed this approach for OIF activities in several non-binding decisions. Support for smaller-scale research is also reflected in the approach taken by parties to governing ocean

345 *London Convention*, *supra* note 155, art III(1)(a); *London Protocol, supra* note 264, art 1.4.1.1.

346 *London Protocol, supra* note 264, art 1.4.1.2.

347 *Ibid*, art 1.4.2.2.

348 See also Reynolds, *supra* note 201 at 88; Scott, "Mind the Gap", *supra* note 307 at 46.

349 The definition of pollution under the LOSC is adopted by the London Protocol, *supra* note 264, art 1.10.

350 Ginzky, *supra* note 305 at 1002.

351 Regulation of Ocean Fertilization, *Report of the Thirtieth Meeting of the Contracting Parties to the London Convention and the Third Meeting of the Contracting Parties to the London Protocol*, UNEP, Res LC-LP.1, Annex 6, LC 30/16 (2008) at para 3. See also Res LP.4(8), *supra* note 39. This amendment is discussed in greater detail below.

352 Assessment Framework for Scientific Research Involving Ocean Fertilization (OFAF), *Report of the Thirty-Second Consultative Meeting and the Fifth Meeting of the Contracting Parties*, UNEP, Annex 6, LC 32/15 (2010) at para 2.2.2 [UNEP, 2010 OFAF]. See also Kerryn Brent et al, "International law poses problems for negative emissions research" (2018) 8:6 Nature Climate Change 451 [Brent et al, "International law poses problems"].

353 UNEP, 2010 OFAF, *supra* note 352.

354 *London Convention*, *supra* note 155, art IV(1)(a), Annex I. Annex II of the London Convention lists substances that require a special permit to be dumped.

355 *Ibid*, art IV(1).

356 Reynolds, *supra* note 201 at 89.

357 *London Protocol*, *supra* note 264, art 4.1.1, Annex 1.

358 For further analysis, see Scott, "International Law in the Anthropocene", *supra* note 305 at 338.

fertilization in the 2013 marine geoengineering amendment,[359] which is analyzed separately below.

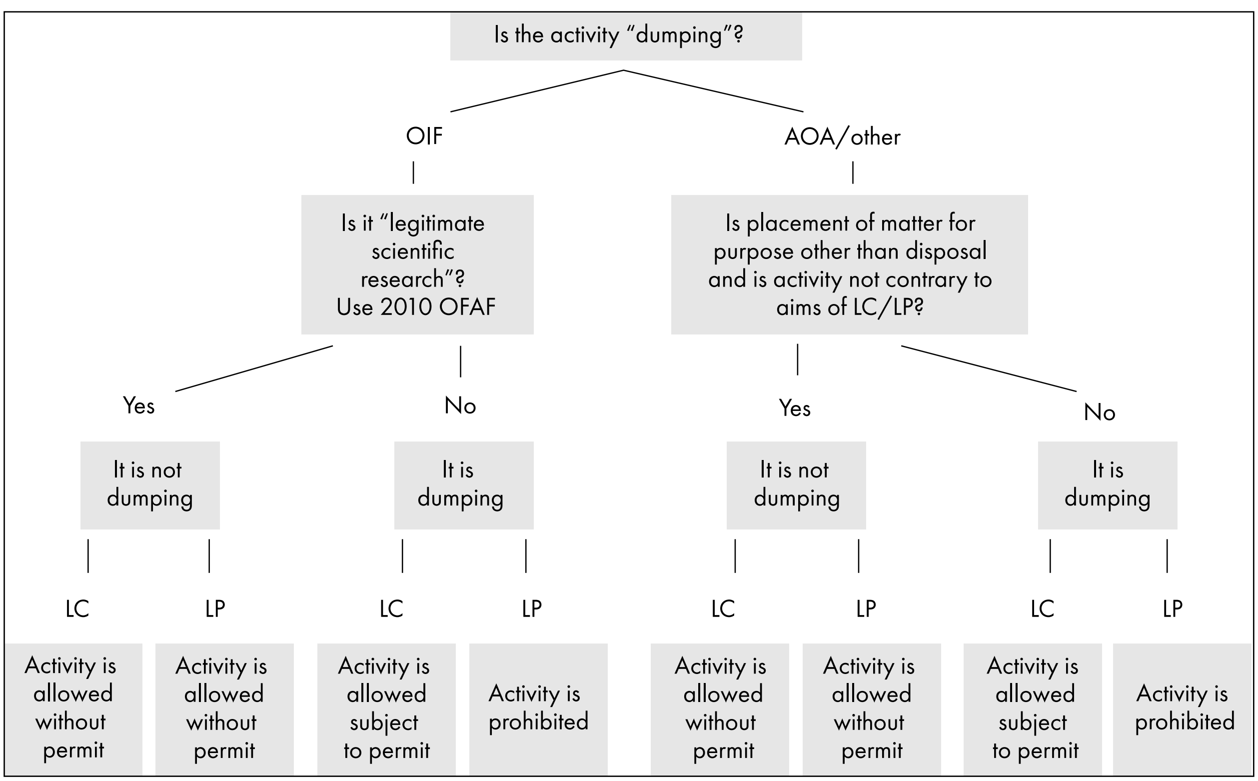
The different obligations established by the London Convention and Protocol regarding marine geoengineering activities are summarized in Figure 3, below.

States therefore have different obligations concerning OIF and AOA activities, depending on whether they are a party to the London Protocol, or only the London Convention.

States that are party to neither the London Convention nor the London Protocol, but are parties to the LOSC, will be bound by a third set of rules that merely require them to "adopt" laws and regulations, and take other "necessary" measures to prevent pollution of the marine environment from dumping.[360] Having three sets of rules in international law that potentially apply to the same activity is likely to cause confusion for researchers and policy makers alike, and detract from the capacity of these rules to govern marine geoengineering activities.

International law contains numerous rules that require states to prevent and/or minimize risks of harm to the territory of other states and the marine environment. These rules provide states with various obligations depending on whether a marine geoengineering activity is likely to have transboundary impacts, is likely to impact on biodiversity or involves the placement of matter into the ocean. The main problem with these obligations is that they are typically very general and open to broad interpretation. States have limited guidance in how they should apply and operationalize these obligations for specific marine geoengineering activities. Moreover, in the case of dumping activities, states have potentially three different sets of obligations, depending on whether they are party to the London Convention, London Protocol or just the LOSC. The differential coverage and complexity of rules applying to activities are significant challenges for building confidence in marine geoengineering activities such as OIF and AOA.

Figure 3: Application of the London Convention (LC) and London Protocol (LP) to Marine Geoengineering



359 Res LP.4(8), *supra* note 39.

360 *LOSC*, *supra* note 41, art 210.

Can a State or Other Actor Be Held Liable for Harm?

The previous section examined rules that aim to prevent or minimize risks of transboundary or environmental harm under international law. In other words, these rules aim to address harm *before* it can occur. This raises the question: how would international law respond to a marine geoengineering activity if it *resulted* in transboundary harm or harm to the marine environment? This section therefore considers the extent to which states can be held responsible and liable for harm caused by marine geoengineering activities under existing rules of international law. It examines the most prominent and widely applicable of these rules, that is, customary law rules of state responsibility and rules for responsibility, liability and enforcement under the LOSC.

State Responsibility

Under customary international law, states are responsible for "wrongful acts," and this responsibility provides states with duties in relation to them, including a duty to make reparations for material damage caused by wrongful acts.[361] Wrongful acts are acts that breach a state's international legal obligations. For example, a wrongful act in relation to marine geoengineering would occur if a state authorized its scientists to conduct marine geoengineering research within the EEZ of another state without first obtaining that state's permission; this would constitute a breach of article 246 under the LOSC. If a marine geoengineering activity results in harm to the marine environment or another state, this does not necessarily mean it is wrongful and will give rise to rules of state responsibility. The rules of state responsibility only apply if the harm results from the breach of a state's international legal obligations.[362]

Establishing that a state has breached an international legal obligation in relation to a marine geoengineering activity, and that this breach resulted in harm, will be difficult. As illustrated above, states have several obligations to prevent transboundary harm and harm to the marine environment. However, many of these obligations are expressed in general terms and are open to wide interpretation, making it difficult to pinpoint when a state has breached an obligation. For example, under article 14(1)(a) of the CBD, states have an obligation "as far as possible and appropriate" to introduce "appropriate" EIA procedures for activities that may significantly affect biodiversity. It would be extremely difficult to identify if a state has breached this obligation, as the CBD does not set precise standards for the EIA and allows states to raise the argument that an EIA was not possible or was inappropriate in the circumstances.

Establishing a breach of the duty to prevent significant transboundary harm is also likely to be difficult, as this rule provides states with little guidance as to when the risks of harm from an activity will meet the threshold level of significant to trigger obligations under this rule. Furthermore, just because harm results from a marine geoengineering activity does not mean a state has breached its obligations under international law. As noted above, the no-harm rule and other obligations to protect and preserve the marine environment under the LOSC provide states with a duty of due diligence to take steps to avoid and minimize harm, but states do not have to absolutely prevent harm from occurring.[363] It is therefore possible for a marine geoengineering activity to cause harm yet not qualify as a wrongful act.

A further challenge is proving attribution. It may be challenging to identify a causal link to attribute damage to a specific marine geoengineering activity.[364] Marine geoengineering is not the only stressor on the world's oceans. Climate change, ocean acidification, plastics and other human activities contribute to marine pollution and have harmful effects on the marine environment. It may be difficult to distinguish whether harm is the result of a marine geoengineering activity or another source. For example, microbubbles have the potential to contribute to ocean acidification, however, it may be difficult to attribute any increase in acidity to a specific microbubble activity, given that ocean acidification is also being caused by high levels of CO_2 in the atmosphere from

361 See e.g. *Corfu Channel Case (United Kingdom v Albania)*, [1949] ICJ Rep 4 at 23; *Case Concerning the Gabçikovo-Nagymaros Project (Hungary v Slovakia)*, [1997] ICJ Rep 7 at 149. The rules of state responsibility are established under customary international law, but have since been codified by the International Law Commission. See "Report of the International Law Commission on the work of its fifty-third session" (UN Doc A/56/10) YB Intl L Commission, vol 2, part 2 (New York: UN, 2001) art 31.

362 *Ibid*, art 31.

363 See also Reynolds, *supra* note 201 at 119. But see also Kerryn Brent, "Solar radiation *management geoengineering and strict liability* for ultrahazardous activities" in Neil Craik et al, eds, *Global Environmental Change and Innovation in International Law* (Cambridge, UK: Cambridge University Press, 2018) 161. Activities that qualify as "ultra-hazardous" may automatically breach customary international law if they cause harm. However, whether ultra-hazardous activities are subject to this different standard is disputed.

364 For a discussion of this challenge in the context of SRM, see David Reichwein et al, "State Responsibility for Environmental Harm from Climate Engineering" (2015) 5:2–4 Climate L 142 at 161–64.

other human activities. From a legal perspective, to qualify as a wrongful act the breach of a rule must also be attributable to the state in question. This may be challenging if non-government actors conduct geoengineering experiments or activities unbeknown to relevant state bodies/institutions.

Rules of state responsibility may provide states with a potential avenue to hold other states responsible and claim reparations (including monetary compensation) for harm caused by marine geoengineering activities. However, these rules only provide a liability regime insofar as harm is the result of breaching an existing rule of international law. As such, they can only respond to harm caused by marine geoengineering activities in a limited number of circumstances. Moreover, if an incident is disputed, it would be up to the states in question to consent to submit the dispute to the International Court of Justice or International Arbitration Tribunal for determination, or settle the dispute through other means, such as bilateral negotiations. The practical operation of state responsibility rules under customary international law therefore depends heavily on the consent of all states concerned. If consent is not present, and absent any compulsory adjudication under a treaty, international adjudication will likely be stymied.

State Responsibility and Enforcement Rules under the LOSC

The LOSC also establishes rules for responsibility, liability and enforcement of rules for the protection of the marine environment. Articles 213–222 set out rules that require states to enforce their domestic laws against states and non-state actors within their jurisdiction to minimize, prevent and control pollution of the marine environment. Article 235 reiterates the rules under customary international law, in that states are responsible for upholding their obligations to protect and preserve the marine environment. However, this rule also requires states to ensure that avenues for recourse are available within their domestic legal systems to provide compensation for harm caused by pollution.[365] It also require states to cooperate to implement their existing rules under international law and develop further rules for state responsibility and liability for marine environmental pollution. States have yet, however, to develop more detailed rules. Taken together, these rules do not significantly build on the existing rules of customary international law on state responsibility. Instead, they merely articulate these rules in the context of marine environmental protection provisions under Part XII of the LOSC.

A key difference, however, between the LOSC and customary international law, is that the LOSC provides states with *compulsory* dispute resolution mechanisms.[366] A state party to the LOSC may refer a dispute about any provision under the LOSC to an international court or tribunal for adjudication without first requiring the other state's consent. So long as the other state in the dispute is party to the LOSC, they will be taken to have given advance consent to international adjudication by the International Tribunal for the Law of the Sea, the International Court of Justice, an arbitral tribunal as set out under Annex VI of the LOSC, and/or a special arbitral tribunal set out under Annex VIII of the LOSC.[367] No matter which court or tribunal is selected, it will have the power to prescribe provisional (i.e., interim) measures to prevent serious harm to the marine environment while a dispute is being adjudicated.[368] If a marine geoengineering activity risks causing significant harm to the marine environment and is the subject of a dispute under the LOSC, it may be possible for an international court or tribunal to respond to the risks of the activity before they can materialize, or before further harm can be caused. In this sense, dispute resolution mechanisms under the LOSC may provide more effective means to respond to harm caused by marine geoengineering activities.

This section demonstrates that there are numerous existing rules of international law pertinent to marine geoengineering activities. However, these rules were negotiated for different purposes, and not specifically for the governance of marine geoengineering. The extent to which this patchwork of rules can contribute to marine geoengineering governance will vary, depending on the purpose of an activity, where it is conducted, which state is responsible for it and the types of impacts it is likely to have. Interpreting how this patchwork will apply to a specific marine geoengineering activity is complex, and existing rules may provide little concrete guidance as to how an activity ought to be conducted.

365 *LOSC*, *supra* note 41, art 235(2).

366 *Ibid* at XV(2).

367 For further explanation, see Bernard H Oxman, "Courts and Tribunals: The ICJ, ITLOS, and Arbitral Tribunals" in Rothwell et al, *supra* note 157, 394 at 397–401.

368 *LOSC*, *supra* note 41, art 290. See also Oxman, *supra* note 367 at 398.

Efforts have been made under the London Protocol to develop a specific framework for marine geoengineering governance. To date, this development represents the most specific response of the international law system to demands of marine geoengineering. The following section therefore analyzes this development under the London Protocol and considers the extent to which it can strengthen the capacity of international law to govern marine geoengineering.

Marine Geoengineering Amendments under the London Protocol

In 2013, parties to the London Protocol negotiated amendment LP.4(8) to enable this agreement to specifically govern marine geoengineering activities.[369] The LP.4(8) amendment prohibits OIF, except for activities that qualify as legitimate scientific research. It also establishes a framework to enable the London Protocol to govern other marine geoengineering activities in future. The amendment has yet to enter into force, but it is the first attempt by states to negotiate a set of legally binding rules for geoengineering governance within the international law system. It is therefore recognized as a very significant development, and a potential model for future geoengineering governance.[370] The process by which this amendment was negotiated within the ocean dumping regime has been extensively analyzed elsewhere.[371] This report considers instead the related issue of whether the LP.4(8) amendment, when it comes into force, can provide a comprehensive governance framework for marine geoengineering research, field testing and deployment.First, the rules that the LP.4(8) amendment establishes for ocean fertilization are analyzed, followed by the framework it establishes for future governance of other marine geoengineering activities.

369 Res LP.4(8), *supra* note 39.

370 Ginzky, *supra* note 305.

371 See e.g. McGee, Brent & Burns, *supra* note 82 at 67; Kemi Fuentes-George, "Consensus, Certainty, and Catastrophe: Discourse, Governance, and Ocean Iron Fertilization" (2017) 17:2 Global Environmental Politics 125; Harald Ginzky & Robyn Frost, "Marine Geo-Engineering: Legally Binding Regulation under the London Protocol" (2014) 8:2 Carbon & Climate L Rev 82.

Ocean Fertilization

The LP.4(8) amendment operates through a positive list governance approach. New article 6*bis* prohibits geoengineering activities that are specifically listed under Annex 4, which currently lists only ocean fertilization activities. Ocean fertilization is defined as "any activity undertaken by humans with the principal intention of stimulating primary productivity in the oceans," except for "conventional aquaculture, or mariculture, or the creation of artificial reefs."[372] This is a broad definition that includes ocean fertilization for the purpose of addressing climate change, as well as activities that primarily intend to enhance marine productivity, such as the Haida Gwaii experiment, which involved a salmon fishery off the coast of Canada.[373] The LP.4(8) amendment effectively prohibits all ocean fertilization activities, except those carried out for legitimate scientific research.[374] Until other marine geoengineering activities are listed under Annex 4, they are permitted, so long as they do not otherwise constitute dumping under the London Protocol,[375] or are contrary to the objectives of the Protocol to protect and preserve the marine environment.[376]

Whether a proposed ocean fertilization activity constitutes legitimate scientific research will be determined by the 2010 OFAF.[377] This framework requires the state responsible for a proposed marine geoengineering activity[378] to conduct an initial assessment of the activity's scientific attributes, including whether the activity will lead to direct economic gains[379] and whether it will be subject to scientific peer review.[380] If the activity passes the initial assessment, the state must then conduct an EIA, which includes considering the site of the proposed activity, likely environmental effects and risk management procedures. An OIF activity will only be considered legitimate scientific research if all steps of the framework have been satisfied to minimize the impact on the environment and maximize the scientific benefits from the activity, and if consent has been sought from any other countries likely to be affected by the activity.[381] LP.4(8) and the 2010 OFAF therefore provide a very cautious and restrictive framework for ocean fertilization governance.

The LP.4(8) amendment to the London Protocol is therefore a significant development in international law. It may not yet be in force, but still provides the most detailed provisions for the governance of ocean fertilization activities agreed upon to date. Moreover, it is the first attempt of the international law system to develop binding rules for any type of geoengineering proposal.

Framework for Marine Geoengineering Governance

In addition to establishing specific rules for OIF, the LP.4(8) amendment establishes a set of rules for the governance of other types of marine geoengineering technologies. The rationale for developing this framework is that other marine geoengineering technologies may be developed that will present risks of harm to the marine environment and fall within the scope of the ocean dumping regime.[382] Other marine geoengineering activities can be governed if parties agree to list them under Annex 4. This annex system provides for greater flexibility in governing future marine geoengineering proposals. Under article 22 of the London Protocol, any party can propose an addition to Annex 4 to prohibit other marine geoengineering activities and provide for any exceptions to the prohibition (i.e., carrying out legitimate scientific research).[383] Any additions to Annex 4 must be accepted by a two-thirds majority of the London Protocol parties and will enter into force after 100 days.[384] Unlike the process for amending the text of the Protocol,[385] parties do not need to formally adopt amendments to Annex 4 before it

372 Res LP.4(8), *supra* note 39 at Annex 4, 1.1.

373 For an overview of this experiment, see Abate, *supra* note 205 at 52–57.

374 Res LP.4(8), *supra* note 39 at Annex 4, 1.3.

375 *London Protocol*, *supra* note 264, art 1.4.1–3.

376 Reynolds, *supra* note 201 at 90.

377 UNEP, 2010 OFAF, *supra* note 352; Res LP.4(8), *supra* note 39, at Preamble, para 3.

378 A state will be responsible for an ocean fertilization activity if it is to be conducted within their jurisdiction, if the nutrients to be placed into the ocean were loaded from their territory or if it is the flagship state of the vessel being used in the activity. See *London Protocol*, *supra* note 264, arts 9–10.

379 UNEP, 2010 OFAF, *supra* note 352 at 2.2.2; see also Brent et al, "International law poses problems", *supra* note 352.

380 UNEP, 2010 OFAF, *supra* note 352 at 2.2.3.

381 UNEP, 2010 OFAF, *supra* note 352 at 4.1–4.2.

382 See McGee, Brent & Burns, *supra* note 81 at 71.

383 *London Protocol*, *supra* note 264, art 22(1).

384 *Ibid*, art 22(2)–(4).

385 *Ibid*, art 21(3).

can enter into force.[386] This means that new marine geoengineering technologies can be more readily governed.[387] Although the London Protocol parties have the option of adding new activities to Annex 4 at the present time, it is important to bear in mind that any additions will not actually take effect until the LP.4(8) gains enough ratifications to enter into force.[388]

If a new marine geoengineering activity is listed under Annex 4 of the LP.4(8) amendment, the London Protocol parties can decide to prohibit it outright, or create exceptions where the activity might be allowed, but subject to the issue of a permit to ensure that any risks of harm to the marine environment are minimized.[389] Annex 5 of the LP.4(8) amendment establishes a general assessment framework, which is similar to the 2010 OFAF, which sets out decision-making rules for states to apply to marine geoengineering activities when considering whether a permit should be granted. It includes criteria for determining whether a proposed marine geoengineering research activity is legitimate, rules for consulting with potentially affected states, and detailed provisions for carrying out EIAs and ongoing monitoring of activities that are authorized.[390] Moreover, London Protocol parties are only allowed to authorize marine geoengineering activities if marine environmental pollution can be minimized, so that the activity is not thereby contrary to the aims of the London Protocol.[391] The general assessment framework in Annex 5 of the LP.4(8) therefore requires states to adopt a highly precautionary approach when deciding whether to issue a permit for marine geoengineering activities, in keeping with their existing obligations under the London Protocol.[392]

The general assessment framework for marine geoengineering in Annex 5 has two broad purposes. States can use the general assessment framework to determine whether a marine geoengineering activity listed in Annex 4 should take place. The framework can also be used to develop additional assessment frameworks that are tailored to specific marine geoengineering proposals, just as the OFAF has been tailored to the features of OIF research. Either way, states must develop domestic laws or regulations to ensure any permits they issue meet the requirements of Annex 5.[393] Annex 5 thus creates a minimum standard that new specific assessment frameworks must meet.[394] This approach provides some degree of flexibility in governing future marine geoengineering activities by ensuring that parties are not stuck with the same assessment framework for all new marine geoengineering activities.[395]

The LP.4(8) amendment provides a detailed framework for marine geoengineering governance that has capacity to adapt to future scientific and technological developments. It is a highly precautionary framework,[396] significantly informed by expert scientific advice as well as the advice of environmental policy makers and international lawyers.[397] It not only provides a model for future geoengineering governance, but also provides an example of the processes through which new governance mechanisms for marine geoengineering might be developed within existing international organizations and treaty bodies.[398] However, it is important to keep in mind that LP.4(8) is an amendment to protect the marine environment *from* geoengineering technologies, not to govern research or development of geoengineering technologies per se. LP.4(8) is an amendment to an existing environmental protection treaty and its capacity to provide a comprehensive governance framework for marine geoengineering activities will therefore be limited by the aims, scope and membership of the London Protocol itself. These limitations of the London Protocol are set out further below.

386 Parties will be automatically bound by the amendment, unless they make a declaration that they are unable to accept it. *London Protocol*, *supra* note 264, art 22(4).

387 See Chiara Armeni & Catherine Redgwell, "International legal and regulatory issues of climate geoengineering governance: rethinking the approach" (2015) Climate Geoengineering Governance Working Paper Series 021 at 26–27, online: <http://geoengineering-governance-research.org/perch/resources/workingpaper21armeniredgwelltheinternationalcontext-3.pdf>.

388 *London Protocol*, *supra* note 264, art 22(6).

389 Res LP.4(8), *supra* note 39 at Annex 5, para 26, establishes conditions for a permit.

390 See also Karen Scott, "Geoengineering and the Marine Environment" in Rosemary Rayfuse, ed, *Research Handbook on International Marine Environmental Law* (Cheltenham, UK: Edward Elgar, 2015) 451 [Scott, "Geoengineering and the Marine Environment"] at 460.

391 Res LP.4(8), *supra* note 39 at Annex 5.26.7.

392 See also Scott, "Mind the Gap", *supra* note 307 at 50.

393 Res LP.4(8), *supra* note 39, art 6*bis*(2).

394 *Ibid* at Annex 5(2). See also Ginzky, *supra* note 305 at 1006.

395 See also Anna-Maria Hubert, "Marine Scientific Research" in Salomon & Markus, *supra* note 305, 933. Hubert describes the amendment overall as flexible and adaptive in its design (at 944).

396 Scott, "Geoengineering and the Marine Environment", *supra* note 390 at 460.

397 Ginzky & Frost, *supra* note 371 at 94.

398 See *ibid*, 94–96. See also Fuentes-George, *supra* note 371, who analyzes the institutional behaviour that led to this amendment.

The LP.4(8) amendment may not be able to govern all marine geoengineering activities

The LP.4(8) amendment defines "marine geoengineering" as follows: "a 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."[399]

Any activities that might be considered for listing under Annex 4, and hence be governed by the LP.4(8) amendment, must, as a threshold issue, fall within this definition. The definition is wide enough to include activities to address climate change, but also other activities for other purposes, such as enhancing marine productivity, or addressing ocean acidification.[400] However, the definition excludes activities that are not deliberately intended to manipulate natural processes but may nevertheless manipulate natural processes as a side effect. According to Ginzky, examples of such activities include the laying of submarine cables and the creation of artificial reefs.[401] Moreover, the definition applies only to activities that have the potential to have "deleterious effects," presumably on the marine environment. This is in keeping with the objectives of the London Protocol to protect and preserve the marine environment.[402] The threshold for harm is, however, very low, in that an activity need show only the potential of risk of harm, and thus, harm does not actually need to eventuate.[403]

The main provision of the LP.4(8) amendment, article 6*bis*, further limits the capacity of the amendment to govern marine geoengineering activities. Article 6*bis* prohibits "the placement of matter into the sea from vessels, aircraft, platforms or other man-made structures at sea for marine geoengineering activities listed in annex 4." This has led several international environmental law experts to conclude that the amendment can govern only those marine geoengineering activities that involve the placement of matter into the oceans.[404] According to Harald Ginzky and Robyn Frost, "activities which do not place matter into the marine environment would not come within the scope of the amendments. For example, the extraction of sea water for the purpose of cloud seeding in order to increase the albedo effect would not fall within the scope of the new regulation. Nor would a geoengineering technique be regulated that, for example, involved the introduction of energy into the ocean."[405]

The amendment has the capacity to govern AOA activities, as they would involve the placement of calcium carbonate or other matter into the ocean.[406] The amendment could also apply to blue carbon initiatives, such as enhanced kelp farming, if they involve the placement of matter (i.e., nutrients) into the ocean. The amendment will likely apply to microbubble techniques that involve placing matter into the ocean (i.e., glass microbeads). However, as noted by Karen Scott, "the creation of microbubbles through 'the expansion of air saturated water through vortex nozzles' is likely to be excluded from the remit of Article 6bis — since 'matter' is effectively not 'placed' into the sea. Furthermore, the regime does not cover schemes such as marine cloud brightening which utilize the oceans as a tool from which to effect geoengineering but which do not involve the placement of matter therein."[407]

The LP.4(8) amendment is also unlikely to apply to ocean upwelling/downwelling, as this involves the transfer of water/nutrients from one part of the ocean to another, rather than the introduction of new matter.[408] LP.4(8) therefore cannot provide a comprehensive governance framework for marine geoengineering activities, as key proposals are currently beyond its scope.[409]

The amendment does not consider the need to address climate change

A further limitation of LP.4(8) is that it does not consider the growing need to develop geoengineering technologies to ameliorate climate change. Admittedly, this amendment was negotiated prior to the signing of the Paris Agreement, and the

399 Res LP.4(8), *supra* note 39, art 1 (5bis).

400 Ginzky & Frost, *supra* note 371 at 86.

401 Ginzky, *supra* note 305 at 1005.

402 Ginzky & Frost, *supra* note 371 at 86.

403 *Ibid*; Scott, "Mind the Gap", *supra* note 307 at 48.

404 Ginzky & Frost, *supra* note 371 at 86; Scott, "Geoengineering and the Marine Environment", *supra* note 390 at 461.

405 Ginzky & Frost, *supra* note 371 at 86.

406 Scott, "Geoengineering and the Marine Environment", *supra* note 390 at 459.

407 *Ibid* at 459. See also Ginzky & Frost, *supra* note 371 at 86.

408 Ginzky, *supra* note 305.

409 See Scott, "Geoengineering and the Marine Environment", *supra* note 390 at 461.

assumptions about negative emissions contained therein. The IPCC's 5th Assessment Working Group I Report was published in 2013, but the fact that CDR geoengineering had been incorporated into most pathway scenarios to limit global temperature increase to 2ºC was not yet widely publicized.[410] At the time LP.4(8) was negotiated, geoengineering therefore did not have as prominent a role in international climate change policy as it does today.

It is possible that a closer linkage of the Paris Agreement and London Protocol may emerge in the future. However, although the London Convention parties have previously carried out some important work around CO_2 sequestration in geological structures,[411] the LP.4(8) amendment's failure to directly consider wider issues posed by climate change is conspicuous, especially as the LP.4(8) amendment draws links to other international treaties, organizations and broader environmental issues. The preamble to the LP.4(8) amendment highlights the need to conserve the marine environment and promote sustainable use of the world's oceans. It notes the COP decisions of the CBD discouraging states from engaging in geoengineering activities that might have an impact on biological diversity. The preamble also notes the IPCC's 5th Assessment report and the expert meeting it held in 2011 on geoengineering. It is therefore surprising that the amendment makes no reference to climate change as a significant environmental issue. It does not acknowledge the risks climate change poses to the marine environment, nor does it recognize the broader objectives of the UNFCCC to stabilize the levels of GHGs in the atmosphere.[412] It also does not require or encourage any cross-organizational cooperation with the UNFCCC. Annex 5 requires permits for marine geoengineering activities to, as far as practicable, minimize environmental impacts and "maximize benefits."[413] However, LP.4(8) also does not provide governance mechanisms that allow for any sort of risk-risk trade-off between the marine pollution risks posed by marine geoengineering activities and the wider risk of not engaging in such activities (i.e., climate change continuing unabated).

In short, the LP.4(8) amendment focuses only on the risks marine geoengineering activities might pose to the marine environment, with a particular emphasis on the placement of matter, without considering the bigger picture of geoengineering or climate change governance.[414] Given the extent to which CDR geoengineering is now incorporated into international climate change policy, this is a significant omission that further detracts from the amendment's capacity to comprehensively govern marine geoengineering technologies.

The amendment has slow uptake with limited potential parties

The LP.4(8) amendment needs to enter into force before it can form a part of the London Protocol and become legally binding on state parties. Under article 21, to enter into force, two-thirds of state parties to the London Protocol must accept the amendment.[415] As of October 22, 2019, 53 states are party to the London Protocol,[416] meaning that a minimum of 35 states must accept the LP.4(8) amendment for it to enter into force. On face value, this does not appear to be a prohibitively large number. However, uptake of LP.4(8) has been slow. In the five years since the LP.4(8) amendment was negotiated, only five parties have accepted it (Estonia, Finland, the Netherlands, Norway and the United Kingdom).[417] The amendment is therefore unlikely to enter into force and become an operative part of the London Protocol anytime soon.

Even if the amendment enters into force, its capacity to govern marine geoengineering activities will not extend to the activities of all states. The LP.4(8) amendment can only bind states that are party to the London Protocol.[418] As noted above, this is currently only 53 states. This number is significantly less than the

410 See e.g. Sabine Fuss et al, "Betting on negative emissions" (2014) 4 Nature Climate Change 850; Kevin Anderson & Glen Peters, "The trouble with negative emissions" (2016) 354:6309 Science 182.

411 *Resolution LP.1(1) on the Amendment to Include CO_2 Sequestration in Sub-Seabed Geological Formations in Annex 1 to the London Protocol* (adopted 2 November 2006) (LC-LP.1/Circ.5), online: <www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/London-Convention-London-Protocol-(LDC-LC-LP)/Documents/LP.1(1).pdf>; *Resolution LP.3(4) on the Amendment to Article 6 of the London Protocol* (adopted 30 October 2009).

412 *UNFCCC*, *supra* note 2, art 2.

413 Res LP.4(8), *supra* note 39 at Annex 5, para 28.

414 See also Karen N Scott, "Regulating Ocean Fertilization under International Law: The Risks" (2013) 2 Carbon Climate L Rev 108 at 116.

415 See also Scott, "Geoengineering and the Marine Environment", *supra* note 390 at 461.

416 IMO, "Status of IMO Treaties", online: <www.imo.org/en/About/Conventions/StatusOfConventions/Documents/Status%20-%202019.pdf>.

417 *Ibid* at 558.

418 See also Scott, "Geoengineering and the Marine Environment", *supra* note 390 at 461.

87 states in the London Convention,[419] and represents only one-quarter of the world's states. As illustrated in Figure 3 above, several key states (i.e., those with likely capacity to engage in marine geoengineering activities) are not bound by the London Protocol, including India, Indonesia, Malaysia, Russia and the United States. Furthermore, of those states in the London Protocol, the LP.4(8) amendment will only bind those states that accept it.[420] The only key state to accept the LP.4(8) amendment so far is the United Kingdom. As things stand, the LP.4(8) amendment is therefore unlikely to bind all key states that may engage in marine geoengineering.[421] This detracts from the amendment's capacity to govern marine geoengineering activities.

The capacity of LP.4(8) to bolster the capacity of international law to govern marine geoengineering technologies is significantly limited. The amendment has some capacity to adapt to new technologies and changes in scientific understandings. However, this feature cannot help the LP.4(8) amendment to overcome the shortcomings discussed above. For the above reasons, international policy makers will likely find it difficult to rely on this amendment alone to comprehensively govern marine geoengineering activities. It is therefore important to look beyond the London Protocol and to consider how other rules and regimes in international law might be developed to contribute to the governance of marine geoengineering activities. Current efforts to negotiate a new international agreement to protect biodiversity in areas beyond national jurisdiction (i.e., the high seas) may provide an important opportunity to do this.

419 As of October 16, 2019, 87 states are contracting parties to the London Convention. IMO, "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter", online: <www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx>.

420 *London Protocol*, *supra* note 264, art 21.

421 See also Ginzky & Frost, *supra* note 371 at 92.

Biodiversity Beyond National Jurisdiction — An Opportunity to Strengthen Marine Geoengineering Governance under International Law?

Negotiations are presently under way to establish a new agreement under the LOSC aimed at the conservation of marine biodiversity beyond national jurisdiction (BBNJ).[422] If successfully negotiated, this agreement will establish new rules and obligations for activities on the high seas. This section considers whether the negotiation of this new agreement has the potential to fill some of the gaps in the existing patchwork of international law rules governing activities in the world's oceans and enhance the capacity of the international law system to govern marine geoengineering activities.

A new agreement for BBNJ is not likely to provide a perfect solution to the challenges of marine geoengineering governance. As a new agreement, it will face many similar hurdles to the LP.4(8) amendment to the London Protocol, that is, scope, membership and entry into force. However, despite these limitations, it is essential that geoengineering scientists and governance experts actively engage with negotiation of this new agreement. This is to ensure that whatever new rules might be developed through BBNJ negotiations will enhance the capacity of international law to govern marine geoengineering activities and are not overly prohibitive of responsible research and development.

422 *Development of 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*, GA Res 69/292, UNGAOR, 69th Sess, UN Doc A/Res/69/292 (2015).

An Overview of BBNJ

The process to develop a BBNJ agreement was initiated by the United Nations General Assembly in its 2015 resolution 69/292.[423] This resolution established a preparatory committee open to all states to participate in and develop a draft of a new treaty. The preparatory committee adopted a set of recommendations to form a draft text in July 2017.[424] States participated in the first round of negotiations in September 2018, followed by a second round in March 2019 and a third in August 2019; a final round is scheduled to take place in the first half of 2020.[425] A more detailed draft text of the new agreement has been made available, which includes different governance options for negotiation.[426] Although the precise content of the new agreement remains unsettled, there is undoubtedly a considerable degree of momentum behind the development of a new BBNJ agreement.

The BBNJ agreement is intended to establish rules for various issues relating to activities in or affecting areas of the marine environment of the high seas. These issues were set out in the preparatory committee's 2017 recommendations and have since been fleshed out in more detail in the 2019 draft. The draft rules pertinent to marine geoengineering activities are as follows. First, the agreement aims to establish area-based management tools for activities in the high seas, such as rules for establishing marine protected areas.[427] Parties are yet to agree on the precise objectives and operation of such tools, but marine protected areas typically involve significant restrictions on fishing and other extractive or harmful activities in a defined area of the ocean. Such rules could have significant implications for where marine geoengineering activities can be conducted.

Second, the BBNJ agreement aims to establish detailed EIA rules for activities conducted in, or likely to affect, the marine environment of the high seas.[428] This includes specifying thresholds and criteria for when an EIA is required,[429] provisions to address cumulative impacts from activities,[430] and establishing procedures for the preparation and content of an EIA.[431] The new agreement may also list activities that automatically require an EIA.[432] The development of more specific EIA rules and procedures for activities on the high seas would fill a considerable gap in the existing patchwork of international oceans governance, described above. These rules have the potential to provide states, researchers and policy makers with more specific guidance on how EIAs ought to be conducted for marine geoengineering activities in high-seas areas.

Third, the BBNJ agreement intends to create rules for capacity building and the transfer of marine technologies.[433] The precise content of these rules has yet to be agreed, but their broad objective will be to support states to achieve "conservation and sustainable use of biological diversity in areas beyond national jurisdiction."[434] This might be achieved through capacity-building mechanisms that facilitate the transfer of marine technology.[435] Such rules could potentially assist developing states to contribute to marine geoengineering research and develop their capacity to participate in any eventual deployment activities. A new agreement for BBNJ could therefore have significant implications for marine geoengineering research, field testing and eventual deployment.

BBNJ and Geoengineering Governance

The potential for the new BBNJ agreement to contribute to geoengineering governance has already been identified by several states and non-governmental organizations (NGOs) in preparatory committee meetings. In 2016, the African Group suggested that marine geoengineering activities in high-seas areas

423 *Ibid*.

424 *Report of the Preparatory Committee established by General Assembly resolution 69/292: Development of 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*, UNGAOR, UN Doc A/AC.287/2017/PC.4/2 (2017) at part III [*Preparatory Committee Recommendations*].

425 Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdiction, online: <www.un.org/bbnj/>.

426 *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*, UNGAOR, A/CONF.232/2019/6 (17 May 2019) [*Draft BBNJ Agreement*].

427 *Preparatory Committee Recommendations*, *supra* note 424, art 4; *Draft BBNJ Agreement*, *supra* note 426, Part III.

428 *Draft BBNJ Agreement*, *supra* note 426, Part III.

429 *Ibid*, art 24.

430 *Ibid*, art 25.

431 *Ibid*, art 35.

432 *Ibid*, art 29.

433 *Ibid*, Part V.

434 *Ibid*, *Preparatory Committee Recommendations*, *supra* note 424, art 6.1.

435 *Draft BBNJ Agreement*, *supra* note 426, arts 43–46.

should be specifically listed under the new agreement as automatically requiring an EIA.[436] In 2017, the High Seas Alliance, an international environmental NGO, argued that EIAs relating to geoengineering proposals should be subject to an international decision-making process under the BBNJ.[437] These examples suggest that, although the BBNJ agreement is intended to be broad in its scope, some states and NGOs may use the negotiation process as a vehicle to develop new rules pertinent to marine geoengineering governance.

The negotiation of a new BBNJ agreement presents both an opportunity and a risk for marine geoengineering governance. The opportunity is that a new agreement has the potential to fill key gaps in the existing international law framework for marine geoengineering activities in high-seas areas.[438] In particular, an agreement on BBNJ could result in more detailed EIA rules that are easier to operationalize for marine geoengineering activities. There is, however, a risk that new rules under the BBNJ could be overly restrictive and prevent responsible research and development of marine geoengineering. That is, they might not necessarily be "fit for purpose" when it comes to the bigger picture of marine geoengineering governance.

Given that this is an agreement to protect biological diversity in the world's oceans, and not an agreement under the auspices of the UNFCCC, there is a further risk that rules may be developed that do not allow for risk-risk trade-offs to be made between the risks of marine geoengineering and the risks of climate change under business-as-usual scenarios. This risk is not unfounded, as recent attempts to govern geoengineering activities under the CBD and the London Protocol have also failed to develop mechanisms to allow for risk-risk trade-offs. It is therefore essential that experts in marine geoengineering science and governance actively engage in the development of this new agreement and be consulted in further drafting and negotiation processes.

436 "Summary of the Second Session of the Preparatory Committee on Marine Biodiversity beyond Areas of National Jurisdiction, 26 August–9 September 2016", *IISD Reporting Services Earth Negotiations Bulletin*, online: <http://enb.iisd.org/vol25/enb25118e.html>.

437 "Summary of the Fourth Session of the Preparatory Committee on Marine Biodiversity beyond Areas of National Jurisdiction, 10–21 July 2017", *IISD Reporting Services Earth Negotiations Bulletin*, online: <http://enb.iisd.org/vol25/enb25141e.html>.

438 See also Scott, "Mind the Gap", *supra* note 307 at 53–54.

Conclusion

The 2015 Paris Agreement has set a collective global goal of holding temperatures to between 1.5 and 2°C above pre-industrial levels. However, after more than two decades of UN negotiations, global GHG emissions continue to rise.[439] Current projections indicate that even with full implementation of Paris Agreement pledges, the planet is on a pathway to a temperature increase of approximately 3.2°C by 2100, well beyond what is considered climatically safe. As discussed in the first section of this report, most integrated assessment model runs that hold temperatures to within 1.5 and 2°C contemplate large-scale deployment of technologies to draw CO_2 from the atmosphere. It is therefore becoming increasingly clear that countries must expedite efforts to reduce their GHG emissions, but that CDR will almost assuredly be needed to hold climate change within safe limits. Unlike CDR, SRM does not feature in the integrated assessment models. However, it may also have an important role in preventing global temperatures from overshooting the Paris targets.

To date, sulfur aerosol injection and BECCS proposals have taken centre stage in academic and policy discussions on geoengineering. However, as described above, there are numerous marine CDR and SRM geoengineering proposals that also have the potential to address anthropogenic climate change. This report examined the following key proposals: MCB, microbubbles, OIF, artificial upwelling/downwelling, AOA and blue carbon enhancement. These proposals are diverse in terms of their purpose, scale of application, likely effectiveness, levels

439 See IPCC, *Global Warming of 1.5°C*, *supra* note 8 at 1.

of environmental and social risks, and levels of requisite international cooperation. Some marine geoengineering techniques, such as kelp farming, might be carried out purely within domestic waters, with little risk that the effects might spread beyond these areas. However, other marine geoengineering proposals, such as OIF, AOA, MCB and marine microbubbles, involve environmental and/or social risks that are likely to have impacts in transboundary or high-seas contexts. If marine geoengineering is to contribute to the suite of climate change response measures (i.e., mitigation, adaptation, technology transfer, and financing), it will need to move beyond the laboratory to small-scale field testing, large-scale field testing and eventual deployment. As the history of OIF research demonstrates, field testing and deployment of marine geoengineering techniques that have transboundary and/or high-seas impacts will place new and significant demands upon the international law system to provide governance of their potential risks and opportunities.

As illustrated by the third section of this report, the international law system is based upon state sovereignty (i.e., domestic jurisdiction over land, internal waters, territorial seas and EEZ) and operates primarily on the consent of states to various treaties and rules of customary international law. The international law system has, over time, developed various rules in response to issues affecting the oceans, such as maritime access, fisheries management and pollution, resulting in a patchwork of global framework agreements, sectoral agreements and customary international law rules. This patchwork of rules for ocean governance contains several bodies of rules that might apply in governing marine geoengineering activities. This includes rules under global agreements, such as the LOSC, sectoral agreements such as the London Convention and Protocol, CCAMLR and the Madrid Protocol to the Antarctic Treaty, regional seas agreements and RFMOs.

However, these bodies of rules were negotiated for quite different purposes, and none were specifically developed for the governance of marine geoengineering. The extent to which this patchwork of rules might contribute to marine geoengineering governance will vary, depending on the purpose of an activity, where it is conducted, which state is responsible for the activity, and the types of impacts it is likely to have. The global framework agreements generally have wide coverage (i.e., membership of most states, including key geoengineering states), but lack specificity in their obligations. The customary international law rules on transboundary harm to global commons are binding on all states, but similarly suffer from a lack of specificity. Rules of international law emanating from regional or sectoral agreements generally have greater specificity, but restricted participation and scope of geographical application. The LP.4(8) amendment to the London Protocol is a case in point. It was negotiated specifically to govern marine geoengineering activities, but it does not have nearly enough ratifications to enter into force. The fourth section of the report highlights further challenges that significantly limit the capacity of the LP.4(8) amendment to govern marine geoengineering activities. Together, the third and fourth sections illustrate that applying this patchwork of rules from the international law system to a specific marine geoengineering activity is a complex task that is not conducive to providing clear guidance to states, researchers and funding bodies.

With an eye to the future, the fifth section of this report examines negotiations that were recently launched under the LOSC to establish a new global treaty on conservation of marine biological diversity in areas beyond national jurisdiction. Under the international law system, the high-seas areas have traditionally had the least-developed rules of governance for resource use, and hence are most vulnerable to exploitation. The BBNJ negotiation process has therefore been launched to develop new rules for high-seas area-based management, EIA and capacity building/technology transfer to developing countries. While the BBNJ negotiations are at an early stage, the fifth section outlines how marine geoengineering activities have been raised by several states and NGOs as a topic for consideration. The BBNJ negotiation is both an opportunity and a risk for marine geoengineering governance. A new agreement has the potential to fill key gaps in the existing international law for marine geoengineering activities in high-seas areas; however, it is also important that any BBNJ treaty is not overly restrictive in terms of responsible research and development of marine geoengineering in high-seas areas. Recent attempts to govern geoengineering activities under the CBD and the London Protocol have failed to develop mechanisms to allow for risk-risk trade-offs. It is therefore essential that experts in marine geoengineering science and governance actively engage in the negotiation of any BBNJ agreement to ensure that its rules are appropriate for marine geoengineering governance.

Marine geoengineering poses a new set of challenges that international law must adapt and respond to.

These challenges include the environmental and social risks posed by individual proposals. The LP.4(8) amendment to the London Protocol demonstrates that existing international agreements have the capacity to respond to these challenges. However, the most significant governance challenge stems not from the proposals themselves, but from climate change pathway models and policy. Rapid and dramatic cuts in GHG emissions alone are unlikely to keep global temperatures within safe limits, and geoengineering technologies may therefore have an essential role to play in meeting the temperature targets set by the Paris Agreement. This reality must be acknowledged by any new attempts in international law to govern marine geoengineering. Moving forward, states, policy makers and international lawyers will need to develop tools that can balance the individual risks of marine geoengineering proposals against the imperative to address climate change.

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