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BALANCING THE RISKS: MANAGING TECHNOLOGY AND DANGEROUS CLIMATE CHANGE

Geoengineering Governance

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Geoengineering Governance*

Albert C. Lin

Abstract

The difficulties encountered in accomplishing the drastic greenhouse gas emissions reductions necessary to avoid dangerous anthropogenic interference with the Earth's climate system have led to incipient interest in geoengineering. Geoengineering proposals, such as the release of sulfur into the stratosphere in order to block sunlight, might serve as an emergency option should emissions reductions efforts fail, or even as a nonemergency policy alternative to emission reductions. This article examines the largely unexplored issue of geoengineering governance, namely, questions regarding who should decide whether geoengineering research or deployment should go forward, how such decisions should be made, and what mechanisms should be in place to address the risk of deployment by rogue actors. The article recommends that the international community begin to address geoengineering governance promptly through the Framework Convention on Climate Change and the bodies established by that agreement, and that geoengineering governance be treated as a series of adaptive management decisions to be reviewed periodically. Such an approach will allow the incorporation of new information into the decisionmaking process and promote the development of consensus and international norms with respect to geoengineering techniques.

KEYWORDS: geoengineering, environmental governance, climate change

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INTRODUCTION

Mounting evidence of the seriousness of the climate change problem has prompted increased domestic and international efforts to slow or counter expected changes. The main focus of such efforts has been to curb greenhouse gas (GHG) emissions, whether through cap-and-trade schemes, vehicle emission standards, land use regulation, or other tools. Recent proposals in Congress have called for an 80% reduction in U.S. GHG emissions from 2005 levels by the year 2050,[1] and according to widely accepted estimates, GHG emissions must decrease by at least 50% worldwide within the same period if the most serious climate change impacts are to be avoided.[2]

Global and national-level efforts to reduce emissions, however, have been relatively unsuccessful thus far. Internationally, the Kyoto Protocol called for reductions of up to eight percent in GHG emissions from 1990 levels by industrialized countries during the period from 2008 to 2012,[3] yet even this modest goal appears out of reach.[4] Meanwhile, atmospheric GHG concentrations have continued rising steadily, as have mean global temperatures.[5] Indeed, observations of actual changes in climate, such as the rate of glacial retreat and the extent of polar ice melt, have tended to exceed predictions regarding such changes.[6]

The difficulties associated with achieving the drastic emissions reductions needed to avoid the more serious risks of climate change have led scientists, scholars, and policymakers to begin to consider potential technological approaches to the problem.[7] One such approach, carbon capture and sequestration

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[1] *See* American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. § 703 (2009) (requiring 83% reduction in emissions from covered entities by 2050).

[2] *See, e.g.,* Malte Meinshausen et al., *Greenhouse-Gas Emission Targets for Limiting Global Warming to 2°C*, 458 NATURE 1158 (2009); *see also infra* note 52.

[3] *See* Kyoto Protocol to the United Nations Framework Convention on Climate Change, Annex B, Dec. 10, 1997, U.N. Doc. FCCC/CP/1997/L,7/ADD.1, 37 I.L.M. 32 [hereinafter "Kyoto Protocol"] (listing emissions reduction commitments by individual countries).

[4] *See infra* note 56.

[5] *See* David Biello, *How Much Is Too Much?: Estimating Greenhouse Gas Emissions*, SCI. AM., Apr. 29, 2009, *available at* http://www.scientificamerican.com/article.cfm?id=limits-on-greenhouse-gas-emissions.

[6] *See* Alan Carlin, *Why a Different Approach Is Required If Global Climate Change Is To Be Controlled Efficiently or Even at All*, 32 WM. & MARY ENVTL. L. & POL'Y REV. 685, 697 (2008).

[7] *See, e.g.,* Paul Crutzen, *Albedo Enhancement By Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?*, 77 CLIMATIC CHANGE 211, 211-12 (2006); Jay Michaelson, *Geoengineering: A Climate Change Manhattan Project*, 17 STAN. ENVTL. L.J. 73, 87-98 (1998) (urging consideration of geoengineering in light of "difficulties of cost, equity, complexity, disagreement, and institutional efficacy" associated with emissions reductions); David G. Victor et al., *The Geoengineering Option*, FOREIGN AFFAIRS, Mar./Apr. 2009, at 64; Alok Jha, *Obama Climate Adviser Open to Geoengineering to Tackle Global Warming*, GUARDIAN.CO.UK, Apr. 8,

(CCS), would capture CO_2 from power plants and compress it for sequestration in stable geological formations underground or in the oceans.[8] CCS is not a perfect solution: some of the sequestered CO_2 would likely return to the atmosphere over time;[9] additional energy would be required to separate, compress, and inject CO_2;[10] and surface releases of CO_2 at high concentrations could result in deaths or cause harm to flora and fauna.[11] Nevertheless, policymakers consider CCS to be a low-risk abatement strategy, the design of potential regulatory regimes for CCS is underway,[12] and implementation of CCS projects has begun.[13]

Another, more controversial, technological approach to climate change is geoengineering. Geoengineering refers to various techniques, such as the release of aerosols into the stratosphere or the fertilization of the oceans, that focus on mitigating the consequences of higher GHG concentrations, rather than on reducing GHG emissions or capturing emissions before they are released into the environment.[14] To date, the debate over geoengineering technologies among policymakers and scientists has tended to concern whether or not they should be deployed in response to the climate change problem. What has received less attention are the preliminary yet fundamental questions of geoengineering governance. These questions include: who should decide whether geoengineering research or deployment should go forward, how such decisions should be made,

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2009, *available at* http://www.guardian.co.uk/environment/2009/apr/08/geo-engineering-john-holdren.

[8] *See* David W. Keith, *Geoengineering*, *in* ENCYCLOPEDIA OF GLOBAL CHANGE: ENVIRONMENTAL CHANGE AND HUMAN SOCIETY 495, 497 (Andrew S. Goudie, ed., 2002); *see generally* NATIONAL ACADEMY OF ENGINEERING, NATIONAL RESEARCH COUNCIL, THE CARBON DIOXIDE DILEMMA: PROMISING TECHNOLOGIES AND POLICIES (2003).

[9] *See* Keith, *supra* note 8, at 498 (estimating that 20% of carbon sequestered would return to the atmosphere over a three-hundred year time period); *but cf.* IPCC SPECIAL REPORT ON CARBON DIOXIDE CAPTURE AND STORAGE 14 (Bert Metz et al. eds., 2005) (estimating that for well-selected sites, over 99% of injected CO_2 is very likely to remain underground for over one hundred years).

[10] *See* Keith, *supra* note 8, at 498.

[11] *See* Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long-Term Storage of Carbon Dioxide*, 58 EMORY L.J. 103, 118-19 (2008).

[12] *See, e.g., id.* at 158-78 (proposing federal governance model for managing liability for CCS projects).

[13] *See id.* at 117; Keith, *supra* note 8, at 497.

[14] *See* David W. Keith, *Geoengineering*, 409 NATURE 420 (2001) [hereinafter "Keith, *Geoengineering*"]. Geoengineering proposals can be distinguished from CCS techniques in that the latter seek to control CO_2 emission to the active biosphere, whereas geoengineering seeks to control atmospheric CO_2 post-emission. *See* David W. Keith, *Geoengineering the Climate: History and Prospect*, 25 ANN. REV. ENERGY ENV'T 245, 248-49 (2000) [hereinafter "Keith, *History*"]. Nonetheless, the line between geoengineering and less controversial methods for addressing climate change is not well-established; one commentator suggests that "[g]eoengineering has become a label for technologically overreaching proposals that are omitted from serious consideration in climate assessments." Keith, *Geoengineering*, *supra*, at 420.

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and what mechanisms should be in place to address the risk of deployment by rogue actors.

This Article explores the problem of geoengineering governance and makes recommendations for international action on the issue. Part I of the Article provides a brief overview of geoengineering technologies that could be deployed in response to climate change. Part II considers the current policy focus on reducing emissions (broadly understood to include CCS), and compares the relative merits of that approach with geoengineering. Although geoengineering is an approach that involves serious risks and great uncertainty, it warrants international attention because of the difficulties of coordinating a successful emission reduction strategy, as well as the growing potential for geoengineering to be implemented unilaterally. Part III recommends that the international community begin to address geoengineering governance promptly through the Framework Convention on Climate Change (FCCC) and the bodies established by that agreement, and that geoengineering governance be treated as a series of adaptive management decisions to be reviewed periodically. Such an approach will allow the incorporation of new information into the decisionmaking process and promote the development of consensus and international norms with respect to the use (or nonuse) of geoengineering techniques.

I. The Basics of Geoengineering

In contrast to relatively uncontroversial technologies that reduce GHG emissions through increased energy efficiency or the use of renewable energy, geoengineering technologies involve projects that are intended specifically to mitigate the effects of GHG emissions once they are released. This intent, combined with the grand scale of these projects, are defining features of geoengineering proposals, scientist David Keith has suggested.[15] This Part provides a brief overview of leading geoengineering proposals, including potential risks associated with each.

A. Albedo Modification

Some geoengineering proposals seek to reduce the amount of energy the Earth absorbs by modifying the Earth's albedo (i.e., reflectivity). Examples of such proposals include (1) the release of particles into the stratosphere, and (2) the use of space-based deflectors. Each of these technologies presents its own engineering challenges and environmental risks.

[15] Keith, *Geoengineering*, *supra* note 14, at 420.

Scientists have observed that the addition of sulfur to the stratosphere, either through natural activity such as volcanic eruptions or through human activity that generates SO_2 and other pollutants, produces a cooling effect by causing more sunlight to be reflected into space.[16] Chemical and micro-physical processes convert the SO_2 into light-reflecting particles (or aerosols) that remain in the stratosphere for one to two years, counteracting the warming effect associated with higher GHG concentrations.[17] While the deliberate release of SO_2 might stabilize global average temperatures to some degree, it would not necessarily prevent significant local climate changes from taking place.[18] Nevertheless, the use of stratospheric aerosols is probably the most seriously discussed geoengineering proposal because of its relative technical and economic feasibility.[19]

There could be substantial environmental and safety impacts associated with implementing such a scheme, however. One serious concern involves ozone depletion: scientists have found that the release of particles by large volcanic eruptions damages the stratospheric ozone layer that provides protection from the sun's ultraviolet rays.[20] The addition of SO_2 particles to the stratosphere is likely to have a similar effect.[21] Another shortcoming of the release of aerosols is that there would be little or no effect on atmospheric GHG concentrations. This means that such a scheme would only provide temporary relief from any warming effect; the release of aerosols would have to continue for several hundred years to allow the oceans to absorb gradually the CO_2 currently being released by humans.[22] This form of geoengineering, in other words, would only buy time to

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[16] *See* Crutzen, *supra* note 7, at 211-12.
[17] *See id.* at 212.
[18] *See* Oliver Morton, *Is This What It Takes to Save the World?*, 447 NATURE 132, 134 (2007) (reporting modeling results finding temperature and precipitation shifts, notwithstanding fact that warming from emissions and cooling from aerosols largely cancelled each other out); Stephen H. Schneider, *Geoengineering: Could – or Should – We Do It?*, 33 CLIMATIC CHANGE 291, 297-98 (1996) (explaining that because greenhouse forcing is itself not evenly distributed, the relatively uniform distribution of stratospheric aerosols would not precisely cancel out warming effects in all regions).
[19] *See* Crutzen, *supra* note 7, at 212-13 (estimating annual cost of $25-50 billion, approximately 2.5-5% of annual global military expenditures).
[20] *See* Simone Tilmes et al., *The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes*, 320 SCIENCE 1201 (2008); Crutzen, *supra* note 7, at 215-16.
[21] *See* Tilmes et al., *supra* note 20, at 1203-04; Crutzen, *supra* note 7, at 215-16. Like volcanic eruptions, the release of stratospheric aerosols would also whiten the sky. *See* Keith, *supra* note 8, at 496.
[22] *See* Lennart Bengtsson, *Geo-Engineering to Confine Climate Change: Is It At All Feasible?*, 77 CLIMATIC CHANGE 229, 231 (2006) (explaining that dissolution of CO_2 into oceans sequesters 70-80% of CO_2 over several hundred years and that cessation of a sulfur release project would quickly lead to renewed warming).

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reduce GHG emissions or to find other means of countering climate change.[23] Meanwhile, cessation of aerosol release after such a program had been in place for some time could cause far more rapid climate change than would have occurred in the absence of any initial geoengineering efforts.[24] Furthermore, the release of aerosols would do nothing to counter the problem of ocean acidification. The acidity of the ocean is directly correlated to GHG levels, and increased acidity could lead to the loss of many of the Earth's coral reefs, which serve as important marine habitat.[25] Elevated GHG levels would affect terrestrial ecosystems as well, as plant species that flourish under high concentrations of atmospheric CO_2 gain a competitive advantage over other species, leading to changes in habitat and biodiversity.[26] In addition to these concerns, there may be other adverse effects that we cannot currently anticipate.[27]

An alternative albedo modification approach that could sidestep some of these problems would deploy deflectors in outer space. Under one such proposal, a fleet of almost-transparent discs the size of dustbin lids would be launched into orbits that would keep them between the Earth and the sun, reducing sunlight by nearly two percent,[28] an amount sufficient to counter the warming effect of a doubling of atmospheric GHG concentrations.[29] The use of space-based deflectors would avoid the aforementioned risks (such as ozone depletion) associated with tinkering with the Earth's atmosphere via aerosol releases.[30] The deflectors, however, would have to be replaced at the end of their useful lives, lest rapid climate change occur, and would generate debris that could interfere with

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[23] *See* Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. & RES. ECON. 45, 47 (2008) ("Geoengineering is a stopgap measure, a 'quick fix,' a 'Band-Aid.'").
[24] *See* H. Damon Matthews & Ken Caldeira, *Transient Climate-Carbon Simulations of Planetary Geoengineering*, 104 PROC. NAT'L ACAD. SCI. 9949, 9951-52 (2007) (describing how temperatures, previously suppressed by aerosols, would quickly rebound to the levels they would have reached had no geoengineering been implemented).
[25] For further discussion regarding the problem of ocean acidification, see Ken Caldeira & Michael E. Wickett, *Ocean Model Predictions of Chemistry Changes From Carbon Dioxide Emissions to the Atmosphere and Ocean*, 110 J. GEOPHYSICAL RES. C09S04, doi:10.1029/2004JC002671 (2005); Elizabeth Kolbert, *The Darkening Sea*, NEW YORKER, Nov. 20, 2006, at 66, 69-74. Higher GHG concentrations in the atmosphere may also affect terrestrial ecosystems by changing the competitive balances between different plant species. *See* Bengtsson, *supra* note 22, at 231.
[26] *See* Govindswamy Bala, *Problems With Geoengineering Schemes to Combat Climate Change*, 96 CURRENT SCI. 41, 45-46 (2009).
[27] *See* Morton, *supra* note 18, at 135 (remarking that the stratosphere "is tied to the troposphere below in complex ways that greenhouse warming is already changing").
[28] *See id.* at 135-36 (describing proposal by Roger Angel); Roger Angel, *Feasibility of Cooling the Earth With a Cloud of Small Spacecraft Near the Inner Lagrange Point*, 103 PROC. NAT'L ACAD. SCI. 17,184 (2006).
[29] *See* Angel, *supra* note 28, at 17,184.
[30] *See* Keith, *supra* note 8, at 497.

Earth-orbiting spacecraft.[31] And compared to the use of stratospheric aerosols, this approach would be far more costly and would face immensely more complicated barriers to implementation.[32]

Finally, albedo modification proposals in general would reduce the amount of sunlight reaching the Earth, and thus likely would have other effects that are not yet fully understood. Sunlight plays a key role in global hydrology, for instance, and reduced solar forcing could disrupt the Asian and African monsoons that are vital to food supplies in those regions of the world.[33]

B. Enhancing Oceanic Sinks

Another set of geoengineering proposals involves the addition of micronutrients to the oceans in order to increase the uptake of carbon by phytoplankton. The theory underlying ocean fertilization proposals is that unavailability of various micronutrients limits biological productivity in certain oceanic regions, such that adding a relatively small amount of the limiting micronutrients will drastically increase phytoplankton populations.[34] While some of the carbon absorbed by phytoplankton will return to the surface ocean through natural decay processes, the sinking of dead phytoplankton will remove the rest of the carbon to the deep ocean and prevent it from reentering the atmosphere.[35] The most common ocean fertilization proposal involves iron. Ice-core data reveals that relatively abundant iron supplies from atmospheric dust during glacial periods coincided with lower atmospheric CO_2 concentrations, leading some scientists to conclude that iron is the most important limiting micronutrient.[36] Although an iron fertilization scheme would require significant quantities of iron, global supplies of this micronutrient are sufficient to support the execution of the proposal at a relatively moderate cost.[37]

Experimental studies, however, have yielded unimpressive results regarding the amount of CO_2 that an iron fertilization scheme would ultimately remove from

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[31] *See* Angel, *supra* note 28, at 17,188-89.

[32] Approximately 16 trillion discs would need to be manufactured and placed in orbit, and the cost of the proposal has been estimated at $5 trillion. *See* Morton, *supra* note 18, at 136.

[33] *See* Alan Robock, *Whither Geoengineering?*, 320 SCIENCE 1166 (2008); Bala, *supra* note 26, at 45.

[34] *See* James Edward Peterson, *Can Algae Save Civilization? A Look at Technology, Law, and Policy Regarding Iron Fertilization of the Ocean to Counteract the Greenhouse Effect*, 6 COLO. J. INT'L ENVTL. L. & POL'Y 61, 69-70 (1995) (describing the "iron hypothesis" that iron may be the limiting micronutrient).

[35] *See id.* at 68-69 (describing "biological carbon pump").

[36] *See id.* at 70.

[37] *See id.* at 76 (reporting estimated costs for iron fertilization range from $0.5 billion to $3 billion per billion tons of atmospheric carbon transferred to the deep ocean, less than the cost of reducing equivalent emissions or removing equivalent emissions from power plant smokestacks).

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the atmosphere.[38] Uncertainties surround the rate of vertical mixing in the oceans (which would be necessary to remove carbon from the atmosphere), the form of iron that would optimize phytoplankton growth, and the presence of other nutrients necessary for iron fertilization to be effective.[39] Moreover, ocean fertilization schemes risk significant alteration of marine ecosystems. Phytoplankton form the foundation of marine food webs, and changes in their populations could lead to unpredictable changes in ecosystems, as well as heightened production of methane and other GHGs.[40] Perhaps ameliorating these concerns somewhat, the iron fertilization process can be halted fairly readily if serious negative consequences arise.[41]

II. ADDRESSING CLIMATE CHANGE: REDUCING EMISSIONS VS. GEOENGINEERING

Up to the present, climate change discussions have presumed control of GHG levels to be the primary, if not the only, mode of response. The FCCC, for example, calls for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system,"[42] a goal that envisions reducing GHG emissions from sources and sequestering GHGs in sinks. The Kyoto Protocol requires modest emissions reductions by certain industrialized countries, with the expectation that these would be the first in a series of increasingly stringent reductions.[43] And domestic initiatives in the United States have focused on emissions reductions

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[38] *See* O. Aumont & L. Bopp, *Globalizing Results From Ocean In Situ Iron Fertilization Studies*, 20 GLOBAL BIOGEOCHEMICAL CYCLES GB 2017 (2006) (reporting results from global ocean model based on iron fertilization experiments and concluding that factors other than iron also influence effectiveness of sequestration, that fertilization outside the Southern Ocean is relatively ineffective, and that fertilization, if carried out, must be performed continuously in order to prevent carbon from returning to atmosphere); Philip W. Boyd et al., *Mesoscale Iron Enrichment Experiments 1993-2005: Synthesis and Future Directions*, 315 SCIENCE 612 (2007) (summarizing results of various small-scale iron fertilization experiments); Ken O. Buesseler & Philip W. Boyd, *Will Ocean Fertilization Work?*, 300 SCIENCE 67, 68 (2003) ("ocean iron fertilization may not be a cheap and attractive option if impacts on carbon export and sequestration are as low as observed to date"); *see also* Peterson, *supra* note 34, at 74.

[39] *See* Peterson, *supra* note 34, at 76-77; Stephane Blain et al., *Effect of Natural Iron Fertilization on Carbon Sequestration in the Southern Ocean*, 446 NATURE 1070, 1073 (2007) (noting "complex interplay between the iron and carbon cycles" and cautioning against assumption that iron fertilization will work based on observed natural phytoplankton bloom).

[40] *See* Peterson, *supra* note 34, at 77-78.

[41] *See id.* at 78 ("Iron fertilization has the advantage of being limited in duration.").

[42] United Nations Framework Convention on Climate Change, art. 2, May 9, 1992, S. TREATY DOC. NO. 102-38, 1771 U.N.T.S. 164, *available at* http://untreaty.un.org/English/notpubl/unfccc_eng.pdf [hereinafter "Framework Convention"].

[43] Kyoto Protocol, *supra* note 3, art. 3 ¶ 1.

through cap-and-trade schemes as well as measures to increase energy efficiency and the use of renewable energy.[44] This Part discusses the barriers to a successful emissions reduction strategy and explores the case for geoengineering. While emissions reductions should remain the principal response to climate change, geoengineering merits further attention from the international community.

A. Obstacles to Emissions Reduction Strategies

Despite the attention devoted to emissions reduction strategies, global GHG emissions, atmospheric GHG concentrations, and average global temperatures have continued to rise.[45] Although the parties to the FCCC are scheduled to negotiate a successor treaty to the Kyoto Protocol by the end of 2009,[46] the prospects for achieving emissions reductions sufficient to avoid dangerous anthropogenic interference with the Earth's climate system appear increasingly tenuous. The immensity of the task, as well as the difficulty of achieving the collective effort required, warrant a closer look at geoengineering as either an emergency option or an alternative approach.[47]

There are several reasons why exclusive reliance on GHG emissions reduction strategies may not be prudent. First, the scale of reductions required is tremendous. One frequently mentioned goal is to avoid a global average temperature rise of more than 2°C; it is believed that an increase beyond that carries substantially greater risks of dangerous consequences.[48] Scientists estimate that to have a reasonable chance of achieving this goal, we must stabilize the concentration of CO_2 in the atmosphere at or below 450 parts per million

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[44] *See, e.g.,* American Clean Energy and Security Act of 2009, *supra* note 1; CALIFORNIA AIR RESOURCES BOARD, CLIMATE CHANGE SCOPING PLAN: A FRAMEWORK FOR CHANGE 27-71 (2008), *available at* http://www.arb.ca.gov/cc/scopingplan/document/ adopted_scoping_plan.pdf (identifying emissions reductions measures, including emission cap and trade program, to meet requirements of Global Warming Solutions Act of 2006, Cal. A.B. 32).

[45] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, FOURTH ASSESSMENT REPORT, CLIMATE CHANGE 2007, WORKING GROUP I REPORT: THE PHYSICAL SCIENCE BASIS, SUMMARY FOR POLICYMAKERS 2, 5-6 (2007).

[46] *See* Guy Chazan, *Large Firms Agree Carbon Emissions Must Be Cut*, WALL ST. J., May 28, 2009, at A18.

[47] *Cf.* Victor et al., *supra* note 7, at 65-66 (contending that slow progress in cutting emissions and looming danger of sudden adverse consequences require policymakers to consider geoengineering as emergency strategy).

[48] *See, e.g.,* Council of the European Union, Climate Change: Medium and Longer-Term Emission Reduction Strategies, Including Targets 2 (2005), *available at* http://register.consilium.eu.int/pdf/en/05/st07/st07242.en05.pdf; Alan Carlin, *Global Climate Change Control: Is There a Better Strategy than Reducing Greenhouse Gas Emissions?*, 155 U. PA. L. REV. 1401, 1430 (noting that most major proposals to limit GHG emissions specify a goal of a maximum 2°C rise).

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(ppm).[49] It should be noted that these figures, which are based on findings compiled by the Intergovernmental Panel on Climate Change (IPCC), may not be stringent enough to avoid dangerous consequences of climate change.[50] The consensus-based processes followed by the IPCC in generating reports and projections have consistently produced underestimates of the speed and extent of climate change thus far.[51]

Second, assuming the IPCC's figures to be correct, the drastic emissions reductions needed to avoid a 2°C temperature rise would require an unprecedented degree of international cooperation. According to typical estimates, global emissions would have to be reduced 40-50% below 2000 levels by 2050, while emissions from industrialized nations would have to be reduced by 80% or more in the same period to allow for economic development in poor countries.[52] A portion of the necessary reductions can be achieved through relatively inexpensive or even cost-saving measures, such as improvements in energy efficiency.[53] The expected costs of accomplishing reductions of the scale needed, however, are substantial, particularly in the wake of rising fossil fuel

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[49] *See* Brian C. O'Neill & Michael Oppenheimer, *Dangerous Climate Change Impacts and the Kyoto Protocol*, 296 SCIENCE 1971 (2002); Carlin, *supra* note 48, at 1430 (noting that Congressional proposals specify goals of average temperature rises of no more than 2°C and stabilization of CO_2 levels at 450 ppm). Figures referring to CO_2 concentrations in the atmosphere are shorthand for CO_2 equivalents, which are the standardized measure for expressing emissions of a GHG as a function of its global warming potential compared with CO_2.

[50] Some scientists have suggested that an even more stringent goal is necessary. *See, e.g.,* James Hansen et al., *Target Atmospheric CO_2: Where Should Humanity Aim?*, 2 OPEN ATMOSPHERIC SCI. J. 217, 226 (2008) (proposing a goal of 350 ppm – lower than the current atmospheric concentration of 385 ppm – as necessary to prevent melting of the Greenland and Antarctic ice sheets). *See also* Carlin, *supra* note 6, at 697-98 (discussing uncertainties involved in climate modeling and questioning whether it is possible to determine justifiable goals as to atmospheric GHG levels).

[51] *See* Carlin, *supra* note 6, at 697; Julienne Stroeve et al., *Arctic Sea Ice Decline: Faster than Forecast*, GEOPHYSICAL RES. LETTERS, vol. 34, L09501, doi:10.1029/2007GL029703.

[52] *See* UNION OF CONCERNED SCIENTISTS, HOW TO AVOID DANGEROUS CLIMATE CHANGE: A TARGET FOR U.S. EMISSIONS REDUCTIONS 1 (2007), *available at* http://www.ucsusa.org/global_warming/solutions/big_picture_solutions/a-target-for-us-emissions.html; *see also* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, FOURTH ASSESSMENT REPORT, CLIMATE CHANGE 2007: SYNTHESIS REPORT, SUMMARY FOR POLICYMAKERS 20 (2007), available at http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf (Table SPM.6 listing GHG stabilization scenarios, required emissions reductions, and projected mean global temperature changes); Biello, *supra* note 5 (reporting on two new papers that estimate remaining "budget" of CO_2 that can be emitted).

[53] *See* NICHOLAS STERN, THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW 243, 264 (2006); Michael P. Vandenbergh et al., *Individual Carbon Emissions: The Low-Hanging Fruit*, 55 UCLA L. REV. 1701 (2008).

consumption in China and other developing countries.[54] In the end, significant emissions reductions will require international cooperation, but our experience to date gives little reason simply to assume that the necessary reductions will be achieved.

The 1992 Framework Convention imposed no binding emissions limits on signatories, and ensuing efforts have failed to halt the increase in global GHG emissions. Although the Kyoto Protocol did establish binding emission caps on a number of industrialized countries beginning in 2008, it established no such limits on the United States, which never ratified the Protocol, or on China, India, or any other developing countries.[55] Moreover, to the extent that Kyoto did establish binding caps on some nations, it is now becoming apparent that many of these countries will be unable to meet their caps.[56] Compounding the difficulty, the modest reductions required by Kyoto – in the range of 5-7% for industrialized countries – are now widely recognized as being too anemic to have much of an effect on climate change.[57]

Global GHG emissions reduction presents an especially difficult collective action problem because it requires an aggregate effort by a large number of actors to address a problem with a long time horizon, and the temptation for individual countries to free-ride off of the efforts of others is strong.[58] While a few nations

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[54] *See* STERN, *supra* note 53, at 191 (estimating that costs of reducing GHG emissions to avoid the worst impacts of climate change can be limited to around 1% of global GDP each year); *cf.* Carlin, *supra* note 6, at 721-24 (arguing that contemplated reductions are unrealistic, given behavioral changes and energy efficiency improvements that would be necessary). The cap-and-trade portion of the Waxman-Markey legislation currently under consideration in Congress – which takes only a small step towards achieving the necessary emissions reductions – is predicted by the Congressional Budget Office to cost each household an average of $175 per year. *See* Congressional Budget Office, The Estimated Costs to Households from the Cap-and-Trade Provisions of H.R. 2454, June 19, 2009, *available at* http://www.cbo.gov/ftpdocs/103xx/doc10327/06-19-CapAndTradeCosts.pdf. The EPA predicts that as a whole, the legislation actually will save each household $80 to $111 each year. *See* EPA Analysis of the American Clean Energy and Security Act of 2009 H.R. 2454 in the 111th Congress, June 23, 2009, *available at* http://www.epa.gov/climatechange/economics/pdfs/HR2454_Analysis.pdf.

[55] *See* Kyoto Protocol, *supra* note 3, Annex B.

[56] *See, e.g.,* SCOTT BARRETT, WHY COOPERATE?: THE INCENTIVE TO SUPPLY GLOBAL PUBLIC GOODS 92-93 (2007) (noting concession by Canada that its emissions in 2010 will be at least 45% above its Kyoto target); Carlin, *supra* note 48, at 1431 (reporting projections that many EU signatories will not meet Kyoto targets); *see also* Carlin, *supra* note 6, at 720-21 (arguing it is politically unrealistic to expect politicians to force constituents to adopt the measures necessary to reduce emissions).

[57] *See* Carlin, *supra* note 48, at 1432; Tony Grayling*, Beyond Kyoto*, 10 NEW ECON. 125, 125 (2003) ("Kyoto is little more than a very small first step towards addressing climate change."); O'Neill & Oppenheimer, *supra* note 49, at 1971 (noting that "the emissions limits required by the Kyoto Protocol would reduce warming only marginally").

[58] *See* BARRETT, *supra* note 56, at 6.

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may be willing to reduce emissions unilaterally, a sustained aggregate effort, as a practical matter, requires a multilateral treaty with binding commitments by all significant sources of emissions.[59] Setting aside the difficulties involved in the actual implementation of treaty commitments,[60] merely reaching a consensus on the key issues surrounding climate change and an emissions reduction strategy presents a herculean task. Those issues include contentious questions such as what constitutes "dangerous anthropogenic interference with the climate system"; what CO_2 concentration levels we should aim for, and with what level of uncertainty;[61] how to determine emissions caps for each nation; and what tools nations may use to meet their treaty obligations.[62]

B. The Potential Allure of Geoengineering

In light of the difficulties just described, a growing number of commentators have suggested that it will be impossible – and unwise – to rely solely on emissions reductions to combat climate change.[63] Geoengineering offers options that sidestep some of the more imposing barriers to multilateral emission reductions. For purposes of discussion, I focus on the proposal to release aerosols into the stratosphere, since it is generally considered "the easiest and most cost-effective [geoengineering] option."[64]

Perhaps the most attractive characteristic of the scheme to release aerosols is its low cost, dramatically less than the cost of emissions reductions necessary to

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[59] All of this assumes agreement that climate change presents a problem in the first instance. At least in the short term, some countries, such as Russia, might benefit from higher agricultural yields, lower winter mortality, and reduced heating requirements. *See* STERN, *supra* note 53, at 138.

[60] *See* Carlin, *supra* note 6, at 725-26 (contending that full implementation of emissions reduction commitments by individual nations is not likely, given political opposition, weak political capacity, and role of individual and corporate decisions); Carlin, *supra* note 48, at 1442-43 (noting lack of effective enforcement mechanisms under Kyoto and other international agreements).

[61] *See* BARRETT, *supra* note 56, at 88-89 (noting uncertainty regarding consequences of 2°C temperature increase and uncertainty regarding relationship between CO_2 concentrations and temperature).

[62] *See generally* Lisa Schenck, *Climate Change "Crisis" – Struggling for Worldwide Collective Action*, 19 COLO. J. INT'L ENVTL. L. & POL'Y 319 (2008) (discussing barriers to international cooperation and issues to be addressed).

[63] *See, e.g.,* Carlin, *supra* note 6, at 706-16; Crutzen, *supra* note 7, at 217 (expressing preference for emissions reductions, but suggesting that alternative responses should be researched); James Hansen et al., *Climate Change and Trace Gases*, 365 PHIL. TRANS. R. SOC. A 1925, 1950 (2007) (concluding that "the dangerous level of atmospheric GHGs will be passed, at least temporarily," even assuming emissions reduction efforts, and suggesting that "a feasible strategy for planetary rescue almost surely requires a means of extracting GHGs from the air").

[64] Victor et al., *supra* note 7, at 69; *see* Barrett, *supra* note 23, at 49 (describing economics of some geoengineering proposals as "incredible" compared to cost of emissions reductions).

achieve an equivalent cooling effect. Releasing aerosols into the stratosphere would cost an estimated few billion dollars per year, less than one percent of the cost of reducing emissions.[65] The relatively low cost not only makes the option economically feasible, but also makes it more politically feasible. Because a number of countries have the economic resources to finance a geoengineering project on their own, "solving" global warming would not necessarily require the painstaking process of agreeing upon and coordinating an aggregate effort[66] – although any unilateral action would raise concerns about potential negative effects on others. Even if geoengineering were to be carried out as an international project, the implementation of such a project would be less complicated as an institutional matter than that involved in effectuating large-scale emission reductions on a global basis.[67] Indeed, the geoengineering option – *if* it can be shown to work without significant adverse consequences – could prove quite appealing because it ostensibly requires no dramatic policy interventions, behavioral changes, or reductions in standard of living.[68] Of course, the supposition that there would be no significant adverse consequences is problematic; as discussed above, releasing aerosols would cause ozone depletion and would not prevent ocean acidification or local climate changes from taking place.

Another advantage to the proposed use of stratospheric aerosols is that it offers temporal flexibility. In contrast to emissions reduction efforts, which generally require long lead times, aerosols can be deployed quite rapidly. The cooling effect that would promptly follow could buy time for more gradual emissions reductions to be put in place and to take effect.[69] Furthermore, the relatively short atmospheric life of the particles (one or two years) would allow fine-tuning or cessation – at least in theory – of further particle releases should adverse effects become apparent.[70] We may not be able to identify adverse effects immediately, however, and once stratospheric aerosols have been used for some time, the halting of such releases would be difficult because of the drastic climatic changes that might follow.[71]

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[65] *See* Victor et al., *supra* note 7, at 69; Carlin, *supra* note 6, at 739 (claiming the marginal cost of stratospheric aerosol release to be about 1/10,000 that of emissions reductions).

[66] *See* Keith, *supra* note 8, at 500; Thomas C. Schelling, *The Economic Diplomacy of Geoengineering*, 33 CLIMATIC CHANGE 303, 306 (1996) (contending that, compared to reducing emissions, geoengineering "is certainly way ahead in administrative simplicity").

[67] *See* Michaelson, *supra* note 7, at 118-19.

[68] *See* Carlin, *supra* note 6, at 736; Michaelson *supra* note 7, at 110-14 (contending that geoengineering leaves powerful actors and their interests relatively intact and imposes "almost no social costs").

[69] *See* Morton, *supra* note 18, at 133.

[70] *See* Carlin, *supra* note 6, at 739.

[71] *See supra* note 24.

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C. Why the Focus of Climate Change Strategy Should Remain on Emissions Reductions

Notwithstanding the apparent cost advantages of geoengineering, there remains strong opposition to geoengineering proposals among both policymakers and scientists. Indeed, even many proponents of further geoengineering research express a clear preference for emissions reductions in the first instance, with geoengineering to be considered only as an emergency measure.[72]

An important reason why policymakers have concentrated on reducing emissions is our incomplete understanding of the Earth's climate systems. While scientists have long understood the basic mechanics of the greenhouse effect, there are numerous factors other than GHG concentrations that determine temperature and climate patterns. These factors, which include cloud patterns, land surface properties, ocean currents, and feedback mechanisms activated by climate change, greatly complicate the task of predicting the effects of rising GHG concentrations.[73] Emissions reduction strategies are attractive because they rest on the reasonable assumption that we can restore a climate equilibrium without necessarily having a complete understanding of the climate system. This approach is a precautionary one that reflects a sense of humility regarding our limited knowledge and our unproven ability to engineer our way to a solution.[74]

Another reason for favoring an emissions reduction approach is that it treats the causes of the problem rather than its symptoms and avoids introducing additional risks to an already perilous situation. As explained above, potential geoengineering techniques tend to be incomplete solutions that fail to counter all of the problems associated with higher GHG concentrations in the atmosphere.[75] The release of aerosols into the stratosphere, for instance, would help to manage the amount of solar radiation the Earth receives, but would do nothing to counteract the problem of ocean acidification.[76] Even more worrisome, the cure suggested by various geoengineering proposals may prove worse than the disease. Each geoengineering technique poses its own risks, and in contrast to emissions

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[72] *See, e.g.,* Crutzen, *supra* note 7, at 216; Barrett, *supra* note 23, at 46.
[73] *See* Carlin, *supra* note 6, at 690-91 (discussing various uncertainties caused by complexity of Earth's climate system); Morton, *supra* note 18, at 134 (stating that general circulation models "do not provide a perfect understanding of the climate system").
[74] *Cf.* Jeffrey T. Kiehl, *Geoengineering Climate Change: Treating the Symptom Over the Cause?*, 77 CLIMATIC CHANGE 227, 227 (2006) (contending that geoengineering projects represent "the ultimate state of hubris to believe we can control the Earth").
[75] *See* Victor et al., *supra* note 7, at 66 (noting that geoengineering strategies have been "widely shunned" because "they would not stop the buildup of carbon dioxide or lessen all its harmful impacts").
[76] *See* Morton, *supra* note 18, at 133 (noting ocean acidification as one reason why geoengineering would not eliminate the need for emissions reductions).

reduction strategies, introduces new uncertainties that further study and small-scale experiments can only begin to unpack.[77] For example, we have limited understanding of the effects of aerosols on climate, including how aerosols interact with clouds and how clouds in turn regulate climate under changed radiative forcing conditions.[78]

Finally, there is also an ethical component to objections to geoengineering. The ethical argument for reducing emissions is that lowering emissions reduces humanity's impact on the Earth and thereby works toward restoring a responsible and harmonious relationship between humans and their surrounding environment. Geoengineering, in contrast, seeks to ameliorate the effects of existing anthropogenic interferences with natural processes by introducing additional anthropogenic interferences.[79] These ethical concerns help to explain the apparent taboo against even discussing the concept of geoengineering in certain scientific reports on climate change.[80] There is a very practical reason for this taboo, of course; geoengineering proposals present a moral hazard by offering the prospect of a quick and seemingly painless solution to a complicated, long-term problem.[81] A taboo on consideration of geoengineering not only strengthens political resolve to deal with the causes of climate change, but also reflects a sense that reducing emissions is a "natural" response to the problem, whereas geoengineering is not.

There are thus quite compelling reasons not to rely on geoengineering to "solve" the climate change problem. Nonetheless, the international community should not ignore geoengineering altogether. Research and development of geoengineering options can strengthen our ability to respond to climate change by broadening the range of tools available to us. Moreover, individual nations may undertake geoengineering projects on their own as climate change accelerates. As the next Part explains, a system of geoengineering governance should be adopted to oversee geoengineering research efforts, address potential unilateral

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[77] *See* Matthews & Caldeira, *supra* note 24, at 9952-53 (explaining that "geoengineering is not an alternative to decreased emissions" because decreasing emissions reduces environmental risk, whereas continued emissions, combined with geoengineering, increases environmental risk).

[78] *See* Bengtsson, *supra* note 22, at 230.

[79] *See* Kiehl, *supra* note 74, at 227-28 (contending that "we need to address the fundamental issue of value before tinkering with a system that we do not completely understand"); Keith, *supra* note 8, at 500-01 (discussing ethical objections to geoengineering); Schneider, *supra* note 18, at 300 ("since human systems have already disturbed nature in the first place, . . . the risks of countering inadvertent human impacts on nature should next be borne by humans, not an already besieged nature"); *see also* Michaelson, *supra* note 7, at 127-29 (setting out argument that geoengineering is "unnatural" and responses to that argument).

[80] *See* Keith, *supra* note 8, at 500; Schneider, *supra* note 18, at 295 (noting taboo).

[81] *See* Keith, *History*, *supra* note 14, at 276. Geoengineering proposals may seem "painless" only because adverse effects have yet to be identified.

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geoengineering deployment, and establish a mechanism to make collective decisions on any future geoengineering efforts.

III. GEOENGINEERING GOVERNANCE

A. Background

1. A Treaty Approach

The most obvious option for geoengineering governance is through multilateral treaty making.[82] Treaties are the principal means by which the international community has attempted to address global environmental problems.[83] And with respect to climate change, there is already a relevant treaty in place: the 1992 Framework Convention, which boasts near universal membership by the nations of the world.[84] Geoengineering governance seems to fall logically within the purview of the FCCC, and in the absence of alternative initiatives, one might expect that a future protocol or amendment to the FCCC would take up the issue.

We should not rest easy in this expectation, however. First, nowhere does the FCCC directly address geoengineering. The negotiations leading up to the FCCC focused on limiting GHG emissions, not on other ways to respond to climate change.[85] Indeed, the agreement arguably passes over geoengineering as a viable response to climate change in its objective to stabilize GHG concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system." Second, the commitments made in the FCCC are general in nature and do not create a binding obligation on parties, individually or collectively, to address geoengineering.[86] Nor, as far as the proposed release of stratospheric aerosols is concerned, are there any other international treaties that appear directly

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[82] While some customary or soft law instruments, such as the Stockholm Declaration and Rio Declaration, may be indirectly relevant to geoengineering, the principles found in these instruments tend to be very general in nature, and in any case are not readily enforceable. *See* Peterson, *supra* note 34, at 79-84 (discussing soft law instruments that might be applicable).

[83] *See* PHILIPPE SANDS, PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW 126 (2d ed. 2003).

[84] *See* UNFCCC, The United Nations Framework Convention on Climate Change, http://unfccc.int/essential_background/convention/items/2627.php (last visited July 6, 2009) (stating that 192 countries – almost all the nations of the world – have ratified the FCCC).

[85] *See* Daniel Bodansky, *May We Engineer the Climate?*, 33 CLIMATIC CHANGE 309, 313 (1996).

[86] *See* Framework Convention, *supra* note 42, art. 4 (Commitments); Bodansky, *supra* note 85, at 313 (observing that the FCCC "has relatively little to say about climate engineering specifically; but it is likely that the institutions created by the Convention would provide the principal international fora for consideration of climate-engineering proposals"). The FCCC does establish a Conference of the Parties, which is required to evaluate periodically the implementation of the convention to ensure that the parties' commitments are adequate. Framework Convention, *supra* note 42, art. 7(2)(a), 7(2)(e).

applicable.[87] Consequently, any effort to address geoengineering, even if done under the auspices of the FCCC, may require a new round of treaty making.[88] Multilateral treaty making, however, is a complex, time-consuming, and difficult process.[89] The adoption of a treaty requires consensus – agreement among all parties without formal objections[90] – which means that any agreements that are achieved often contain watered-down obligations.[91]

The potential for geoengineering to be implemented by a single nation, or even a single corporation or individual, further complicates the international governance of geoengineering. On the one hand, cooperative efforts to develop these relatively nascent proposals are arguably necessary to identify risks, to determine whether any proposal is truly feasible, and to lay the groundwork for implementation should it prove necessary. On the other hand, developmental efforts may heighten the danger that a country or entity would take unilateral action to implement a geoengineering scheme, notwithstanding any risks, uncertainties, or adverse effects on other countries.[92] International efforts to govern climate change, as complicated as they already may be, should be equipped to manage for this possibility.

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[87] *See* Bodansky, *supra* note 85, at 311 (contending that the U.N. Environment Programme's Weather Modification Guidelines concern only the modification of atmospheric properties in regional contexts and that the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) applies only to environmental modification for hostile purposes); *see also id.* at 314 (discussing potential applicability of other treaties to particular types of geoengineering); *cf.* Karen N. Scott, *The Day After Tomorrow: Ocean CO_2 Sequestration and the Future of Climate Change*, 18 GEO. INT'L ENVTL. L. REV. 57 (2005) (analyzing potential applicability of various treaties to different types of ocean CO_2 sequestration).

[88] *Cf.* DAVID HUNTER ET AL., INTERNATIONAL ENVIRONMENTAL LAW & POLICY 670 (3d ed. 2007) (noting that FCCC "did establish an institutional framework for the progressive development of the [climate change] regime through protocols or amendments").

[89] *See id.* at 298, 303 (noting that process of informal exchange leading up to formal treaty negotiations "may continue for years" and that the negotiations themselves "often drag on for years").

[90] *See* JOANNA DEPLEDGE, THE ORGANIZATION OF GLOBAL NEGOTIATIONS: CONSTRUCTING THE CLIMATE CHANGE REGIME 92 (2005) (distinguishing consensus from unanimity, with the former "defined negatively to mean that there are no stated or formal objections to a decision").

[91] *See* David A. Wirth, *Reexamining Decision-Making Processes in International Environmental Law*, 79 IOWA L. REV. 769, 791 (1994); Daniel Bodansky, *The Legitimacy of International Governance: A Coming Challenge for International Environmental Law?*. 93 AM. J. INT'L L. 596, 607 (1999) (noting problems associated with consensus decision making).

[92] *See* Victor et al., *supra* note 7, at 71-72; Keith, *supra* note 8, at 500 (noting that harmful climatic events may be blamed on operators of geoengineering projects).

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2. Geoengineering Governance as a Public Good

If characterized purely as an emissions reduction exercise, climate change boils down to a classic collective action scenario whose solution depends on the aggregate effort of multiple nations. This is hardly a simple problem, as our experience to date reflects. Nevertheless, it is one familiar to international environmental lawyers and negotiators.[93]

To understand the effect of adding the geoengineering option to this analysis, it is useful to draw on a taxonomy of global public goods developed by Scott Barrett. Distinguishing collective action problems according to the type of effort needed to supply a public good, Barrett proposes five basic types of global public goods: (1) those supplied through a *single best effort* – such as joint peacekeeping missions; (2) those whose supply is determined by the *weakest link* – such as efforts to eradicate disease; (3) those whose supply is determined by the *aggregate effort* of all countries – such as GHG emissions reduction; (4) those dependent on *mutual restraint* – such as nuclear testing bans; and (5) those requiring *coordination* – such as setting measurement standards.[94]

We might describe geoengineering as a hybrid public good in that it exhibits characteristics of several of the basic types in Barrett's taxonomy. Climate change as a whole remains an aggregate effort problem, particularly if geoengineering is considered as an option to be deployed only in an emergency or under dire circumstances. Aggregate effort problems are difficult to address because they are particularly susceptible to free riding, as supply of a public good by one group of countries (e.g., in the form of emissions reductions) may create incentives for other countries not to cooperate (e.g., in the form of emissions increases).[95] These features complicate treaty making and necessitate the creation of incentives to encourage participation as well as enforcement mechanisms to counter the temptation to backslide on commitments.[96]

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[93] *See* BARRETT, *supra* note 56, at 74 (noting that addressing environmental issues typically involves the aggregation of nations' efforts).

[94] *See id.* at 1-21.

[95] *See id.* at 6, 101.

[96] *See id.* at 93, 101. To encourage widespread international participation in emissions reductions, some commentators have advocated the linkage of trade sanctions with emissions performance, and such matters are likely to be the subject of the next round of climate change negotiations. *See, e.g.,* Paul Krugman, Editorial, *Empire of Carbon*, N.Y. TIMES, May 15, 2009, at A39 (raising possibility of imposing trade sanctions on China if it does not cooperate in reducing emissions); *see also A Special Report on the World Economy: Beyond Doha*, ECONOMIST, Oct. 11, 2008, at 68 (discussing option of trade sanctions against countries that do not reduce emissions). Enforcement by the United Nations Security Council offers another possible means to compel emissions reductions. *See* Christopher K. Penny, *Greening the Security Council: Climate Change as an Emerging "Threat to International Peace and Security,"* 7 INT'L ENVTL. AGREEMENTS: POLITICS, LAW & ECON. 35 (2007).

A geoengineering project, in contrast, could be supplied through a "single best effort" involving an international research program sponsored by multiple countries or a unilateral project implemented by a single country.[97] If the international community made a decision to proceed with geoengineering research or implementation, its execution would likely require only modest international cooperation to pool resources. Such an effort is relatively easy to supply, so far as global public goods are concerned, and generally does not require strict enforcement mechanisms.[98]

Decisions regarding whether to proceed with geoengineering should not be made in isolation, however, but as part of a more comprehensive decisionmaking process regarding how to respond to climate change.[99] Geoengineering, because it offers the temptation to avoid difficult emission reductions, can undermine the negotiation of aggregate efforts to reduce emissions collectively, as well as the implementation of those efforts. This point is well-understood by those who seek to keep the geoengineering option off the table in policy discussions as well as in international negotiations.

But geoengineering cannot simply be ignored. Because geoengineering could be deployed unilaterally, might have adverse impacts on other countries, and might be used as a weapon, it must be addressed one way or another.[100] Ultimately, if the international community decided that geoengineering has such adverse national or global impacts that such projects should be renounced, the enforcement of any such decision would present a different type of collective action problem – one that would require mutual restraint by the international community.

B. Implications for Geoengineering Governance

What does all of this mean in terms of agreements and institutions for geoengineering governance? First, notwithstanding the FCCC's general orientation towards emission reductions, geoengineering should be addressed within the structure of the existing FCCC.[101] The FCCC identifies as one of its principles that parties "should protect the climate system for the benefit of present and future generations of humankind,"[102] a premise that encompasses

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[97] *See* BARRETT, *supra* note 56, at 38.
[98] *See id.* at 2-3, 20, 23.
[99] *See id.* at 41 ("A geoengineering treaty needs to be part of a coordinated response to the threat of global climate change: a protocol, one of many probably, under a comprehensive umbrella convention on global climate change.").
[100] *See* Victor et al., *supra* note 7, at 71-72.
[101] This would likely require a revision of the FCCC to embrace a wider objective of reducing climate change risk. *See* Barrett, *supra* note 23, at 53.
[102] *See* Framework Convention, *supra* note 42, art. 3(1).

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geoengineering governance. Moreover, the FCCC has already established a forum – the Conference of the Parties – and has at its disposal technical bodies, such as the IPCC and the Subsidiary Body for Scientific and Technological Advice, that can facilitate research, peer review, discussion, and development of consensus in this area.[103] Given the potential substitutability of geoengineering projects for emissions reductions, it makes no sense to develop an entirely separate international regime to address geoengineering.[104]

Second, it is critical that geoengineering be addressed explicitly by the Conference of the Parties, and that it be addressed soon. Failing to address geoengineering research needs as well as potential geoengineering deployment heightens the risk that events will unfold in ways that are less than desirable. One possibility is that there will be underinvestment in the public good of geoengineering research. Such research is critical to determining whether geoengineering can provide a viable option – emergency or otherwise – for combating climate change without endangering human health, the environment, or global security.[105] Even if the international community ultimately decides to ban geoengineering completely or to bar the use of geoengineering projects as a source of carbon offsets, research likely would prove valuable in facilitating detection and monitoring of covert geoengineering projects.[106] Another possibility, at the other extreme, is that inattention to geoengineering will allow unilateral geoengineering schemes to proceed without international oversight or consideration of global ramifications.[107] In addition to countering these risks,

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[103] Thus far, the Conference of the Parties has chosen to use the Subsidiary Body for Scientific and Technological Advice primarily for obtaining advice rather than for generating new scientific information. *See* Dagmar Lohan, *Assessing the Mechanisms for the Input of Scientific Information into the UNFCCC*, 17 COLO. J. INT'L ENVTL. L. & POL'Y 249, 257-62 (2006).

[104] *Cf.* Daniel C. Esty, *The Case for a Global Environmental Organization*, *in* MANAGING THE WORLD ECONOMY: FIFTY YEARS AFTER BRETTON WOODS 287, 292 (Peter B. Kenen ed., 1994) (advocating comprehensive approaches to solving environmental problems, rather than ad hoc issue-by-issue management).

[105] *See* Victor et al., *supra* note 7, at 74 (contending that international research effort would "transform the discussion about geoengineering from an abstract debate into one focused on real risk assessment," "could secure funding and political cover for essential but controversial experiments," and would facilitate the development of norms that "would make countries less trigger-happy and more inclined to consider deploying geoengineering systems in concert rather than on their own"); Ralph J. Cicerone, *Geoengineering: Encouraging Research and Overseeing Implementation*, 77 CLIMATIC CHANGE 221, 223 (2006) (explaining that refereed papers on geoengineering topics "will permit poor or dangerous ideas to be seen as such and meritorious ones to develop further").

[106] *See* Mark G. Lawrence, *The Geoengineering Dilemma: To Speak or Not to Speak*, 77 CLIMATIC CHANGE 245, 246 (2006).

[107] *See* Bodansky, *supra* note 85, at 310 (noting that international rules governing global commons "are generally permissive: they allow states to use the global commons freely, subject only to very general standards to prevent pollution, consult with others and so forth"). In his 1996 article on

addressing governance issues while geoengineering is in its infant stages minimizes the influence that an established industry or other constituency with vested interests in geoengineering might have on governance structures and decisions.[108]

Third, the Conference of the Parties should confront the risk that geoengineering or similar climate modification techniques could be used as weapons. Here, the Conference can look to the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), which bans environmental modification for military or hostile purposes.[109] Unlike the FCCC, ENMOD does not command universal assent. Although most of the world's major powers have ratified the treaty, only 73 countries are parties to it.[110] More importantly, ENMOD is limited in scope: on its face, it prohibits only the intentional use of environmental modification techniques by one party against another.[111] It apparently does not govern attacks by a party state on a non-party state, it does not authorize affirmative steps to block use of environmental modification techniques by non-states, and it lacks provisions for penalizing parties that violate its terms.[112]

Notwithstanding these flaws, the provisions of ENMOD offer a sound starting point for geoengineering governance. The prospects for achieving consensus on a ban on the use of geoengineering for military or hostile purposes are probably more favorable than on other aspects of geoengineering. Efforts in this area should of course address the weaknesses of ENMOD, particularly with respect to

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geoengineering, however, Bodansky was relatively unconcerned that a country would proceed with a geoengineering project on its own because of his view that it "would be unwilling to incur the political costs of proceeding without international approval." *Id.*

108 *See* Victor et al., *supra* note 7, at 72 (noting possibility that "private sector could emerge as a potent force by becoming an interest group that pushes for deployment or drives the direction of geoengineering research and assessment").

109 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, May 18, 1977, art. 1(1), 31 U.S.T. 333, 1108 U.N.T.S. 152, *reprinted in* 16 I.L.M. 88 [hereinafter "ENMOD"] ("Each State Party to this Convention undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party.").

110 *See* http://disarmament.un.org/TreatyStatus.nsf/ENMOD%20(in%20alphabetical%20order)?OpenView. ENMOD has been described as relatively "unused"; during its quarter century of existence, no state Party has been formally accused of a violation and only two review conferences have been held. *See* Susana Pimiento Chamorro & Edward Hammond, *Addressing Environmental Modification in Post-Cold War Conflict*, at 14 (2001), *available at* http://www.edmonds-institute.org/pimiento.html.

111 *See* ENMOD, *supra* note 109, art. 1(1).

112 *See generally* ENMOD, *supra* note 109; *see also* Chamorro & Hammond, *supra* note 110 (listing concerns); Charles R. Wunsch, *The Environmental Modification Treaty*, 4 ASILS INT'L L.J. 113, 128-30 (1980) (noting difficulties in enforcement).

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verification and enforcement mechanisms, as well as the potential use of geoengineering techniques by rogue states or rogue actors. Although it is unclear at this time whether such techniques could be targeted effectively against other countries, securing a ban on the hostile use of geoengineering ultimately may require mutual promises to defend other parties against such use.[113]

Fourth, parties will have to think creatively to develop mechanisms for making collective decisions on geoengineering and for managing the risk of unilateral geoengineering. That is, even if agreement can be reached to ban geoengineering as a weapon, the risk remains that one country or a small group of countries might be desperate enough to undertake a geoengineering project unilaterally, disregarding the potential harmful impacts on others. Consensus-based decision making, the predominant model for cooperative international action on environmental matters, is not well-suited for responding promptly to such a scenario. Nor is consensus formation likely for climate change issues more generally, given the disparity of interests among states, the high costs of responding to climate change, and the need for rapid adjustments as scientific knowledge changes.[114]

An obvious alternative to a consensus model of decisionmaking would be to adopt nonconsensus processes such as rules providing for passage of measures by a supermajority.[115] Nonconsensus arrangements, however, are rarely found in international environmental law because countries are often reluctant to yield autonomous control over economic activity and resource use.[116] Objections to nonconsensus decisionmaking are also rooted in legitimacy concerns: in contrast to treaty commitments, whose legitimacy rests on explicit consent, obligations adopted through nonconsensus processes must be justified by some other theory.[117]

There are nevertheless several examples of treaties that provide for the adoption of amendments binding on *all* parties to those treaties via nonconsensus processes. The legitimacy of these amendments rests on a theory of general consent – i.e., that signatories have consented to an ongoing system of governance.[118] Countries have tended to be more open to these nonconsensus

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[113] Such promises would be similar to mutual defense promises that underlie military alliances. *See* BARRETT, *supra* note 56, at 138 (discussing NATO and Non-Proliferation Treaty).
[114] *See* Bodansky, *supra* note 91, at 607.
[115] *See* Wirth, *supra* note 91, at 792-97 (pointing to examples of nonconsensual approaches in international law); Bodansky, *supra* note 91, at 608 (discussing Hague Declaration, which endorsed institutional authority with nonunanimous decision making power to address climate change).
[116] *Cf.* Bodansky, *supra* note 91, at 604.
[117] *See id.* at 604 (noting "predominant role" of specific consent in formation of international environmental law).
[118] *See id.* at 604.

arrangements where technical matters are at issue or where the range of possible amendments is limited in nature.[119] Although the FCCC does not presently authorize amendments to be adopted in this manner,[120] several international environmental agreements do provide for nonconsensus decisionmaking.[121]

How might the parties to the FCCC incorporate within the architecture of the FCCC a nonconsensus process to deal with geoengineering? Of course, the FCCC – a *framework* convention – contemplates the subsequent development of specific protocols to address substantive details, such as those pertaining to geoengineering.[122] One possibility would be to develop a protocol that treats geoengineering governance as a series of adaptive management decisions, rather than as a single binary choice to be made once and for all.[123] Geoengineering governance, in other words, would involve adaptive governance, in which decisionmaking structures would be put in place to foster adaptive management.[124] Breaking up the geoengineering issue into smaller incremental decisions may make nonconsensus processes more palatable while facilitating adaptive decisionmaking. Ideally, an adaptive governance approach would promote learning, conceive of policy choices as an integral part of the learning

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[119] *See id.* at 604, 609; Wirth, *supra* note 91, at 792 (stating that "[a]mendments to existing multilateral agreements are particularly promising candidates for nonconsensus techniques").

[120] *See* Framework Convention, *supra* note 42, art. 15 (providing that an amendment may be adopted by a ¾ majority vote, but that such amendment is binding only on parties who have accepted it).

[121] For example, the Montreal Protocol, the largely successful agreement to phase out the use of ozone-depleting substances, allows a qualified majority to tighten controls on regulated substances. *See* Montreal Protocol on Substances that Deplete the Ozone Layer, Sept. 16, 1987, art. 2(9), 26 I.L.M. 1541 (entered into force Jan. 1, 1989); Bodansky, *supra* note 91, at 604 & n.47. Other environmental treaties where binding decisions may be adopted without unanimity include certain maritime pollution agreements and agreements establishing harvest limits for whales and seals. *See* Wirth, *supra* note 91, at 795 & nn.116-122. In addition, three bodies set up under the Kyoto Protocol do allow for majority voting as a last resort for decisions made within their limited jurisdiction. *See* DEPLEDGE, *supra* note 90, at 103.

[122] *See generally* Jutta Brunnée, *The United States and International Environmental Law: Living with an Elephant*, 15 EUR. J. INT'L L. 617, 636-37 (2004) (describing framework-protocol approach commonly found in international environmental agreements).

[123] The concept of adaptive management has been defined as "an iterative, incremental decisionmaking process built around a continuous process of monitoring the effects of decisions and adjusting decisions accordingly." J.B. Ruhl, *Regulation by Adaptive Management: Is It Possible?*, 7 MINN. J.L. SCI. & TECH. 21, 28 (2005); *see also* Holly Doremus, *Precaution, Science, and Learning While Doing in Natural Resource Management*, 82 WASH. L. REV. 547, 568-70 (2007).

[124] *See* Rosie Cooney & Andrew T.F. Lang, *Taking Uncertainty Seriously: Adaptive Governance and International Trade*, 18 EUR. J. INT'L L. 523, 534-39 (2007) (explaining concept of adaptive governance).

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process, and protect the resilience of the Earth's climate system by seeking to avoid decisions that foreclose future options.[125]

A critical initial question would involve the baseline from which geoengineering governance decisions would be made. Given the widespread unease and uncertainty associated with geoengineering proposals, the international community should begin with a default presumption against the implementation of any geoengineering project. Such a presumption is also warranted by the difficulty of reversing course after a geoengineering project has already been operating for many years: suddenly stopping a long-running aerosol release program, for instance, would almost surely cause a rapid warming that both human and nonhuman populations would struggle to adjust to.[126] Notwithstanding any presumption against geoengineering deployment, an adaptive governance approach counsels in favor of revisiting that presumption at regular intervals.

Regularly revisiting the issue offers several advantages. First, this would allow the parties to take account of updated information regarding climate change and its impacts, the success (or lack thereof) of efforts to reduce emissions, and geoengineering risks and refinements.[127] Review of the issue must be sufficiently frequent to allow the parties to respond to "climate surprises"[128] – unexpectedly rapid or large climate changes that are not accounted for in most climate models, which tend to assume relatively smooth increases in GHG concentrations and temperature. Second, a schedule to periodically reconsider the issue reduces the stakes involved in each vote, thereby ameliorating the tendency for parties to assume entrenched positions that make agreement more difficult and increasing the likelihood that parties will be willing to agree to a nonconsensus decisionmaking process.[129] Third, repeated consideration of geoengineering can foster a continuing international dialogue on the matter. Such a dialogue essentially would serve as ongoing negotiations that can lead to the building of

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[125] *See id*.

[126] *See* Matthews & Caldeira, *supra* note 24, at 9952.

[127] *Cf.* Cass Sunstein, *Irreversible and Catastrophic*, 91 CORNELL L. REV. 841 (2006) ("If more accurate decisions can be made in the future, then there is a (bounded) value to putting the decision off to a later date. The key point is that uncertainty and irreversibility should lead to a sequential decision-making process.").

[128] *See* Katharine Ricke et al., Unilateral Geoengineering: Non-Technical Briefing Notes for a Workshop at the Council on Foreign Relations, May 5, 2008, at 10, *available at* http://www.cfr.org/content/thinktank/GeoEng_041209.pdf (sketching out two examples of climate surprises).

[129] *Cf.* DEPLEDGE, *supra* note 90, at 97 (noting that provision of assurances to reluctant parties that issues of importance to them will be considered in the future can serve as a procedural safety valve).

coalitions or the formation of consensus on an issue.[130] In addition, consistent views or decisions with regard to the conditions under which geoengineering may be deployed can also promote the formation of norms and even customary international law to govern the conduct of nations and institutions with respect to geoengineering.[131]

If a decision ever were made to proceed with a particular geoengineering scheme, new procedures and governance mechanisms specific to that scheme would have to be devised. The international community would need to address the specifics of deployment and the procedures for review and reconsideration, including an accounting of the risks of discontinuing such a project.[132] At this time, however, those details can wait; what should command attention in the near-term is a more general framework for managing geoengineering.

CONCLUSION

The immensity of the task of dealing with climate change, the difficulty of securing cooperation in reducing GHG emissions, and the growing interest in geoengineering demand that the international community pay attention to issues of geoengineering governance as part of its response to climate change. The international community can take steps now to promote sound and thorough geoengineering research and ensure that geoengineering techniques will not be used for military or hostile purposes. And it can put in place procedures for deciding whether and how we ought to proceed with any geoengineering proposal, now or in the future. Ultimately, a comprehensive approach to the climate change crisis requires that the international community address geoengineering governance while maintaining its focus on emission reductions.

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[130] *See* Marc A. Levy et al., *Improving the Effectiveness of International Environmental Institutions*, *in* INSTITUTIONS FOR THE EARTH: SOURCES OF EFFECTIVE INTERNATIONAL ENVIRONMENTAL PROTECTION 397, 413-14 (Peter M. Haas et al. eds., 1993).

[131] *See* Ricke et al., *supra* note 128, at 12 (discussing norm-building as a complementary approach to treaties for managing geoengineering, and noting that "similar norms emerged around the deployment of nuclear weapons"); *see generally* SANDS, *supra* note 83, at 147 ("State practice in treaty-making and in accordance with obligations under treaties can contribute to the development of customary law.").

[132] With respect to aerosol release, for example, Matthews and Caldeira point out that "inconsistent or erratic deployment (either because of shifting public opinions or unilateral action by individual nations)" might lead to "large and rapid temperature oscillations." Matthews & Caldeira, *supra* note 24, at 9952.

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