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[**] Professor and Victor and Carol Alvarez Fellow in Law, University of Iowa College of Law. I am grateful to Sam Perlmutter for his research assistance and helpful comments on this paper. This article would not have been written at all, however, but for the example of Professor Burns H. Weston, whose career-long commitment to human rights and social justice is celebrated in this issue of *Transnational Law and Contemporary Problems*. Elsewhere in this issue I offer some brief comments on Weston's remarkable career. I wish only to add here that his ceaseless commitment to ensuring that the human rights dimensions of problems are always within the scope of the discussion provided the inspiration for this Article's attempt to consider how international norms can lead to a system of geoengineering governance in which justice and equity play a central role.

Here Phaëthon lies who drove the Sun-god's chariot. Greatly he failed, but he had greatly dared.

- Inscription upon the tomb of Phaëthon[1]

I. INTRODUCTION

The myth of the mortal Phaëthon is a cautionary tale. According to Greek lore, the young Phaëthon convinced his father, the sun god Helios, to allow the boy any single wish he desired. More than anything, the boy yearned to drive the god's "chariot," the sun, from east to west across the sky and through the heavens as the sun god himself did each day. Helios cautioned Phaëthon, however, that no other being—not even the almighty Zeus himself—could maintain control of the sun. Disregarding this warning from his father, the rash and unknowing Phaëthon took charge of the fiery chariot. Just as Helios had feared, Phaëthon scorched much of the earth as he lost control of the unyielding sun. Intervening to save the planet from primordial climatic ruin, Zeus destroyed Phaëthon and returned the sun to Helios' control.[2]

The tale of Phaëthon is an apt metaphor for the position in which humanity finds itself today. Indeed, the earth has entered a new epoch in its geological history that many are coming to call the "Anthropocene" to mark the increasing human influence on global natural systems.[3] It is an era in which humankind through its Phaëthonic actions will take on an increasing "responsibility for the welfare and future evolution of life on the planet."[4] As a result of anthropogenic greenhouse gas emissions in particular, the climate of the planet will, for millennia, significantly deviate from its natural trajectory.[5]

The release of greenhouse gases ("GHGs"), especially carbon dioxide (CO_2) from the burning of fossil fuels, is the primary driver of global climatic

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[1] EDITH HAMILTON, MYTHOLOGY: TIMELESS TALES OF GODS AND HEROES 184 (1942).

[2] For a more complete rendering of the tale of Phaëthon, see *id.* at 180–84. The Roman poet Ovid described Phaëthon's ride in his METAMORPHOSES 46–64 (Charles Martin trans., W.W. Norton Company 1st ed. 2005) including the prophetic details that Phaëthon's failure to control the sun melted the polar icecap and destroyed agriculture across the world.

[3] *See, e.g.*, WALTER ANDERSON, TO GOVERN EVOLUTION: FURTHER ADVENTURES OF THE POLITICAL ANIMAL (1987); Paul J. Crutzen, *Geology of Mankind*, 415 NATURE 23 (2002) [hereinafter Crutzen, *Geology*]; Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?*, 7 CLIMATIC CHANGE 211 (2006) [hereinafter Crutzen, *Albedo*]; ROBERT L. OLSON, WOODROW WILSON INT'L CTR. FOR SCHOLARS, SCIENCE AND TECHNOLOGY INNOVATION PROGRAM: GEOENGINEERING FOR DECISION MAKERS 2 (2011), *available at* http://www.see.ed.ac.uk/~shs/Climate%20change/Geo-politics/Wilson%20decison%20makers.pdf.

[4] OLSON, *supra* note 3, at 2.

[5] Crutzen, *Geology*, *supra* note 3.

change.[6] At a concentration of 390 parts per million and climbing, high levels of atmospheric CO_2 are contributing to a rise in global average temperature that could potentially exceed two degrees Celsius by 2100.[7] As more heat energy gathers in the climatic system, unpredictable and non-linear positive feedbacks—including melting sea ice and the exposure of less reflective sea surface, the release of methane from thawing Arctic permafrost, and higher levels of water vapor in the lower atmosphere—make it more likely that the climate will reach dangerous "tipping points"[8] beyond which mitigation of our effects on the environment and adaptation to changes in the climate would be very difficult.[9]

As data begins to confirm some of the worst-case projections from climate scientists around the world, policymakers seem to be at an impasse on enacting a solution.[10] Critics excoriated the 2009 Copenhagen Accord as "climate change skepticism in action," reflecting the "lowest level of ambition you can imagine."[11] In 2010, the U.S. Senate rejected the House of Representatives' weak climate legislation. Delegates at 17th Conference of the Parties ("COP-17") to the United Nations Framework Convention on Climate Change ("UNFCCC") in 2011 opined that the agreement reached in Durban, "while sufficient to keep the negotiating process alive, would not

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[6] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT, SUMMARY FOR POLICYMAKERS 2, 5 (2007), *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf.

[7] OLSON, *supra* note 3, at 22–23 (citing Kevin Anderson & Alice Bows, *Reframing the Climate Challenge in Light of Post-2000 Emission Trends*, 366 PHIL. TRANSACTIONS OF THE ROYAL SOC'Y. 3863 (2008), *available at* http://www.ncbi.nlm.nih.gov/pubmed/18757271); THE ROYAL SOC'Y., GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY 57 (2009) [hereinafter ROYAL SOC'Y 2009], *available at* http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf.

[8] *See generally* JASON J. BLACKSTOCK ET AL., CLIMATE ENGINEERING RESPONSES TO CLIMATE EMERGENCIES (2009), *available at* http://arxiv.org/pdf/0907.5140; James Hansen et al., *Target Atmospheric CO2: Where Should Humanity Aim?*, 2 OPEN ATMOSPHERIC SCIENCE JOURNAL 217 (2008), *available at* http://arxiv.org/abs/0804.1126; David G. Victor et al., *The Geoengineering Option: A Last Resort Against Global Warming?*, 88 FOREIGN AFF. 64 (2009); OLSON, *supra* note 3, at 20–24; NAT'L ACAD., UNDERSTANDING AND RESPONDING TO CLIMATE CHANGE 7 (2008), *available at* http://dels.nas.edu/dels/rpt_briefs/climate_change_2008_final.pdf (explaining climate forcings and feedbacks).

[9] For a review of the harmful effects of climate change see INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY (2007), *available at* http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm.

[10] *See, e.g.*, OLSON, *supra* note 3, at 1–2.

[11] John Vidal et al., *Low Targets, Goals Dropped: Copenhagen Ends in Failure*, THE GUARDIAN, Dec. 19, 2009 (quoting Lumumba Di-Aping, chief climate change negotiator for the 130-nation G77 group of developing countries), *available at* http://www.guardian.co.uk/environment/2009/dec/18/copenhagen-deal.

have a significant impact on climate change."[12] In fact, climate change has all the makings of a "wicked problem"—a problem that "defies resolution because of the enormous interdependencies, uncertainties, circularities, and conflicting stakeholders implicated."[13] Climate change is wrought with "temporal and spatial complexities,"[14] a deficiency in governance, powerful economic incentives for the polluters to resist mitigation, and no single solution.[15] Moreover, climate change creates spin-off problems that are themselves wicked problems with deficiencies in governance.[16]

Geoengineering represents one such problem. Geoengineering is "intentional large-scale manipulation of the environment."[17] Whereas mitigation efforts seek to reduce humanity's influence on the natural world, geoengineering "seeks to ameliorate the effects of existing anthropogenic interferences with natural processes by introducing additional anthropogenic interferences."[18] Indeed, a group of notable scientists has emerged to tell us that they have discovered the secret to manipulating earth's radiative balance and that they can restore climate stability if given the money and

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[12] John M. Broder, *Climate Talks in Durban Yield Limited Agreement*, N.Y. TIMES, Dec. 12, 2011, at A9.

[13] Cinnamon P. Carlarne, *Arctic Dreams and Geoengineering Wishes: The Collateral Damage of Climate Change*, 49 COLUM. J. TRANSNAT'L L. 602, 606 (2011) (quoting Richard J. Lazarus, *Super Wicked Problems and Climate Change: Restraining the Present To Liberate the Future*, 94 CORNELL L. REV. 1153, 1159 (2009)).

[14] 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, 685 (2008).

[15] Carlarne, *supra* note 13, at 606–09; WILLIAM F. RUDDIMAN, PLOWS, PLAGUES, AND PETROLEUM 183 (2005).

[16] Carlarne, *supra* note 13, at 609.

[17] David Keith, *Geoengineering the Climate: History and Prospect,* 25 ANN. REV. ENERGY ENV'T 245, 245 (2000); *see generally* Alan Carlin, *Implementation & Utilization of Geoengineering for Global Climate Change Control*, 7 SUSTAINABLE DEV. L. & POL'Y 56, 56 (2007) (quoting Keith, *supra*); OLSON, *supra* note 3, at 2–3 (advocating a broad definition of geoengineering); Mark A. Latham, *The BP Deepwater Horizon: A Cautionary Tale for CCS, Hydrofracking, Geoengineering and Other Emerging Technologies with Environmental and Human Health Risks*, 36 WM. & MARY ENVTL. L. & POL'Y REV. 31, 59–60 (2011) (citing STAFF OF H. COMM. ON SCI. & TECH., 111TH CONG., ENGINEERING THE CLIMATE: RESEARCH NEEDS AND STRATEGIES FOR INTERNATIONAL COORDINATION 1–2 (Comm. Print 2010)); BIPARTISAN POL'Y CTR., TASK FORCE ON CLIMATE REMEDIATION RESEARCH,, GEOENGINEERING: A NATIONAL STRATEGIC PLAN FOR RESEARCH ON THE POTENTIAL EFFECTIVENESS, FEASIBILITY, AND CONSEQUENCES OF CLIMATE REMEDIATION TECHNOLOGIES 6–7 (2011) [hereinafter TASK FORCE], *available at* http://www.bipartisanpolicy.org/sites/default/files/BPC%20Climate%20Remediation%20Final%20Report.pdf (employing the term "climate remediation").

[18] Albert C. Lin, *Geoengineering Governance,* 8 ISSUES LEGAL SCHOLARSHIP 3, 14 (2009) (internal citation omitted); *see also* KELSI BRACMORT ET AL., CONG. RESEARCH SERV., R41371, GEOENGINEERING: GOVERNANCE AND TECHNOLOGY POLICY 1–2 (2011), *available at* http://www.fas.org/sgp/crs/misc/R41371.pdf; OLSON, *supra* note 3, at 4 fig.1 (explaining the concepts of mitigation and adaptation in the context of geoengineering); Naomi E. Vaughan & Timothy M. Lenton, *A Review of Climate Geoengineering Proposals*, 109 CLIMATIC CHANGE 745, 745–46 (2011).

power to do so.[19] These modern-day Phaëthons would grab the reins of Helios's chariot and, like the sun god himself, select a path for the global environment that will restore climatic equilibrium to the planet. Yet, like climate change, geoengineering solutions are themselves wicked problems that challenge our understanding of the climatic system and raise questions of risk, equity, and justice. Even if climate engineering reduces the global mean temperature, it is virtually inevitable that some group of people will be harmed in the process.[20] Moreover, in the context of domestic and international environmental law, geoengineering the climate is an ungoverned novel concept, "creating an open playing field for debating an entirely new governance system."[21]

Geoengineering raises fundamental philosophical, political, scientific, and legal questions. What type of relationship should humankind maintain with the natural environment? Is geoengineering an answer to collective action problems in the governance of the global climate commons? Which methods warrant a closer examination? What parameters should govern the choice of one geoengineering technique over another? How should the public be involved in decision making on climate engineering? Should those communities harmed by geoengineering be compensated, and if so, how? The legal and policy questions themselves are numerous and dense and are increasingly the subject of international discussion and concern.[22]

This article aims to contribute to the emerging debate about geoengineering by suggesting governance principles and mechanisms. Part I provides an overview of the history, rationale, and methods of geoengineering. Part II outlines some of the risks of geoengineering. These matters have been extensively discussed elsewhere, and we seek here primarily to orient readers new to the subject to the possibilities and risks of geoengineering.[23] In our estimation, geoengineering is almost certainly going to be attempted—and on a planetary scale. We therefore suggest that the international community act now to take charge of this activity to ensure that

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[19] ROYAL SOC'Y 2009, *supra* note 7, at 1; *see* Symposium, *Geoengineering the Climate? A Southern Hemisphere Perspective*, NAT'L COMM. FOR EARTH SYS. SCI., (Sept. 26, 2011), *available at* http://science.org.au/natcoms/nc-ess/documents/GEsymposium.pdf; Div. of Ecological & Earth Sciences, U.N. Educ., Scientific, and Cultural Org., Engineering the Climate: Research Questions and Policy Implications (Nov. 1, 2011), http://unesdoc.unesco.org/images/0021/002144/214496e.pdf.

[20] *See* ROYAL SOC'Y 2009, *supra* note 7, at 40–41.

[21] Carlarne, *supra* note 13, at 609.

[22] *See generally* Lauren Morello, *A Search for Rules Before Climate-changing Experiments Begin*, N.Y. TIMES, Jan.18, 2010, www.nytimes.com/cwire/2010101/181/18climatewire-a-search-for-rules-before-climate-changing -e-40048.html; THE ROYAL SOC'Y, ENVTL. DEF. FUND & TWAS, SOLAR RADIATION MANAGEMENT: THE GOVERNANCE OF RESEARCH 18 (2011) [hereinafter ROYAL SOC'Y 2011], *available at* http://www.srmgi.org/files/2012/01/DES2391_SRMGI-report_web_11112.pdf.

[23] For an excellent and more comprehensive review of various climate modification proposals, see Vaughan & Lenton, *supra* note 18.

it is studied and deployed with full attention to the rights and interests of everyone on the planet. In Part III of this paper, we suggest principles that should guide an international regulatory effort, and we sketch out the contours of an appropriate regulatory structure. In particular, we argue for the following propositions:

1. An international structure should be established for the governance of geoengineering and geoengineering research on a multilateral, global level. There should be a ban on geoengineering activities outside that governance framework.

2. The following principles should be applied to the governance of geoengineering within that international framework:

> a. Relative climate stability is a common heritage of humankind and a shared natural resource. For that reason, any geoengineering activities aimed at stabilizing climate should be undertaken in the interests of all states and peoples. Principles of precaution and equity should guide decision making. Decisions should be made on the basis of sound science.
>
> b. Geoengineering activities should be approved only after notification and consultation with all states.
>
> c. Information concerning geoengineering activities should be publicly disclosed at the planning stage (i.e., before an activity is approved or undertaken), once an activity is initiated, and after the activity has been completed.
>
> d. An environmental impact assessment should be required for all geoengineering activity, and the results of that assessment should be included in the information disclosed prior to approval of the activity.
>
> e. Compensation should be provided to persons harmed by geoengineering activities, whether directly or indirectly as a result of its effects on weather or the environment.

3. An *effective* governance mechanism must be established. This means abandoning the one-nation/one-vote, conference-oriented governance structure of most international environmental agreements in favor of weighted voting and governance by a relatively small executive body charged with responsibility to evaluate and make decisions concerning geoengineering proposals.

II. GEOENGINEERING

A. History and Rationale

The concept of engineering the climate predates the climate crisis. In fact, the notion that humans could (and should) attempt to deliberately alter weather patterns dates to at least the 1830s.[24] By the late 1930s, the Soviet Union and the United States were both actively exploring techniques of climate modification to, for example, open shipping routes through the Arctic or gain tactical military advantages.[25] One of the earliest mentions of geoengineering as a technology to reduce the human impact on the climate came in a 1965 report issued to Lyndon B. Johnson by the President's Science Advisory Council—notably, one of the first high-level acknowledgements of the human hand in climate change.[26] By 2008, China was employing 50,000 laborers and spending more than $100 million annually using artillery to seed clouds with silver iodide in an attempt to control the weather for the 2008 Summer Olympic Games.[27] Indeed, geoengineering has recently made its way back into the popular vogue, generating worldwide debate that is drawing commentary not only from the policy and natural science communities, but also from non-governmental organizations ("NGOs"), the media, legal and social scholars, philosophers, research corporations, and wealthy philanthropists.[28] These stakeholders are giving geoengineering options a great deal of attention for a variety of reasons.

First, there is a growing recognition that the governance mechanisms in place—at both domestic and international levels—are inadequate to overcome collective action problems in time to stave off harmful global warming.[29] Even if humanity were to stop emitting CO_2 today, the planet would continue to warm an additional 0.5 degrees Celsius over the next two centuries due to the hundred-year residence time of CO_2 in the atmosphere.[30] Furthermore, the improving knowledge of the global climatic system suggests that the positive feedbacks mentioned above could trigger climate tipping

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[24] ROYAL SOC'Y 2009, *supra* note 7, at 4.

[25] Daniel J. Chepaitis & Andrea K. Panagakis, *Individualism Submerged: Climate Change and the Perils of an Engineered Environment*, 28 UCLA J. ENVTL. L. & POL'Y 291, 306 (2010); Victor et al., *supra* note 8, at 66; Alan Robock, *20 Reasons Why Geoengineering May Be a Bad Idea*, 64 BULL. OF THE ATOMIC SCIENTISTS 14, 14 (2008), *available at* http://www.thebulletin.org/files/064002006_0.pdf.

[26] OLSON, *supra* note 3, at 5–7; ROYAL SOC'Y 2009, *supra* note 7, at 4; Victor et al., *supra* note 8. For a thorough history of the concept of geoengineering, see Keith, *supra* note 17.

[27] Stephen Wade, *Beijing Aims to Control Weather at Olympics*, ASSOCIATED PRESS, Feb. 28, 2008, *available at* http://www.msnbc.msn.com/id/23397205/ns/weather/t/beijing-aims-control-weather-olympics/#.

[28] ROYAL SOC'Y 2011, *supra* note 22, at 18; *See also* Vidal et al., *supra* note 11; Carlarne, *supra* note 13, at 638; OLSON, *supra* note 3, at 5–7 (attributing the resurgence in attention to articles by Paul Crutzen and Ralph Cicerone).

[29] Chepaitis & Panagakis, *supra* note 25, at 637–38; ROYAL SOC'Y 2009, *supra* note 7, at 1, 4–5; Carlarne, *supra* note 13, at 639; Latham, *supra* note 17, at 60; TASK FORCE, *supra* note 17, at 12; Vaughan & Lenton, *supra* note 18, at 746, 749; David G. Victor, *On the Regulation of Geoengineering*, 24 OXFORD REV. ECON. POL'Y 322, 323–24 (2008).

[30] ROYAL SOC'Y 2011, *supra* note 22, at 19 (citing INTERNATIONAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: THE PHYSICAL BASIS (2007)). *See also* ROYAL SOC'Y 2009, *supra* note 7, at 1, 4–5.

points, which would require response mechanisms that have quicker effects on the climate than mitigation techniques have.[31] In fact, some technologies could begin to have a measurable effect on the global climate within a matter of months after deployment.[32] Climate engineering advocates, therefore, promote geoengineering as an "insurance mechanism," "Plan B," or "last resort" in the face of climate emergencies[33] and as an interim measure to buy time for a mitigation strategy to be selected and take effect.[34]

Second, many advocates support geoengineering—regardless of its usefulness as an emergency option—as a cost savings mechanism vis-à-vis economically disruptive mitigation measures, the most effective of which would require substantial reductions in GHG emissions.[35] They suggest that certain techniques could act as a complement to mitigation[36] while others have the potential to displace the need for mitigation altogether.[37] The exact capital investments and operating costs involved vary with the engineering technique and deployment method, but for many of the methods being widely discussed, the costs are low enough for single nations or even corporations to carry out geoengineering unilaterally.[38] David Victor notes that "the discounted present cost of a geoengineering programme extended into perpetuity is of the order of $100 billion"—an amount he finds to be "shockingly small."[39] On the other hand, Nicholas Stern estimates that the cost of conventional mitigation would be approximately one trillion dollars—between 1 and 2 percent of global GDP—per year.[40] To William Nordhaus, this difference in cost between mitigation and geoengineering is so great that

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[31] Chepaitis & Panagakis, *supra* note 25, at 638–39; ROYAL SOC'Y 2009, *supra* note 7, at 4–5; Carlarne, *supra* note 13, at 639; Vaughan & Lenton, *supra* note 18, at 746.

[32] ROYAL SOC'Y 2011, *supra* note 22, at 19.

[33] Chepaitis & Panagakis, *supra* note 25, at 638; Carlarne, *supra* note 13, at 640; Victor et al., *supra* note 8; ROYAL SOC'Y 2009, *supra* note 7, at 44–45, 54; Lin, *supra* note 18, at 13; William Daniel Davis, Note, *What Does "Green" Mean?: Anthropogenic Climate Change, Geoengineering, and International Environmental Law*, 43 GA. L. REV. 901, 905 (2009).

[34] ROYAL SOC'Y 2011, *supra* note 22, at 19.

[35] Carlarne, *supra* note 13, at 640–41; Chepaitis & Panagakis, *supra* note 25, at 316–17. Climate change mitigation involves reducing sources of or increasing sinks for GHG emissions. The most commonly discussed policy tools to achieve GHG mitigation are tax and marketable allowance schemes for carbon dioxide emissions. *See* BRACMORT ET AL., *supra* note 18, at 1–2; OLSON, *supra* note 3, at 4 (contrasting mitigation with adaptation and geoengineering).

[36] ROYAL SOC'Y 2009, *supra* note 7, at 54.

[37] ROYAL SOC'Y 2011, *supra* note 22, at 19.

[38] Carlarne, *supra* note 13, at 640–41; Vaughan & Lenton, *supra* note 18, at 782; Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. RESOURCE ECON. 45, 49 (2007).

[39] Victor, *supra* note 29, at 326.

[40] NICHOLAS STERN, THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW 232, 238–39 (2007).

he treats the act of developing and deploying geoengineering as essentially "costless."[41]

The combination of low cost and quick benefits allows geoengineering to escape most collective action problems.[42] Every stage of research, development, and deployment of geoengineering can be done unilaterally[43]—by wealthy individuals and corporations as well as nations.[44] At least a dozen nations already possess the technological and economic capacity to conduct a planetary geoengineering effort by themselves.[45] It is not inconceivable that one of these nations would decide that the harm it faces from climate change is so grave that it should resort to manipulating the climate, especially if it concludes that the harmful effects of climate modification would fall outside its borders.[46] The fear of unilateral action with planetary effects, therefore, provides a third reason why geoengineering proposals are drawing attention—particularly from stakeholders who take an interest in designing potential governance mechanisms.[47]

Geoengineering represents a novel challenge, as no regulatory structure exists to govern implementation or research and development efforts.[48] Nonetheless, experiments on several geoengineering techniques are already underway.[49] Scientists and corporations are seeking funding while governments are eagerly reviewing findings to determine what role geoengineering should play in their mix of technological responses to climate change. That no governing mechanism exists to constrain geoengineering activity only increases the likelihood that some nation or group will actually attempt climate modification in the coming decades.[50] The uncertain risks inherent in all geoengineering techniques, combined with the threat of unilateral climate manipulation by undisciplined and unaccountable public or private actors, create a pressing need for the development of governance mechanisms to inform the public and stakeholders, guide research and

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[41] William D. Nordhaus, *An Optimal Transition Path for Controlling Greenhouse Gases*, 258 SCIENCE 1315, 1317 (1992).

[42] Victor, *supra* note 29, at 324.

[43] BLACKSTOCK ET AL., *supra* note 8, at 44; Victor, *supra* note 29, at 324; Latham, *supra* note 17, at 73–75.

[44] Victor et al., *supra* note 8; Davis, *supra* note 33, at 925–26.

[45] TASK FORCE, *supra* note 17, at 29–30.

[46] *Id.*; Victor et al., *supra* note 8.

[47] Carlarne, *supra* note 13, at 640–41.

[48] ROYAL SOC'Y 2011, *supra* note 22, at 33; ROYAL SOC'Y 2009, *supra* note 7, at 60; Carlarne, *supra* note 13, at 609; Davis, *supra* note 33.

[49] Carlarne, *supra* note 13, at 640–41; OLSON, *supra* note 3, at 35, 37.

[50] ROYAL SOC'Y 2009, *supra* note 7, at 5.

development, and allow governments to responsibly consider deployment options.[51]

B. Methods

Broadly, geoengineering includes any large-scale technique designed to manipulate the environment. In the context of climate change, there are two primary classes of proposed geoengineering options: carbon dioxide removal ("CDR") technologies are being designed to draw CO_2 from the atmosphere to increase the amount of outgoing longwave, thermal infrared radiation, whereas solar radiation management ("SRM") technologies are being designed to lower the amount of incoming shortwave solar radiation.[52] Geoengineering methods are not "one size fits all." The choice of method should turn on the nature of the climate emergency at hand. The costs and timeframes for implementation and climate response differ with each method. A predictable future climate impact (e.g., sea-level rise) may therefore call for a slower CDR method, while a sudden and unexpected climate emergency (e.g., the rapid onset of severe droughts) may call for a SRM method with a quick climate response.[53]

1. Carbon Dioxide Removal

Methods that remove CO_2 from the atmosphere have an advantage over SRM measures because CDR technologies address the underlying cause of climate change. Though other greenhouse gases—methane (CH_4), nitrous oxide (N_2O), ground-level ozone (O_3), halocarbons, and water vapor—contribute to global warming, carbon dioxide is by far the primary greenhouse gas responsible for climate change.[54] Thus, CDR methods will remove CO_2 from the atmosphere by employing chemical, biological, or physical mechanisms to enhance existing carbon sinks in the land and ocean or to create new carbon sinks altogether.[55] Moreover, certain of these CDR technologies will undoubtedly play an indispensable role in the solution to climate change: "In the long-term, the only way to return atmospheric CO_2 to pre-industrial levels is to permanently store (in some combination of the

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[51] *Id.* at 55–56.

[52] *Id.* at 1; Davis, *supra* note 33, at 920; BRACMORT ET AL., *supra* note 17.

[53] BLACKSTOCK ET AL., *supra* note 8, at 6–7.

[54] SYNTHESIS REPORT, *supra* note 6, at 2, 5; ROYAL SOC'Y 2009, *supra* note 7, at 21; OLSON, *supra* note 3, at 5; TASK FORCE, *supra* note 17, at 10. Scientists could theoretically fashion technologies that are similar to the CDR methods discussed here to remove other greenhouse gases ("GHGs") from the atmosphere, but those technologies have not been developed. ROYAL SOC'Y 2009, *supra* note 7, at 1, 9.

[55] Vaughan & Lenton, *supra* note 18, at 750; BRACMORT ET AL., *supra* note 17, at 10; ROYAL SOC'Y 2009, *supra* note 7, at 21. For a thorough technical description of the suite of proposed CDR methods, see Vaughan & Lenton, *supra* note 18, at 750–61.

crust, sediments, soils, oceans, and terrestrial biosphere) an equivalent amount of CO_2 to the total emitted to the atmosphere."[56]

Methods that enhance land carbon sinks are the least invasive CDR approaches. For example, afforestation and reforestation measures involve growing forests on non-forested land, thereby creating new carbon sinks in terrestrial vegetation.[57] Other methods that have been discussed include chemically altering soil minerals to uptake additional carbon, increasing the use of biomass energy sources, and carbon capture from emissions streams or even the ambient air, paired with geologic sequestration.[58] The potential usefulness and level of risk to public health and the environment associated with each of these techniques is indeterminate at present.[59] Our focus here, though, is on seemingly more invasive geoengineering measures.

Attempts to enhance ocean carbon sinks are more demanding than land-based measures. The ocean stores CO_2 through two natural mechanisms: a solubility pump and a biological pump.[60] The solubility pump functions through an inorganic physio-chemical process whereby the surface ocean absorbs carbon dioxide from the atmosphere, and the CO_2-rich water sinks to great depths.[61] Through this process, the ocean absorbs roughly one quarter of the anthropogenic CO_2 that we emit into the atmosphere each year,[62] and on a millennial timescale, nearly all anthropogenic CO_2 emissions will end up in the deep ocean.[63] The biological pump, on the other hand, functions through planktonic algae, which absorbs CO_2 through photosynthesis.[64] Though much of the CO_2 taken into the ocean through this process is degassed back into the atmosphere, some CO_2 sinks into deep waters within the remains of planktonic algae and in other debris from the food chain.[65]

Scientists could enhance the solubility pump by increasing the rate at which CO_2-rich waters sink and by altering the chemistry of the surface water to increase the amount of CO_2 absorbed into the ocean.[66] For example,

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[56] Vaughan & Lenton, *supra* note 18, at 750.

[57] *Id.* at 750–51; ROYAL SOC'Y 2009, *supra* note 7, at 10–11; BRACMORT ET AL., *supra* note 17, at 13–14. Avoided deforestation, on the other hand is a mitigation technique designed to limit the loss of an existing carbon sink; ROYAL SOC'Y 2009, *supra* note 7, at 10–11.

[58] ROYAL SOC'Y 2009, *supra* note 7, at 12–16; BRACMORT ET AL., *supra* note 17, at 14–15; Vaughan & Lenton, *supra* note 18, at 750–60.

[59] Vaughan & Lenton, *supra* note 18, at 750–60.

[60] *Id.* at 753.

[61] *Id.*; ROYAL SOC'Y 2009, *supra* note 7, at 19.

[62] Vaughan & Lenton, *supra* note 18, at 753.

[63] ROYAL SOC'Y 2009, *supra* note 7, at 16.

[64] *Id.*

[65] Vaughan & Lenton, *supra* note 18, at 753–54; ROYAL SOC'Y 2009, *supra* note 7, at 16–17.

[66] Vaughan & Lenton, *supra* note 18, at 753; ROYAL SOC'Y 2009, *supra* note 7, at 19.

some scientists have suggested that it would be possible to increase downwelling (sinking) of CO_2-rich waters by mechanically cooling the ocean's surface.[67] On the other hand, increasing the alkalinity of surface water by adding carbonate minerals would increase the surface water's physio-chemical absorption of CO_2.[68]

Though enhancing the solubility pump may be a more effective long-term solution, advocates of geoengineering have given more attention to methods that enhance the biological pump. In addition to being less expensive to develop and deploy, these methods—specifically, ocean iron fertilization proposals—are the only geoengineering technologies that researchers have examined through field experiments.[69] Less promising proposals involve increasing the concentrations of nitrogen and/or phosphorous to areas of ocean that are deficient in those macronutrients by either adding the nutrients to the water or by mechanically enhancing upwelling, which would transport nutrient rich deep water to the surface to stimulate algal growth.[70]

Advocates, though, have given iron fertilization more attention. In the Equatorial Pacific and Southern Ocean, a deficiency in iron limits the growth of phytoplankton.[71] Dispersing iron particles into the ocean, therefore, will stimulate the growth of phytoplankton, which, through photosynthesis, will draw in CO_2.[72] More than a dozen small-scale experiments conducted in the open ocean have demonstrated the potential of iron fertilization;[73] however, a great deal of uncertainty still surrounds iron fertilization as an effective geoengineering technique.[74] Although additional phytoplankton takes in a great deal of CO_2, much of this CO_2 is released back into the atmosphere through physio-chemical respiration.[75] Feeding by zooplankton and crustaceans on the phytoplankton also keeps a notable amount of the CO_2

[67] Vaughan & Lenton, *supra* note 18, at 753–55.

[68] *Id.* at 754; ROYAL SOC'Y 2009, *supra* note 7, at 14.

[69] ROYAL SOC'Y 2009, *supra* note 7, at 18–19.

[70] *Id.* at 16–17; Vaughan & Lenton, *supra* note 18, at 757–58 ("However, these deeper waters are also relatively carbon rich . . . and will also tend to outgas CO_2, so it is not obvious that the method will be effective." *Id.* at 757.).

[71] ROYAL SOC'Y 2009, *supra* note 7, at 16–17.

[72] John H. Martin, & S.E. Fitzwater, *Iron Deficiency Limits Phytoplankton Growth in the North-East Pacific Subarctic*, 331 NATURE 341, 341–43 (1988); Keith, *supra* note 17, at 266–67; ROYAL SOC'Y 2009, *supra* note 7, at 16–18; Vaughan & Lenton, *supra* note 18, at 755–57; Randall S. Abate & Andrew B. Greenlee, *Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change, and the International Environmental Law Framework*, 27 PACE ENVTL. L. REV. 555, 560–62 (2010).

[73] Abate & Greenlee, *supra* note 72, at 562–66; Vaughan & Lenton, *supra* note 18, at 755.

[74] Vaughan & Lenton, *supra* note 18, at 755–56 ("Experimental and observational work has yet to ascertain the magnitude of any impact of additional iron on carbon export." *Id.* at 755.).

[75] ROYAL SOC'Y 2009, *supra* note 7, at 16–18.

near the surface.[76] Therefore, "only a small fraction [of absorbed CO_2] is finally transported and sequestered deep in the water column or in the sediments."[77] Finally, iron fertilization in one area could draw down concentrations of other essential nutrients—e.g., nitrogen and phosphorous—in other, downstream areas in a process called "nutrient robbing."[78] Thus, iron fertilization's effectiveness will turn on an assessment of the entire ocean carbon system.[79]

2. Solar Radiation Management

Whereas CDR methods would slowly draw down levels of atmospheric CO_2, SRM methods have the potential to stimulate rapid changes in the climate[80] and are relatively cheaper to deploy.[81] Full implementation of several SRM techniques could take as little as one year, and the climate would respond quickly with surface temperatures potentially decreasing to pre-industrial levels within a matter of years thereafter.[82] Recall that SRM methods are designed to lower the amount of incoming shortwave solar radiation. They aim to accomplish this by deflecting incoming solar radiation from space or by increasing the reflectivity, or albedo, of the earth itself.[83] Reducing the amount of incoming solar radiation will, in turn, lower the global mean temperature. Yet, although SRM methods block solar radiation from reaching the earth, a fundamental shortcoming of these methods is that they do not decrease the atmospheric concentration of CO_2. Nonetheless, many climate scientists have agreed that a general target for SRM methods should be to avoid the radiative forcing that would accompany a doubling of atmospheric CO_2 from pre-industrial levels.[84] Meeting this target would require a 1.8 percent decrease in the amount of incoming solar radiation.[85]

A variety of space-based deflection techniques have been discussed in the literature, including reflective mirrors, or "solar shields," which would extend for 4.7 million square kilometers to achieve the desired amount of

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[76] *Id.* at 18; OLSON, *supra* note 3, at 37 (concluding that "ocean fertilization is not a highly effective carbon dioxide removal method").

[77] ROYAL SOC'Y 2009, *supra* note 7, at 17.

[78] *Id.*

[79] *Id.*

[80] Vaughan & Lenton, *supra* note 18, at 773; OLSON, *supra* note 3, at 4–5; ROYAL SOC'Y 2009, *supra* note 7, at 21, 58; BRACMORT ET AL., *supra* note 18, at 10.

[81] ROYAL SOC'Y 2011, *supra* note 22, at 16.

[82] *Id.* at 34.

[83] *See generally*, Keith, *supra* note 17; ROYAL SOC'Y 2009, *supra* note 7, at 23; Latham, *supra* note 17, at 60–61; Vaughan & Lenton, *supra* note 18, at 761–71.

[84] Vaughan & Lenton, *supra* note 18, at 761–62.

[85] *Id.* at 762–63.

deflection.[86] To keep pace with increasing GHG emissions, additional space shades would need to be added each year.[87] For the most part, space-based solar deflection methods are unrealistic at this point in time given the large capital investments required to develop and deploy the technology.[88] In addition, there are no nations with both the capacity and political will to deploy space-based SRM.

In contrast, the simplest SRM methods involve enhancing the surface albedo of the earth. These measures involve increasing the reflectivity of human settlements—for example, painting roofs and paved areas white.[89] Efforts like this are not likely to have a global effect, but could reduce the temperature in cities from the "urban heat island effect."[90] In addition to altering human settlements, scientists have suggested that selecting more reflective plant varieties, or even genetically modifying plants to be more reflective, could enhance surface albedo.[91] Finally, others have suggested covering deserts[92] and oceans[93] with reflective surfaces. Each of these methods would likely reduce the global mean temperature; but they would also each present countervailing ecological risks.

On the other hand, some scientists have suggested that enhancing the albedo of clouds is an "ecologically benign" SRM method.[94] Indeed, vessels could seed clouds with sea-salt by spraying ocean water into the atmosphere with the effect of increasing the ocean clouds' droplet concentrations—in other words, "whitening clouds over parts of the ocean"—and thereby making them more reflective.[95] Despite the initial appeal of this approach as

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[86] *Id.* at 762; BRACMORT ET AL., *supra* note 18, at 18; ROYAL SOC'Y 2009, *supra* note 7, at 32–34; *see generally* Roger Angel, *Feasibility of Cooling the Earth with a Cloud of Small Spacecraft Near the Inner Lagrange Point (L1)*, 103 PROC. NAT'L ACAD. SCI. U.S. 17184 (2006), *available at* http://www.pnas.org/content/103/46/17184.full.pdf.

[87] Vaughan & Lenton, *supra* note 18, at 762.

[88] BRACMORT ET AL., *supra* note 18, at 18; ROYAL SOC'Y 2009, *supra* note 7, at 32–34, 36; Davis, *supra* note 33, at 922–23.

[89] BRACMORT ET AL., *supra* note 18, at 16–17; ROYAL SOC'Y 2009, *supra* note 7, at 24–25; Vaughan & Lenton, *supra* note 18, at 769; Elise Stull, Xiaopu Sun & Durwood Zaelke, *Sustainable Development in the Urban Environment: Enhancing Urban Albedo to Fight Climate Change and Save Energy*, 11 SUSTAINABLE DEV. L. & POL'Y 5, 5–6 (2010).

[90] Vaughan & Lenton, *supra* note 18, at 769.

[91] BRACMORT ET AL., *supra* note 18, at 16–17; ROYAL SOC'Y 2009, *supra* note 7, at 25–26; Vaughan & Lenton, *supra* note 18, at 768–69.

[92] ROYAL SOC'Y 2009, *supra* note 7, at 26; Vaughan & Lenton, *supra* note 18, at 769–70.

[93] BRACMORT ET AL., *supra* note 18, at 16–17; ROYAL SOC'Y 2009, *supra* note 7, at 26.

[94] *See* Vaughan & Lenton, *supra* note 18, at 767 (questioning that claim).

[95] ROYAL SOC'Y 2009, *supra* note 7, at 27–29; Vaughan & Lenton, *supra* note 18, at 766–67.

ecologically friendly, little is known about the effects of enhancing cloud albedo, and therefore, some experts have grown skeptical.[96]

The most frequently discussed method of all of the geoengineering proposals, however, is aerosol injection.[97] This method involves the dispersal of aerosols—e.g., hydrogen sulfide (H_2S) or sulfur dioxide (SO_2)—into the stratosphere to reflect solar radiation back towards space, thus limiting the amount of shortwave radiation that can heat the earth.[98] Aerosol injection has drawn a great deal of attention because observational data indicates that this method is theoretically sound. Indeed, aerosol injection proposals are attempts to mimic the effects of volcanic eruptions, which expel massive amounts of dust and debris into the atmosphere. "The cooling impact of these large volcanic eruptions is well documented—[SO_2] ejected into the stratosphere reacts to form sulphate aerosols, which scatter shortwave and absorb and emit longwave radiation."[99] Moreover, dispersing aerosols can be accomplished in a relatively straightforward manner: Potential delivery mechanisms for the gaseous particles include aircraft, artillery shells, and stratospheric balloons.[100] What's more, developing and deploying this technology would be somewhat inexpensive. In fact, deploying a fleet of airplanes to disperse aerosols into the stratosphere would only cost several billion dollars per year—less than the operating costs of major airlines.[101]

While implementation costs are decreasing, advancements in climate science are improving—making it all the more likely that some nation or group of non-governmental actors will begin aerosol injection (or some other geoengineering method) unilaterally. Moreover, it is ironic that aerosol

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[96] BRACMORT ET AL., *supra* note 18, at 16–17 (noting that enhancing cloud albedo carries unknown, possibly harmful risks for marine ecosystems); Vaughan & Lenton, *supra* note 18, at 767 (same).

[97] BLACKSTOCK ET AL., *supra* note 8, at 30; BRACMORT ET AL., *supra* note 18, at 2; Victor, *supra* note 28, at 323.

[98] *See generally* Crutzen, *Albedo*, *supra* note 3. *See also*, BRACMORT ET AL., *supra* note 18, at 18–19; ROYAL SOC'Y 2009, *supra* note 7, at 29–32; Vaughan & Lenton, *supra* note 18, at 764 (noting, however, that larger particles may absorb and emit longwave radiation). For a discussion of this method in the legal literature, see Davis, *supra* note 33, at 903; Carlin 2007, *supra* note 17, at 1459.

[99] Vaughan & Lenton, *supra* note 18, at 764 (noting that smaller particles are ideal because they do not absorb outgoing longwave radiation). *See also* Crutzen, *Albedo*, *supra* note 3 (discussing the cooling observed after Mount Pinatubo erupted in the Philippines in June 1991); BRACMORT ET AL., *supra* note 18, at 18–19; Victor et al., *supra* note 8; ROYAL SOC'Y 2009, *supra* note 7, at 29–32 (stating, however, that the volcano analogy is imperfect because volcanic eruptions are rapid and massive events while SRM would rely on the cumulative effects of small-scale aerosol injections over time).

[100] Crutzen, *Albedo*, supra note 3; BRACMORT ET AL., *supra* note 18, at 18–19; Vaughan & Lenton, *supra* note 18, at 764–65; *see generally* JUSTIN MCCLELLAN ET AL., AURORA FLIGHT SCIS.GEOENGINEERING COST ANALYSIS FINAL REPORT (July 27, 2011), *available at* http://people.ucalgary.ca/~keith/Misc/AuroraGeoReport.pdf.

[101] MCCLELLAN ET AL., *supra* note 100, at 74; BRACMORT ET AL., *supra* note 18, at 18–19.

injection has received the most enthusiasm from geoengineering advocates because analyses conducted thus far hint that it also presents the most ecological danger of any climate engineering technique.[102] In the following Parts, we discuss the hazards associated with aerosol injection and the other geoengineering proposals and accordingly suggest a suite of principles and mechanisms to govern geoengineering.

III. THE HAZARDS OF GEOENGINEERING

There are a number of hazards associated with geoengineering techniques that warrant the exercise of caution when considering their deployment. But it is also important to remember that the risks raised by geoengineering should be evaluated ultimately in the greater context of the harms threatened by uncontrolled climate change. [103] To reach an appropriate judgment on whether to authorize a given geoengineering project, a decisionmaker should weigh the risk of harm from the climate modification technique against the risk of harm from climate change.[104]

In this Part, we will review some of the hazards posed by various climate manipulation technologies. In addition, we discuss a number of "derived externalit[ies]," or adverse consequences that could arise from attempts to manipulate the earth's climate.[105] We then explain why our knowledge of geoengineering is not yet sufficient to warrant the drawing of conclusions about whether it should or should not be deployed, although we do believe that enough is known about the potential risks of geoengineering to warrant serious and immediate efforts to develop global mechanisms to govern its deployment.

A. Ecological Hazards of Geoengineering

Though climate engineering is advocated as a technique to protect the planet from major environmental harm, nearly all of the geoengineering techniques mentioned above involve some non-zero risk of causing environmental harm of their own. Researchers and decisionmakers will need

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[102] *See, e.g.*, Vaughan & Lenton, *supra* note 18, at 765 ("The uncertainties surrounding the effects of sulphate aerosol addition to the stratosphere are much greater and more meteorologically complicated than those related to mitigating CO_2 emissions.").

[103] For convenience, we engage in this discussion in a certain amount of conflation of the terms "risk" and "hazard." We recognize that this would be an analytical error if it occurred in the context of a rigorous risk analysis. *See infra* Part II.C; *see also* Ragnar E. Lofstedt, *Risk versus Hazard—How to Regulate in the 21st Century*, 2 EUR. J. OF RISK REG. 149, 153 (2011). In less technical discussions, however, the terms are frequently used synonymously, and we hope our similar practice in this discussion is not distracting or misleading.

[104] Gareth Davies, *Law and Policy Issues of Unilateral Geoengineering: Moving to a Managed World*, *in* 2 SELECT PROCEEDINGS OF THE EUR. SOC'Y OF INT'L LAW 627 (Helene Ruiz Fabri et al. eds., 2010); ROYAL SOC'Y 2009, *supra* note 7, at 37–38, 47–48; *see* OLSON, *supra* note 3, at 19–26.

[105] JOHN D. GRAHAM & JONATHAN B. WIENER, RISK VS. RISK: TRADEOFFS IN PROTECTING HEALTH AND THE ENVIRONMENT 229 (1997)

to evaluate and balance these risks against the risks of climate change before attempting large-scale climate engineering. In this section, we use the above factors to briefly consider some of the known ecological hazards associated with the two most widely discussed geoengineering techniques: ocean iron fertilization and aerosol injection.

All else being equal, decisionmakers should prefer CDR over SRM techniques because CDR addresses the root cause of the climate problem—carbon dioxide emissions. However, CDR methods, including ocean iron fertilization, also raise the potential for harm to ecosystems and those communities who depend on them for their wellbeing. As we note below, the probability of harm (and therefore the certainty in risk estimates) from all geoengineering techniques is indeterminate. The literature characterizes the type of harm that ocean fertilization raises as generally limited to damage to ocean ecosystems through a variety of mechanisms.[106] Fertilization-induced algal blooms could contribute to eutrophication and hypoxia, causing a loss of biodiversity.[107] Moreover, fertilization could incite changes in the macronutrient balance that would undermine productivity in some parts of the ocean,[108] and it may also worsen the growing problem of ocean acidity.[109] Finally, iron fertilization could result in a positive climate feedback through the release of methane and nitrous oxide emissions from chemical interactions associated with algae blooms—limiting the overall effectiveness of iron fertilization as a climate change solution in the first place.[110]

The suite of hazards associated with aerosol injection is broader. One potential problem with SRM, whether through aerosol injection or otherwise, is that it works by reducing the amount of sunlight reaching the surface of the planet. This is likely to have a negative effect on plant photosynthesis, and it may have other adverse impacts that are not yet fully understood.[111] In addition, because scientists do not know exactly how much sunlight to deflect in order to stabilize atmospheric temperatures at any particular level, all forms of SRM carry an inherent risk of overshooting or undershooting target temperature ranges.[112] Because aerosol injection can be stopped relatively quickly, this risk is not as significant as it might otherwise be for this type of SRM. On the other hand, the ease with which aerosol injection can be

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[106] *See, e.g.*, Vaughn & Lenton, *supra* note 18, at 758.

[107] Vaughan & Lenton, *supra* note 18, at 758; ROYAL SOC'Y 2009, *supra* note 7, at 17–18; Abate & Greenlee, *supra* note 72, at 566–69.

[108] Vaughan & Lenton, *supra* note 18, at 758; ROYAL SOC'Y 2009, *supra* note 7, at 17–18; Abate & Greenlee, *supra* note 72, at 566–69.

[109] Latham, *supra* note 16, at 65; BRACMORT ET AL., *supra* note 18, at 13.

[110] Vaughan & Lenton, *supra* note 18, at 758; ROYAL SOC'Y 2009, *supra* note 7, at 17–18; Abate & Greenlee, *supra* note 72, at 566–69.

[111] Vaughan & Lenton, *supra* note 18, at 765; *but see* J. Pongratz et al., *Crop Yields in a Geoengineered Climate,* 2 NATURE CLIMATE CHANGE 101 (2012) (predicting gains in yield).

[112] ROYAL SOC'Y 2009, *supra* note 7, at 23–24.

reversed is also a problem: if a successful program of aerosol injection were used to cool the earth, the abrupt termination of that program would lead to a more rapid and sustained temperature increase than if the program had not been started in the first place[113]—a problem that we discuss in greater detail below.

A more troubling set of hazards relates to the possible impacts of aerosol injection on planetary systems, including the hydrological cycle and the ozone layer. Significant changes in rainfall patterns (e.g., modification of the Asian or African summer monsoons) would disrupt agriculture and could potentially impact the food supply for billions of people, leading to widespread famine in some areas of the world.[114] Even if there are not extreme consequences, reduced evaporation (and hence precipitation) is a likely consequence with possible negative effects on freshwater availability.[115] Scientists also expect that aerosol injection would contribute to ozone depletion—setting back current efforts to repair the hole in the ozone layer over Antarctica.[116]

Whether large-scale ocean fertilization or aerosol injection efforts would actually result in any of these harms is unknown. Moreover, the timeframes associated with those impacts are unknown as well. Harm to the environment from fertilization and aerosol injection—or any geoengineering technique for that matter—is likely to be unpredictable and non-linear. Therefore, the size of the at-risk population is also indeterminate. Careful environmental monitoring following any geoengineering effort will be absolutely critical. Even a simple account of the hazards of geoengineering, though, makes it plain that any undesirable impact will almost certainly be transboundary in nature. This raises the likelihood that any geoengineering effort will have an unbalanced distributional impact: some communities will suffer as a direct result of geoengineering. It is critical that the interests of those nations be weighed in the balance when decisionmakers consider deliberate climate change. By cataloguing a few of the risks associated with

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[113] Victor, *supra* note 29, at 324 (stating that warming could occur at a rate 20 times greater than current warming).

[114] Davis, *supra* note 33, at 924; Latham, *supra* note 17, at 63–64; *see generally* G. Bala et al, *Impact of Geoengineering Schemes on the Global Hydrological Cycle,* 105 PROC. NAT'L ACAD. SCI. 7664 (2008). A hint of the potential impacts that sulfur injection could have on distant weather patterns can be found in recent studies suggesting that sulfur emissions in western South America affect cloud cover in the Eastern Pacific, with potential impacts on the El Niño Southern Oscillation, which itself has a significant impact on weather in North America. *See* N. Huneeus et al., *Offshore Transport Episodes of Anthropogenic Sulfur in Northern Chile: Potential Impact on the Stratocumulus Cloud Deck*, 33 Geophysical Research Letters L19819 (2006); S.N. Spak et al., *Atmospheric Transport of Anthropogenic Oxidized Sulfur over the Southeast Pacific during VOCALS Rex,* 53 CLIVAR: EXCHANGES 20–21 (2010).

[115] Vaughan & Lenton, *supra* note 18, at 764–65.

[116] *Id.* at 765; ROYAL SOC'Y 2009, *supra* note 7, at 36; Robock, *supra* note 25, at 15–17; Simone Tilmes, Rolf Müller & Ross Salawitch, *The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes*, 320 SCIENCE 1201, 1201–04 (2008).

these geoengineering techniques, though, we do not mean to imply that scientists and policymakers should not explore the potential benefits of these techniques. We do think, however, that any serious steps taken toward including geoengineering in the arsenal of tools used to counteract climate change must take into account hazards of this nature and the fact that these hazards threaten others as much as, or even more than, they threaten the potential geoengineers.[117]

B. Derived Externalities & Other Dilemmas

Above, we discussed ecological risks. In this section, we will discuss policy responses that may impede the ability of geoengineering to accomplish its objective. There are indeed a number of problems, or derived externalities, that public policies often encounter, which experts attribute to common behavioral and social responses to public policy as well as various structural elements of our shared international political and economic system. Specifically, a derived externality is "an adverse consequence that is itself derived from the government's effort to redress a market externality."[118] Each of the derived externalities that we identify presents unique challenges to the governance of geoengineering. We ultimately conclude that these problems create a variety of problems, which in combination with the countervailing ecological hazards described above, justify a governance mechanism that takes a cautionary approach, accounts for the distributional effects of geoengineering, and equitably balances the interests of all states.

The most oft-cited derived externality of geoengineering proposals is a "moral hazard" problem. The term moral hazard was originally coined in the context of insurance: "a newly-insured party is more inclined to undertake risky behavior than previously because compensation is available."[119] In the context of climate change, reducing GHG emissions through mitigation efforts, including energy efficiency measures and the replacement of fossil fuels with clean energy technologies, is the only sustainable solution to climate change.[120] Yet, altering the energy infrastructure of our economy, which is based on the burning of fossil fuels, may require great sacrifice. Geoengineering may present a moral hazard by reducing the will to reduce GHG emissions. Indeed, seeking to avoid having to make the tough choice to, for example, place a price on carbon, politicians may come to see geoengineering as a less costly substitute for mitigation options. Indeed, the development of climate manipulation technology may drain political will,

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[117] For example, aerosol injection in one part of the world could alter rainfall patterns in another, with potentially catastrophic consequences (if, for example, the Asian or African monsoons were significantly impacted). *See supra* Part I.B.1.

[118] GRAHAM & WIENER, *supra* note 105.

[119] ROYAL SOC'Y 2009, *supra* note 7, at 37.

[120] Vaughan & Lenton, *supra* note 18, at 745 (arguing that geoengineering is not a substitute for mitigation).

intellectual effort, and financial resources away from mitigation.[121] In fact, some experts already see early evidence that geoengineering proposals are diverting focus from mitigation.[122] Moreover, one of the most discussed mitigation options—a carbon cap-and-trade system with credits for CO_2 removals—could increase the financial incentive for private companies to pursue geoengineering options that promise to remove carbon from the atmosphere (e.g., iron fertilization), even in the absence of a rigorous assessment of the particular technology's likely effectiveness or its potential for harm.

The implications are twofold in the context of SRM methods. All SRM methods treat a symptom of climate change (rising temperature) but fail to ameliorate the underlying cause (GHG emissions). First, failure to address the non-temperature impacts of CO_2 and other GHG emissions will cause great ecological and economic harm. For example, CO_2 reduces carbonate ion concentrations and pH in the ocean, making the oceans more acidic.[123] Ocean acidification makes it more difficult for corals and certain varieties of plankton to develop and maintain their external calcium carbonate skeletons, impeding their ability to survive. In addition to critically damaging the ocean's food chain, the loss of large amounts of coral will have a destructive effect on the marine fishing industry and "the 100 million people who depend on coral reefs for their livelihoods. . . ."[124] Moreover, CDR methods that seek to draw greater concentrations of CO_2 into the ocean would amplify ocean acidification.[125] Thus, either mitigation efforts or land-based CDR techniques must be successfully deployed alongside SRM and ocean-based CDR methods to avoid harmful ocean acidification.

Second, if SRM is deployed without a simultaneous reduction in CO_2 emissions, then the world may encounter what the literature has come to the call the "termination problem."[126] Carbon dioxide would continue to accumulate in the atmosphere, and if the SRM measures were to suddenly stop—due to, for instance, human error, mechanical failure, a loss of funding, war, terrorism, or a natural disaster—the world would instantly face the full temperature impacts from those CO_2 emissions, which had been building up

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[121] ROYAL SOC'Y 2011, *supra* note 22, at 20–21; Lin, *supra* note 18, at 14 (noting that "geoengineering proposals present a moral hazard by offering the prospect of a quick and seemingly painless solution to a complicated, long-term problem"); Keith, *supra* note 17, at 276; Davis, *supra* note 33, at 913–18; Robock, *supra* note 25, at 15–17; OLSON, *supra* note 3, at 13–14; Vaughan & Lenton, *supra* note 18, at 777.

[122] OLSON, *supra* note 3, at 13–14.

[123] *See, e.g.*, Stern, *supra* note 40, at 72; ROYAL SOC'Y 2009, *supra* note 7, at 58; TASK FORCE, *supra* note 17, at 10–12; Vaughan & Lenton, *supra* note 18, at 761–62, 777–78; Victor et al., *supra* note 8. *See also* Davis, *supra* note 33, at 924 (discussing ways in which CO_2 will change ecosystem functions independent of its effects on temperature).

[124] Victor et al., *supra* note 8.

[125] Vaughan & Lenton, *supra* note 18, at 761–62.

[126] ROYAL SOC'Y 2009, *supra* note 7, at 23–24.

in the atmosphere all along. The result would be a sudden and sustained rise in temperature, which would have a devastating effect on ecosystems across the planet and test humanity's ability to adapt.[127] Thus, once SRM is begun, it will need to be maintained indefinitely, unless CO_2 emissions are reduced as well to address ocean acidification and other non-temperature impacts of rising anthropogenic CO_2 emissions.

The "technology control dilemma" is another common analytical problem, which most emerging technologies encounter.[128] In a classic Catch-22, the risks of any new technology only truly become known after its deployment.[129] By the time the technology is adopted, however, it may be very difficult to incorporate the necessary risk management measures into the implementation and design plans. Even when researchers foresee risks in the design phase, they usually cannot examine and address those risks until after the technology is developed and demonstrated at scale.[130] In the context of geoengineering, the literature has identified a number of hazards, but whether those adverse consequences may actually materialize will not be known until the climate modification techniques are developed and tested at scale—at which point, having already committed resources and effort to a certain method, it may be too late to turn back in spite of the countervailing risks that emerge. In fact, some go as far as to say that it would be impossible for any climate engineering deployment to be temporary as "too many countries and individuals would have a vested interest in its continued use."[131]

Indeed, research builds a lobbying constituency of scientists, engineers, investors, and regulators, which can act as a vocal interest group of "geoengineering winners" pushing for full deployment of an emerging technology.[132] In the medical field, for example, researchers successfully lobbied for the widespread and premature use of a number of procedures and devices over the years that later proved to be "ineffective, damaging, or ethically problematic."[133] There is a real danger that geoengineering may fall

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[127] OLSON, *supra* note 3, at 42; ROYAL SOC'Y 2009, *supra* note 7, at 24, 58; TASK FORCE, *supra* note 17, at 10–12; Vaughan & Lenton, *supra* note 18, at 776; Victor, *supra* note 29, at 324 (indicating that warming could occur at a rate 20 times greater than the current rate of warming).

[128] *See* ROYAL SOC'Y 2009, *supra* note 7, at 37; Victor, *supra* note 29, at 327–28; BRACMORT ET AL., *supra* note 18, at 4.

[129] BRACMORT ET AL., *supra* note 18, at 4. The electromagnetic pulse effects of nuclear explosions, for example, were not discovered until atmospheric testing of nuclear weapons began. *Id.*

[130] BRACMORT ET AL., *supra* note 18, at 4.

[131] Chepaitis & Panagakis, *supra* note 25, at 318.

[132] ROYAL SOC'Y 2011, *supra* note 27, at 20–21; OLSON, *supra* note 3, at 17–18; *see generally* John Vidal, *Bill Gates Backs Climate Scientists Lobbying for Large-scale Geoengineering,* THE GUARDIAN (Feb. 6, 2012), www.guardian.co.uk/environment/2012/feb/06/bill-gates-climate-scientists-geoengineering.

[133] OLSON, *supra* note 3, at 17–18.

into the same trap in which research efforts guide decisionmakers to deploy a certain technology prematurely.[134]

Examining the flip side of this phenomenon reveals a collective action problem, which John Graham and Jonathan Wiener identify with the term "omitted voice."[135] The omitted voice problem is defined by "the absence of affected parties from the decision process and the concomitant disproportionate influence of organized interests."[136] Geoengineering's countervailing ecological risks are uncertain and likely to be broadly distributed. Any "geoengineering losers" who attempt to enter the debate are therefore likely to encounter significant transaction and information costs (e.g. determining that they have been harmed by geoengineering in the first place) resulting in an inability to effectively mobilize to make their voices heard in the dialogue on climate manipulation. As a result, decisionmakers are likely to privilege the position of the more vocal group of "geoengineering winners." We find support for this inference in the empirical literature on interest groups. This literature concludes that interest groups more successfully exert influence on low-salience, highly technical issues with concentrated benefits and diffuse harms.[137]

This collective action problem underscores the importance of accounting for the distributional effects of geoengineering by raising the risk of privileging corporate interests to the detriment of the common good.[138] In fact, research scientists, engineers, and corporations have already begun filing patents on geoengineering technologies, raising serious questions about the manner in which these patent-holders will seek to profit from the technologies they develop.[139] To be sure, competition between private firms will drive innovation and capital investment, "lead[ing] to the development of more effective and less costly technologies at a faster rate than in the public sector."[140] However, restricting access to proprietary research findings could also slow progress towards discovering an effective and risk-superior technology in an emerging field where new data is desperately needed to identify risks and guide the development of governance mechanisms.

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[134] *Id.*

[135] GRAHAM & WIENER, *supra* note 105, at 230.

[136] *Id.*

[137] *See, e.g.*, Diana Evans, *Before the Roll Call: Interest Group Lobbying and Public Policy: Outcomes in House Committees*, 49 POL. RES. Q. 287, 298, 301 (1996); FRANK R. BAUMGARTNER ET AL., *Ch. 11: Policy Outcomes*, *in* LOBBYING AND POLICY CHANGE: WHO WINS, WHO LOSES, AND WHY 258 (2009); Susan Webb Yackee, *Sweet Talking the Fourth Branch: The Influence of Interest Group Comments on Federal Agency Rulemaking*, 16 J. PUB. ADMIN. RES. & THEORY 103, 105 (2005); Morten Bennedsen & Sven E. Feldmann, *Lobbying Legislatures*, 110 J. POL. ECON. 919, 920–21 (2006).

[138] OLSON, *supra* note 3, at 35; Vaughan & Lenton, *supra* note 18, at 756; Victor et al., *supra* note 8; Vidal, *supra* note 132.

[139] OLSON, *supra* note 3, at 17.

[140] BRACMORT ET AL., *supra* note 17, at 5.

A governance mechanism could address this dilemma by taking an open-source approach to research and development. "An open-source approach to SRM R&D can speed progress, prevent private companies with proprietary technologies from gaining too much influence over R&D and minimize the risk that the drive for profits could lead to inappropriate testing and deployment." [141] The empirical and theoretical literature on industrial innovation is beginning to support the concept that "useful knowledge is widely distributed, and . . . even the most capable R&D organizations must identify, connect to, and leverage external knowledge sources as a core process in innovation." [142] Furthermore, the uncertain countervailing risks with potentially global implications may justify a global open-source research and development effort.[143]

Finally, given the risks that private interests could drive the world towards the premature adoption of an uncertain, potentially harmful technology, it is prudent to build elements of reversibility (or exit strategies) for both research and implementation into geoengineering governance structures. [144] Hence, engineers should be able to terminate a climate modification project and limit its adverse effects within a short timeframe.[145] Reversibility is crucial to effective risk management,[146] and it is therefore essential that flexibility be built into any technology and governance structure. As a practical matter, most geoengineering methods could be halted within a relatively short timeframe.

The concept of reversibility, though, raises a host of fundamental concerns. Those nations that experience a more favorable climate as a result of temperature modification will oppose halting the geoengineering projects from which they are benefiting. Should those nations (or groups) that benefit from geoengineering be entitled to compensation for foregoing the benefits of geoengineering? Raising this issue begs the question, "What is the optimal global climate?"[147] If humankind establishes mastery over the global climate, who is to say that the rights of the islands of the South Pacific to avoid sea-level rise outweigh Russia's rights to a temperate Siberia?[148]

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[141] OLSON, *supra* note 3, at 35.

[142] Henry Chesbrough, *Chapter 1: Open Innovation: A New Paradigm for Understanding Industrial Innovation*, *in* OPEN INNOVATION: (Henry Chesbrough, Wim Vanhaverbeke & Joel West eds., 2006), *available at* http://www.openinnovation.net/Book/NewParadigm/Chapters/01.pdf.

[143] OLSON, *supra* note 3, at 35.

[144] ROYAL SOC'Y 2011, *supra* note 22, at 20–21.

[145] BRACMORT ET AL., *supra* note 18, at 4; ROYAL SOC'Y 2009, *supra* note 7, at 38–39.

[146] BRACMORT ET AL., *supra* note 18, at 4; Vaughan & Lenton, *supra* note 18, at 775–76.

[147] BLACSTOCK ET AL., *supra* note 8, at v; Robock, *supra* note 25, at 17.

[148] *See* Chepaitis & Panagakis, *supra* note 25, at 318–19 ("Any climate parameters that those in control of the geoengineering mechanism set would significantly benefit certain regions, businesses, and activities over others.").

Happily (or not), the technology to modify the climate with any degree of certainty is not fully functional. In its initial stages of development, geoengineering in fact meets many of the criteria of a relatively *inflexible* technology:

> Indicators of a technology's relative 'inflexibility' include: long lead times from idea to application; capital intensity; large scale of production units; major infrastructure requirements; closure or resistance to criticism; and hype about performance and benefits. As a general guide, the more of these factors that are present, the more caution should be exercised in committing to the adoption of a particular technology.[149]

What's more, even though any given geoengineering activity (e.g. ocean fertilization) could be stopped with relatively short notice, there is a lag time between the termination of a climate modification project and the cessation of the project's effects on the climate.[150] Thus, even though geoengineering could be stopped, it is uncertain how long any countervailing negative effects would last.[151] Finally, if geoengineers employ an SRM method without a simultaneous reduction in GHG emissions, then the termination problem mentioned above may preclude cessation of geoengineering as an option.

The relative uncertainty and inflexibility of geoengineering combined with the possibility that decisions concerning its deployment might unwittingly privilege concentrated interests over the common good justifies a precautionary approach to this awe-inspiring technology. But that does not mean is should not be used. Ultimately, the hazards posed by geoengineering might be minor in comparison to the hazards posed by unmitigated climate change. The next section discusses, primarily in theoretical terms, the parameters of the risk analysis that should be a critical part of the process of deciding whether and how to deploy geoengineering technologies.

C. Weighing Risk Tradeoffs

In their book on risk-risk analysis, Graham and Wiener explain:

> [R]isk tradeoffs are a pervasive and fundamental problem of decisionmaking. In contexts from the care of a single patient to the care of the entire earth, striving to solve one problem often invokes other problems. Each intervention to protect against a target risk can simultaneously generate countervailing risks; these risk tradeoffs at least reduce the

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[149] ROYAL SOC'Y 2009, *supra* note 7, at 37 (citations omitted).

[150] Vaughan & Lenton, *supra* note 18, at 761.

[151] *Id.*

> gross benefits of the intervention and in some cases mean that the intervention will do more harm than good.[152]

This is an apt description of the decision-making problem posed when one considers geoengineering as a solution (temporary or permanent) to climate change. In this context, the target risk—or primary focus of risk reduction efforts[153]—is the probability of harm as a result of climate change. A risk tradeoff is the "change in the collection of risks that occurs when" intervention to ameliorate the target risk produces countervailing risks—"a move from one set of risks to another."[154] Those are the various risks (outlined above) associated with geoengineering. A decisionmaker should choose the course of action that is "risk superior" in that it "reduces the overall risk rather than trading one risk for another."[155]

A central feature of the governance problem with respect to geoengineering is that the state of knowledge regarding geoengineering techniques is in its early stages of development. This makes it impossible to perform the necessary risk analyses. Knowledge of potential hazards is not the same as knowledge of risks—a 'risk' is the probability of an adverse outcome,[156] and a rigorous risk analysis requires knowledge of both adverse outcomes and their probabilities.[157] At the moment, unfortunately, "there is commonly little knowledge . . . about the nature of (potentially unwanted) outcomes [from geoengineering] and still less knowledge of probabilities. This is a situation of 'indeterminacy' (or 'ignorance') rather than risk."[158] So, though we may have used the language of risk from time to time in our previous discussion, we do not actually believe that enough is known at this stage to engage in the kind of risk analysis that should precede any decision on the deployment of geoengineering technology.

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[152] GRAHAM & WIENER, *supra* note 105, at 226. Notably, Graham and Wiener discuss several countervailing risks associated with climate change mitigation. *Id.* at 202–25. However, advances in climate science since the early 1990s suggest that the benefits of climate change mitigation outweigh the countervailing risks that Graham and Wiener identify. *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY (Martin Parry et al. eds., 2007), *available at* www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html.

[153] *Id.* at 23.

[154] *Id.* at 23, 25.

[155] *Id.* at 3. Cost effectiveness is an alternative metric that could be used to compare outcomes with one another; however, cost-effectiveness would require weighing geoengineering against alternative technologies, and there is not enough data as of yet to determine which geoengineering measures will be cost-effective against mitigation and adaptation efforts. Vaughan & Lenton, *supra* note 18, at 775.

[156] GRAHAM & WIENER, *supra* note 105, at 30. *See also* Lofstedt, *supra* note 103, at 149 (defining risk as "a combination of the likelihood and the severity of a substance, activity or process to cause harm").

[157] ROYAL SOC'Y 2009, *supra* note 7, at 37–38.

[158] *Id.*

What we can identify, as we have attempted to do, are the potential *hazards* of geoengineering—the intrinsic potential for this activity to cause harm.[159] Characterizing the hazards of geoengineering is the initial step in a risk analysis,[160] and we believe scientists have taught us enough about those hazards to show that more scientific research, coupled with a rigorous risk analysis, will be required if sensible decisions about geoengineering deployment are to be made. We will briefly return to this point in Part IV.[161]

D. Lack of an International Governance Institution

There are already several comprehensive analyses of the capacity of existing institutions and organizations to govern geoengineering activities.[162] Existing international institutions that may apply to certain geoengineering techniques in limited instances include the Convention on Biological Diversity ("CBD"), the United Nations Framework Convention on Climate Change, the Convention on Long-Range Transboundary Air Pollution, the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, the United Nations Convention on the Law of the Sea, and the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and its more recent embodiment in the London Protocol. The potential governance and advisory organizations that have been discussed in the literature include the United Nations Environment Programme, the International Maritime Organization, the Intergovernmental Panel on Climate Change, and the Group of Twenty among others.[163] International legal scholars widely recognize, however, that none of these institutions or organizations has the resources or jurisdiction to govern the full gamut of geoengineering possibilities.[164]

Even so, the international community has taken several steps within these existing institutional settings that highlight the need for an international governance institution that directly addresses large scale SRM and CDR techniques. First, international legal scholars widely recognize that each of the aforementioned institutions embody a customary international legal duty to avoid activities that would cause significant transboundary

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159 Lofstedt, *supra* note 103, at 149.

160 *Id.* at 149, 153.

161 *See infra* text and notes at notes 192–200.

162 *See, e.g.*, ROYAL SOC'Y 2009, *supra* note 7; ROYAL SOC'Y 2011, *supra* note 27; Carlarne, *supra* note 13; Davis, *supra* note 32; BRACMORT ET AL., *supra* note 18; Abate & Greenlee, *supra* note 72; Latham, *supra* note 16; JONATHAN C. CARLSON, SIR GEOFFREY W.R. PALMER & BURNS H. WESTON, INTERNATIONAL ENVIRONMENTAL LAW & WORLD ORDER: A PROBLEM-ORIENTED COURSEBOOK 640–60 (3d ed. 2012).

163 ROYAL SOC'Y 2011, *supra* note 27, at 2–5.

164 BRACMORT ET AL., *supra* note 18 at 36; ROYAL SOC'Y 2011, *supra* note 22, at 31–32; Carlarne, *supra* note 13, at 642–44.

harm.[165] The International Law Commission ("ILC") adopted the Draft Articles on the Prevention of Transboundary Harm from Hazardous Activities in an attempt to codify this customary principle.[166] Although the Draft Articles were not developed with geoengineering in mind, they have obvious applicability in light of the sections below in which we discuss the potential ecological impacts of the most widely discussed geoengineering methods. Second, the Scientific Group of the London Convention and Protocol issued a Statement of Concern in 2007 regarding ocean iron fertilization stating "that knowledge about the effectiveness and potential environmental impacts of ocean iron fertilization [is] currently insufficient to justify large-scale operations."[167] Finally, the tenth Conference of the Parties to the CBD issued a decision in 2010 to recommend "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 [appropriately consider] the associated risks for the environment and biodiversity . . . ."[168]

However, despite the global community's general concern about activities that threaten significant transboundary environmental harm, despite the expression of particular concern about certain geoengineering techniques, and despite a widespread belief that no single existing institution has jurisdictional authority over all possible geoengineering activities, there has been no significant diplomatic effort to develop a governance structure specifically for geoengineering. We believe that is a mistake. Absent an adequate governance mechanism, fear may lead the international community to continue to adopt ad hoc bans that will either prevent needed research on geoengineering or ensure that study and experimentation are conducted secretly and without transparency or oversight. If (as we think likely) such bans do not prevent unilateral action by some states to undertake or authorize geoengineering activities, considerations of the possible adverse transboundary or extraterritorial impacts of particular geoengineering techniques are far less likely to weigh significantly in the decision-making

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[165] Davis, *supra* note 32, at 930–31; ROYAL SOC'Y 2009, *supra* note 7, at 40; BRACMORT ET AL., *supra* note 18, at 30.

[166] *See Draft Articles on Prevention of Transboundary Harm from Hazardous Activities*, [2001] 2 Y.B. Int'l L. Comm'n 146, U.N. Doc. A/CN.4/SER.A/2001/Add.1 (Part 2) [hereinafter *Transboundary Harm*], *available at* http://untreaty.un.org/ilc/publications/yearbooks/Ybkvolumes(e)/ILC_2001_v2_p2_e.pdf.

[167] Int'l Mar. Org. [IMO], Statement of Concern Regarding Iron Fertilization of the Oceans To Sequester CO_2, P 1 IMO Ref. T5/5.01, LC-LP.1/Circ. 14 (July 13, 2007), *available at* http://www.whoi.edu/cms/files/London_Convention_statement_24743_29324.pdf. *See also* Carlarne, *supra* note 13, at 644–47; Abate & Greenlee, *supra* note 72, at 578–85; BRACMORT ET AL., *supra* note 18, at 33 (discussing the application of the London Convention and Protocol to geoengineering).

[168] Convention on Biological Diversity, COP 10 Decision X/33, 8(w), *available at* http://www.cbd.int/decision/cop/?id=12299. *See also* ROYAL SOC'Y 2011, *supra* note 22, at 7–8, 31–32; Carlarne, *supra* note 13, at 647–50; Abate & Greenlee, *supra* note 72, at 576–77; BRACMORT ET AL., *supra* note 18, at 32 (discussing the application of the CBD to geoengineering).

process than if decisions were made under the umbrella of a multilateral governance framework.

IV. TOWARD GEOENGINEERING GOVERNANCE

The need for regulation of geoengineering is clear and widely acknowledged.[169] A more difficult problem is developing a suitable regulatory structure. In this Part, we identify some useful guideposts that we believe emerge from consideration of forty years of international law development in the environmental arena. First, however, it is necessary to address the claim that it is too soon to begin efforts to secure cooperative international governance of this subject matter.

In a widely read 2008 article, David Victor argued that efforts to assess and govern geoengineering should be developed from the "bottom up,"[170] beginning with scientists engaged in national and international assessment of geoengineering who would then become "advocates for regulation." Their internal pressure on their own governments would "lead countries to create their own capable domestic institutions to fund and regulate geoengineering," eventually leading to a "transnational partnership of expert regulators," and would "press for complementary efforts within pivotal nations."[171]

On the other hand, Victor argued that an early effort to develop international governance norms would be doomed to failure because the interests of potential geoengineers and other non-geoengineering states would be in conflict over basic principles, both because the negotiations would likely raise distracting questions that would obstruct progress, and because we lack the knowledge base to develop sensible governance norms at this stage. Efforts should therefore

> concentrate, today, on laying the groundwork for future negotiations over norms rather than attempting to codify immature norms now. Meaningful norms are not crafted from thin air. They can have effect if they make sense to pivotal players and then they become socialized through practice. To be sensible the norms must be based on evidence and reason; they must be relevant and responsive to core interests of pivotal players.[172]

Only after there has been an "extensive review" of "scenarios for actual geoengineering deployment" will geoengineering experts have enough

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[169] *See generally* ROYAL SOC'Y 2011, *supra* note 22; Victor, *supra* note 29; OLSON, *supra* note 3.

[170] Victor, *supra* note 29, at 332–33.

[171] *Id.* at 333.

[172] *Id.* at 332.

"accepted, shared information" to "inform later formal efforts to create norms."[173]

This analysis, we believe, misconstrues the governance problem. It is not a matter of articulating particular rules to govern the deployment of particular geoengineering systems. It is, instead, a matter of creating a governance structure within which critical decisions about geoengineering can be made in a sensible way and with the interests of all affected parties taken into account. To be sure, any such governance structure must rest on norms that "make sense to pivotal players" and have "become socialized through practice." To be effective, they must, as Victor correctly observes, be "relevant and responsive to core interests of pivotal players."[174] In fact, as we demonstrate below, international environmental law has developed a suite of norms that satisfy these criteria and that provide a workable set of guideposts for the negotiation of an international agreement aimed at the regulation of geoengineering. We believe that those negotiations must begin now, on the basis of basic norms of international environmental governance, *before* states begin large scale geoengineering experiments with potentially harmful transboundary impacts and before the political leaders of those states are captured by scientists or commercial geoengineers who are committed to a particular geoengineering path.[175]

The basic premise of our approach should be acknowledged up front. It is that the deliberate manipulation of the earth's climate system on a global scale is inherently a matter of global concern. Relative climatic stability is, quite literally, a "common heritage" of humankind. Climate stability has been important to the development of human culture in many regions of the world.[176] Ancient and pre-industrial human societies were adapted to

[173] *Id.*

[174] *Id.*

[175] One of Victor's main concerns is that any effort to develop a regulatory structure for geoengineering could "create a taboo against geoengineering" and that such a taboo will make it difficult for states "to invest in the research and deployment of trial geoengineering systems that will be needed to generate useful and relevant knowledge." *Id.* at 333. To be sure, there will be arguments made in favor of a complete ban on geoengineering. Those arguments, however, should be considered and answered rather than avoided. It is, in our view, highly unlikely that states would ultimately favor a ban on geoengineering research or trial deployments if evidence suggested that geoengineering was a reasonable and cost-effective response to the threats of climate change. Even states inclined in that direction would recognize that such a ban would be ineffective given that several states have the technical and financial capacity to engage in geoengineering unilaterally. For states that worry about geoengineering, an international regulatory structure that can attract the participation of the potential geoengineers seems the only realistic solution.

[176] "Civilization is rooted in nature," as the World Charter for Nature expresses it. This is one major reason why climate change is so threatening. World Charter for Nature, Preamble, ¶ 2(b), G.A.Res. 37/7, U.N.Doc. A/RES/37/7 (Oct. 28, 1982). *See* Joan Feynman & Alexander Ruzmaikin, *Climate Stability and the Development of Agricultural Societies,* 84 CLIMATE CHANGE 295 (2007).

particular climate circumstances.[177] Modern industrialized civilizations, likewise, have invested in infrastructure and economic activities that assume a relatively stable climate. In part for these reasons, the avoidance of adverse climate change has been recognized as a "common concern of humankind."[178] Efforts to engineer the global climate system are not a matter over which those who organize or fund the efforts can legitimately claim any exclusive right of control.

In addition, any globally oriented geoengineering program, even some geoengineering research, is likely to have transboundary impacts, at least some of which may prove harmful, perhaps significantly so.[179] Even a state's efforts to offset the effects of climate change locally could have profound environmental consequences elsewhere.[180] For example, the use of geoengineering techniques to cool the western coast of South America could significantly disrupt weather patterns in North America through its impact on water temperature in the Eastern Pacific Ocean.[181] Because geoengineering activity carries an inherent risk of such transboundary impacts, it implicates the responsibility of all states "to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of rational jurisdiction."[182]

Unfortunately, individual states cannot be trusted to regulate geoengineering with adequate attention to its transboundary consequences. Leaders within states answer primarily to their domestic constituencies, raising an omitted voice problem. Their political power depends on satisfying the demands of those constituencies, and while external focus can certainly affect them, leaders (especially in the richest and most powerful states that are likeliest to pursue geoengineering) will ultimately measure the wisdom of a geoengineering effort in terms of its local impact. External effects will be, at

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[177] For a series of compelling descriptions of how changing environmental conditions can cause the failure of social and economic structures based on particular environmental conditions, see JARED DIAMOND, COLLAPSE: HOW SOCIETIES CHOOSE TO FAIL OR SUCCEED (2005).

[178] United Nations Framework Convention on Climate Change, Preamble ¶ 1, May 9, 1992, 1771 U.N.T.S. 107 [hereinafter UNFCCC].

[179] Mark A. Latham, *The BP Deepwater Horizon: A Cautionary Tale for CCS, Hydrofracking, Geoengineering and Other Emerging Technologies with Environmental and Human Health Risks*, 36 WM. & MARY ENVTL. L. & POL'Y REV. 31, 74 (2011).

[180] *Id.*

[181] For the suggestion that anthropogenically created sulfate plumes can impact the clouds and climate of the Eastern Pacific, and hence the occurrence of the El Niño and La Niña events that impact North American weather patterns, see N. Huneeus, L. Gallardo & J.A. Rutllant, *Offshore Transport Episodes of Anthropogenic Sulfur in Northern Chile: Potential Impact on the Stratocumulus Cloud Deck,* 33 Geophysical Letters, L19819, doi: 10.1029/2006GL026921 (2006); S.N. Spak, M.A. Mena, G.R. Carmichael, *Atmospheric Transport of Anthropogenic Oxidized Sulfur over the Southeast Pacific during VOCALS REx,* 15 CLIVAR Exchanges (Climate Variability and Predictability Programme), Apr. 2010, at 20–21.

[182] Declaration of the United Nations Conference on the Human Environment, Stockholm, Swed., Principle 21, U.N.Doc. A/CONF.48/14/Rev.1 (June 16, 1972) [hereinafter Stockholm Declaration].

best, a secondary consideration. The truism that "all politics is local" applies to global as well as national affairs—political decisions (including decisions about how and when to experiment with or use geoengineering) will be made on the basis of the concerns and interests of the politician's constituency, not the planet. That unilateral geoengineers are not likely to consider the concerns of the populations most likely to be harmed by geoengineering's transboundary effects suggests that any unilateral efforts are not only going to have adverse distributional impacts, but will also not maximize social welfare in an economic sense.

Moreover, a state's legal responsibility to avoid causing transboundary environmental harm is not likely, by itself, to be adequate protection for other states adversely affected by geoengineering activities with significant transboundary effects. In the first place, *post hoc* enforcement of the norm against causing transboundary environmental harm is rare in the international community. Even if an injured state could accomplish the notoriously difficult task of demonstrating a causal relationship between a particular geoengineering action thousands of miles away and environmental injury within its borders, its chances of finding a forum in which its claim could be adjudicated are slim.[183] A state that engages in unilateral geoengineering is unlikely voluntarily to admit its responsibility or liability for transboundary harm caused by an activity that it presumably believes serves its interests and that it may consider necessary to avoid significant climate-change-induced damage to itself.

In short, the only effective means to ensure that geoengineering will be carried out with attention to the interests of all potentially affected states is to require that it be conducted within a framework of international governance.[184]

A. Equity and Geoengineering Governance

One of the central challenges of geoengineering governance will be the differing interests of states in whether and how geoengineering occurs. It is conceivable that some states will perceive benefits from a warming climate that will make them hostile to efforts to combat climate change. Even if all states agree, in principle, with the effort to return the climate to a more natural trajectory through geoengineering, the choice of geoengineering techniques and the manner of their implementation will be contested, particularly because different practices will have different effects, those effects will vary geographically, and some effects will be adverse.

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[183] *See* BRACMORT ET AL., *supra* note 18, at 37–38 (briefly discussing the ICJ in the context of geoengineering); *see generally* Stanimir A. Alexandrov, *The Compulsory Jurisdiction of the International Court of Justice: How Compulsory Is It?,* 5 CHINESE J. OF INT'L L. 29 (2006).

[184] Latham, *supra* note 17, at 74.

These governance challenges are not different in kind than the challenges facing states that share a natural resource—one state's efforts to use the resource may adversely affect that other state's use of the resource or conflict with its long-term plans for the resource. The earth's climate is similar to a shared natural resource in the sense that one state's decision to alter the climate will have significant repercussions for others. Such situations pose real challenges to international cooperation, but the difficulties are not insuperable. One widely accepted and applied principle for addressing conflicts over shared resources, as well as situations where useful and important activities in one state may cause incidental harm in another, is the principle that such disputes should be addressed on the basis of an "equitable balance of interests."[185] This principle, we believe, can also be applied to geoengineering governance.

While the concept of equity is subject to the objection that it "encourage[es] instability and relativity" in the legal system,[186] it can play a useful role in situations where "a balancing of interests and consideration of all relevant factors" is necessary.[187] It has appeared most prominently in international legal instruments related to the development and utilization of international watercourses,[188] the regulation of oceanic fisheries,[189] and the use of genetic resources.[190] Most pertinent for the current discussion, the Climate Convention recites in Article 3 that "equity" should guide international action addressing climate change.[191]

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[185] *Transboundary Harm*, *supra* note 166, art. 9(2) & 10 (applying principle of equitable balance of interests to hazardous activities that create a risk of transboundary harm, but excluding harm to global commons from concept of "transboundary harm"). *See also* Convention on the Law of the Non-Navigational Uses of International Watercourses, 4–5, UN Doc. A/51/869, 36 I.L.M. 700 (May 21, 1997) (equitable and reasonable utilization of shared watercourses); INT'L L. ASS'N, BERLIN RULES ON WATER RESOURCES, 12–13, 21 (Aug. 21, 2004) (equitable utilization of internationally shared waters).

[186] PATRICIA BIRNIE & ALAN BOYLE, INTERNATIONAL LAW AND THE ENVIRONMENT, 146 (2d ed. 2002)

[187] *Id.* at 146–47. *See also* PHILIPPE SANDS, PRINCIPLES OF INTERNATIONAL ENVIRONMENTAL LAW, 261–63 (2d ed. 2003).

[188] *See, e.g.,* Convention on the Law of the Non-Navigational Uses of International Watercourses, *supra* note 185, art. 5–6, 21. *See* OWEN MCINTYRE, ENVIRONMENTAL PROTECTION OF INTERNATIONAL WATERCOURSES UNDER INTERNATIONAL LAW 3–8 (2007).

[189] *See, e.g.,* Fisheries Jurisdiction Cases (U.K. v. Ice.; F.R.G. v. Ice.), 1974 I.C.J. 3, 72 (July 25) (parties utilizing shared fishery resources have obligation to cooperate with a view toward "equitable exploitation . . . of those resources . . ."). *See also* Song-Myon Ree Rhee, *The Application of Equitable Principles to Resolve the United States-Canada Dispute Over East Coast Fishery Resources,* 21 HARV. INT'L L. J. 667 (1980).

[190] *See, e.g.,* United Nations Convention on Biological Diversity, art. 15(7), 1760 U.N.T.S. 79 (June 5, 1992); Conference of the Parties to the Convention on Biological Diversity, October 18–29, 2010, *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising From Their Utilization*, U.N. Doc. UNEP/CBD/COP/10/27, Annex I at 87–106 (Jan. 20, 2011).

[191] Climate Convention, *supra* note 178, at art. 3(1).

1. Equity and Risk Analysis

An equitable balancing of interests is an essential step in geoengineering governance for the straightforward reason that it is likely to be impossible to fashion any clear rules for determining whether, when, and how to use a particular geoengineering technique. Every proposed geoengineering scenario will have its own unique properties. For example, different geoengineering proposals are likely to differ in their costs, probabilities of success, impacts on global climate, likely consequences for ecosystems, and the possibility of adverse climate or weather impacts on particular regions of the world.[192] All these factors, and more, should be taken into account in decisions concerning the use of the geoengineering option.

Risk analysis is an inherent part of this balancing of interests. Indeed, the International Law Commission's Draft Articles on the Prevention of Harm from Hazardous Activities incorporate risk analysis directly into the determination of an "equitable balance of interests"—the fundamental principle that the ILC suggests should govern transboundary harm to public health and the environment.[193] To achieve an equitable balance of interests, Article 10 indicates that the actors involved must take into account the risk of harm to the environment and the populations of other states, the availability of risk minimization methods, and the benefits of the activity in question.[194]

The Draft Articles, however, say little about how to weigh risks against one another. On that point, however, the risk analysis literature provides guidance. For example, Graham and Wiener raise six considerations that can help decisionmakers in weighing one risk against another: (1) the probability of harm, or the "magnitude of risk";[195] (2) the size of the at-risk populations;[196] (3) "certainty in risk estimates," distinguishing science from speculation;[197] (4) the "type of adverse outcome";[198] (5) "distributional considerations," including impacts on disadvantaged or under-represented groups;[199] and (6) the timeframe, or imminence, of each of the risks involved.[200]

2. Defining Equity

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[192] *See supra* Part I–II.

[193] *See Transboundary Harm*, *supra* note 166, art. 7 & 10.

[194] *Id.* art. 10.

[195] GRAHAM & WIENER, *supra* note 105, at 30.

[196] *Id.* at 31.

[197] *Id.* at 31–32.

[198] *Id.* at 32–34.

[199] *Id.* at 34–35.

[200] GRAHAM & WIENER, *supra* note 105, at 36.

An equity norm need not be completely open-ended. An international geoengineering agreement embracing such a norm could identify, in advance, a list of factors to take into account in determining whether to move forward with a particular geoengineering project. Such an agreement should make explicitly clear, for example, that any use of geoengineering is appropriate only when undertaken for "the common good of [hu]mankind," consistent with Principle 18 of the Stockholm Declaration.[201] Considerations such as costs,[202] probabilities of success,[203] ecosystem impacts,[204] and adverse weather impacts should also be expressly mentioned, as should the importance of considering the gravity of the threat of climate change and the probability that a particular geoengineering proposal could address that threat effectively.[205] Moreover, certain considerations could be identified, in advance, as deserving more weight than others. For example, protection of weather patterns vital to important agricultural regions of the world, perhaps especially to agricultural regions in poorer nations, ought to carry heavy weight in any assessment of a geoengineering proposal.[206] If such a proposal created a serious threat of disrupting, for example, the East Asian monsoon on which much of India's agriculture depends, that would be a powerful reason in favor of abandoning or altering that particular geoengineering proposal.

At the same time, a norm of equity allows for necessary action to occur despite the possibility that it will cause some harm. Whereas the customary norm that states must "ensure that activities within their jurisdiction or control do not cause damage to the environment of other States"[207] would, if applied in this context, seem antithetical to any geoengineering activity that threatened significant transboundary harm, an equity principle allows for the possibility of such harm where it is warranted by the benefits to be secured by geoengineering.[208] In other words, under an equity principle, the risks of climate change that geoengineering could ameliorate would need to be weighed against the countervailing risks that geoengineering raise. As painful as it is to admit, the international community may soon be facing circumstances in which some states (or ecosystems) must suffer adverse

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[201] Stockholm Declaration, *supra* note 182, at principle 18.

[202] *See* Jay Michaelson, *Geoengineering: A Climate Change Manhattan Project*, 17 STAN. ENVTL. L.J. 73, 125–27 (1998) (responding to arguments that geoengineering's costs make it impractical and inefficient).

[203] *See id.* at 122–25 (noting that some proposals show great promise and certain unknowns require more caution and research, not pessimism).

[204] Carlarne, *supra* note 13, at 661 n.238.

[205] *See generally* GRAHAM & WIENER, *supra* note 105.

[206] Berlin Rules on Water Resources, *supra* note 185.

[207] Stockholm Declaration, *supra* note 182, at principle 21.

[208] *Transboundary Harm*, *supra* note 166, art. 10 (providing that the risk of significant transboundary harm must be balanced against potential benefits of the hazardous activity).

environmental impacts in order to avoid catastrophic climate disruption on an even larger scale. Without denying that transboundary harm should be minimized and that compensation to injured states may be appropriate, any international governance structure for geoengineering should be based on a substantive norm that explicitly accepts that such tradeoffs may be necessary.[209]

B. Important Procedural Norms for Geoengineering Governance

One function of a norm of equity is to ensure that action affecting a shared natural resource (in this case, the climate) takes place in a cooperative legal framework in which "due account is taken of the sovereignty and interests of all States."[210] There are important procedural norms that can facilitate such cooperation and help ensure that the interests of all affected states are considered in decision making. If incorporated into a geoengineering agreement, these norms will enhance the quality and legitimacy of geoengineering decision making. Procedural norms for geoengineering governance include notification, consultation, public disclosure, and preparation of an environmental impact assessment prior to any geoengineering activity.

Two of these important procedural norms are the obligations of notification and consultation. Notice and a period of consultation should be explicitly required before any significant geoengineering activity is approved, including any geoengineering experiment that could have transboundary impacts or impacts on areas outside the jurisdiction of the involved states.[211] Prior notice and a right of consultation will give potentially affected States the right to participate in discussions and perhaps to shape decisions.[212] Notice will also allow potentially affected states to prepare to monitor the impact of the activity and prepare to address any adverse impacts. Notice and consultation may also improve the quality of geoengineering decisions by increasing and broadening scientific scrutiny of particular geoengineering actions, both before and after they occur.[213] For these same basic reasons—improving the quality and legitimacy of geoengineering decision making—a global geoengineering agreement should require public disclosure (and international exchange) of data and information concerning geoengineering actions that have been taken as well as actions that are planned in the

[209] The problem of reconciling a principle of 'no harm' to other users with the desirability of maximizing benefits from a shared resource is a problem common to the use of water resources. In both international practice and in some U.S. states, the reconciliation is accomplished through the concept off equitable and reasonable use.

[210] Stockholm Declaration, *supra* note 182, at principle 24.

[211] Davis, *supra* note 33, at 945.

[212] *See id.* at 946.

[213] *See id.*

future.[214] Information disclosure is a basic requirement of sound international environmental governance[215] and is increasingly a requirement of international agreements addressing the problems of managing shared resources[216] or coping with adverse transboundary impacts.[217]

The norms of notification, consultation, and information sharing ought to apply to all states, including states that are not party to any geoengineering agreement. As we discuss below, effective governance of geoengineering may require that it be accomplished through a governance structure that does not accord equal weight to the views of all states. For this reason, as well as others, some states may choose not to participate in a geoengineering agreement. Some states, for example, may lack the resources to participate. Failure to participate in the treaty structure should not, however, mean that states completely forfeit their sovereign right to be notified and consulted with respect to activities that might affect them.[218]

An environmental impact assessment ("EIA") should also be required prior to approval of any geoengineering activity that has a likelihood of transboundary impact.[219] The practice of environmental impact assessment is today so widespread[220] and so widely acknowledged as a key component of effective international environmental management,[221] that one might argue that it is now required by customary international law. Whether that is the case or not, no geoengineering activity with a potential transboundary impact should be allowed to proceed without such an assessment. The reason, we think, is obvious: an effort to alter a fundamental part of our planet's ecosystem should not proceed without an assessment of its likely consequences, unintended as well as intended. An EIA would fulfill much of the risk-risk comparison necessary to achieve an equitable balance of

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[214] *See* Carlarne, *supra* note 13; Jochen Prantl, *Why We Need a Debate About Geoengineering Governance ... Now*, NTS ALERT (S. Rajaratnam Sch. Of Int'l Studies/Ctr. For Non-Traditional Sec.) April 2011, *available at* http://www.rsis.edu.sg/nts/HTML-Newsletter/Alert/pdf/NTS_Alert_apr_1101.pdf; Jane Long & David Winickoff, *Governing Geoengineering Research: Principles and Process*, SOLUTIONS J., 60–62 (2010), *available at* http://www.thesolutionsjournal.com/node/774.

[215] Rio Declaration on Environment and Development, Annex, U.N. GAOR, U.N. Doc. A/CONF. 151/26 (Vol.1), at principle 19 (June 3–14, 1992).

[216] *See* INT'L L. ASS'N, *supra* note 185.

[217] *See* Carlarne, *supra* note 13.

[218] *See* SCOTT BARRETT, GEOENGINEERING'S GOVERNANCE (2010), *available at* http://science.house.gov/sites/republicans.science.house.gov/files/documents/031210_Barrett.pdf.

[219] *See* 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, 104 (2005); Albert C. Lin, *Revamping Our Approach to Emerging Technologies*, 76 BROOK. L. REV. 1309, 1323–24 (2011); Prantl, *supra* note 214.

[220] William Boyd, *Climate Change, Fragmentation, and The Challenges of Global Environmental Law: Elements of a Post-Copenhagen Assemblage*, 32 U. PA. J. INT'L L. 457, 504–05 (2010).

[221] Rio Declaration, *supra* note 215, at principle 17.

interests. In addition, if the geoengineers know that their models predict some adverse environmental consequences from their activities, those adverse consequences should be revealed and discussed in advance of the activity.

An EIA requirement need not be unduly onerous. In the first place, any potential geoengineers will already be attempting to model and predict the environmental consequences of their action. Moreover, for geoengineering experiments with modest and easily reversed impacts, the assessment could be less thorough than for major geoengineering activity. To ensure fully informed decision making, though, an assessment requirement should nonetheless be built into any international framework for governing geoengineering activities with potential transboundary impacts, regardless of the type of geoengineering.

C. Liability and Compensation

The principle that those who cause environmental harm should provide compensation to injured parties has been strongly endorsed at the international level[222] and embodied in international agreements concerning compensation for damage caused by oil spills,[223] nuclear accidents,[224] industrial accidents,[225] the transboundary movement of hazardous waste,[226] and the production and sale of genetically modified organisms.[227] While some of these agreements are not yet in force, there is a strong and general consensus (reflected in national law as well as international law) that governments should take steps to ensure that compensation is available to victims of activities or accidents that cause major environmental harm, whether through an international compensatory mechanism or through an action for compensation in domestic courts.

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[222] Rio Declaration, *supra* note 215, at principles 13 & 16; Stockholm Declaration, *supra* note 182, at principle 22; *Transboundary Harm*, *supra* note 166.

[223] *See* International Convention on Civil Liability for Oil Pollution Damage, Nov. 27, 1992, 1956 U.N.T.S. 255; International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, Nov. 27, 1992, 1953 U.N.T.S. 330; Supplementary Fund Protocol to the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, May 16, 2003, C.P.N. 6245.

[224] *See, e.g.,* 1997 Vienna Convention on Civil Liability for Nuclear Damage, Sept. 12, 1997, 36 I.L.M. 1462 (1997).

[225] Protocol on Civil Liability and Compensation for Damage Caused by the Transboundary Effects of Industrial Accidents on Transboundary Waters, May 21, 2003, U.N. Doc. ECE/MP.WAT/11-ECE/CP.TEIA/9.

[226] Basel Protocol on Liability and Compensation for Damage Resulting From Transboundary Movements of Hazardous Wastes and Their Disposal, U.N. Doc. UNEP/CHW.1/WG/1/9/2 (Dec.10, 1992).

[227] Nagoya-Kuala Lumpur Supplementary Protocol on Liability and Redress to the Cartagena Protocol on Biosafety, U.N. Doc. UNEP/CBD/BS/COP-MOP/5/17 (Oct.15, 2010).

Any international geoengineering agreement should include provisions for compensation in the event that geoengineering activities lead to environmental harm. A promise of compensation to injured states or individuals[228] will enhance the legitimacy of the geoengineering enterprise from the outset by demonstrating that geoengineering will be driven by considerations of overall global benefits and not by the motivation of particular states to improve their circumstances at the expense of other states.[229] Furthermore, to the extent that geoengineering causes transboundary harm, there will be demands for compensation whether it is addressed in the geoengineering agreement or not, and there are good practical reasons to provide for compensation from the outset.

First, a compensation mechanism, whether in the form of a compensation fund or liability standard must be included in a geoengineering governance institution as a matter of justice.[230] Principles of corrective justice generally favor allowing victims to hold their injurers accountable.[231] Second, inclusion of a compensation mechanism will improve decision making and precaution by encouraging the decisionmakers to factor the probable harms of a particular activity into their decisions about whether or not and how to engage in that activity—commonly referenced as the general deterrence function of liability for caused harms.[232] Third, establishing a liability rule will also reduce uncertainty and transaction costs associated with decision making: if the states likely to be harmed by a geoengineering activity know in advance that they will be compensated for their losses and receive international aid to ameliorate any adverse impacts, then they will be more likely to agree to a geoengineering decision. Fourth, a compensation mechanism may enhance the quality of information gathering before a

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[228] We express no opinion on whether the compensation mechanism should provide for direct compensation to injured individuals or compensation to states.

[229] *See* Noah Sachs, *Beyond the Liability Wall: Strengthening Tort Remedies in International Environmental Law,* 55 UCLA L. REV. 837, 844 (2008).

[230] Considerations of justice cannot be avoided given the inevitable transboundary effects of geoengineering. *See* CHARLES BEITZ, POLITICAL THEORY AND INTERNATIONAL Theory 131 (rev. ed. 1999) ("[T]he requirements of justice apply to institutions and practices (whether or not they are genuinely cooperative) in which social activity produces relative or absolute benefits or burdens that would not exist if the social activity did not take place.").

[231] *See* Gary T. Schwartz, *Mixed Theories of Tort Law: Affirming Both Deterrence and Corrective Justice*, 75 TEX. L. REV. 1801 (1996); Gregory C. Keating, *Distributive and Corrective Justice in Tort Law of Accidents*, 74 S. CAL. L. REV. 193, 193–95 (2000); Roger Meiners & Bruce Yandle, *Common Law and the Conceit of Modern Environmental Policy*, 7 GEO. MASON L. REV. 923, 960 (1999); JULES L. COLEMAN, RISKS AND WRONGS 303–28 (1992); ARTHUR RIPSTEIN, EQUALITY, RESPONSIBILITY, AND THE LAW 24 (1999); ERNEST J. WEINRIB, THE IDEA OF PRIVATE LAW 56–83 (1995); Richard A. Epstein, *A Theory of Strict Liability*, 2 J. LEGAL STUD. 151 (1973); George P. Fletcher, *Fairness and Utility in Tort Theory*, 85 HARV. L. REV. 537, 547 (1972).

[232] *See generally* GUIDO CALABRESI, THE COSTS OF ACCIDENTS: A LEGAL AND ECONOMIC ANALYSIS (1970); Robert D. Cooter, *Economic Theories of Legal Liability*, 5 J. ECON. PERSP. 11, 11 (1991); RICHARD A. EPSTEIN, CASES AND MATERIALS ON TORTS 133–36 (8th ed. 2004); Schwartz, *supra* note 231; Sachs, *supra* note 229, at 844.

geoengineering decision as well as ecological and public health monitoring after geoengineering is underway. Such a mechanism would give states that are likely to be adversely affected a powerful financial incentive insist that an EIA and monitoring are conducted adequately. Finally, it will also be easier to insure against losses or to finance a compensation fund if steps are taken toward this end before, rather than after, harm has occurred. Agreement on details like adjudicative mechanisms, the kind of harms that are compensable, and the standards of proof that must be met to verify losses also will be much more likely if the matter is negotiated in advance of any actual injury.[233]

D. Governance Structure

Some experts suggest that participation in geoengineering governance should be restricted to those states willing to fund geoengineering or to sponsor geoengineering activities.[234] Such a governance model, similar to the structure of the Antarctic Treaty,[235] seems to us to be wholly inappropriate in this context. Geoengineering will affect many (if not all) states whether they participate in the geoengineering deployment or not.[236] Moreover, those impacts could, in some cases, be profoundly negative. While activities in the Antarctic could have transboundary or global impacts, they mostly do not. Geoengineering, on the other hand, would almost certainly have such impacts. All states should have a right to participate in governance of an activity intended to affect the functioning of the global climate system, regardless of their interests in participating in the activity or their ability to pay for it.[237] After all, a stable climate is the "common heritage" of humankind.

By the same token, a governance regime open to all and dependent on one-nation, one-vote decision making has problems of its own. As noted above, climate change is a "wicked problem," and as such, the parties to the UNFCCC have found it impossible to make significant progress toward agreement on mitigation commitments to follow the Kyoto Protocol.[238] While there is no guarantee that a different decision-making process would affect climate negotiations, the need to achieve something near consensus among

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[233] *See id.* at 878–879.

[234] *See Geoengineering: Gambling With Gaia*, ETC GROUP, Oct. 2010, at 1, *available at* http://www.etcgroup.org/sites/www.etcgroup.org/files/publication/pdf_file/ETC_COP10GeoBriefing081010.pdf.

[235] The Antarctic Treaty gives consultative status, and a significant role in governance to a Contracting party only if the party "demonstrates its interest in Antarctica by conducting substantial scientific research activity there . . ." Antarctic Treaty, article IX(2), Dec. 1, 1959, 402 U.N.T.S. 71.

[236] *See* Barrett, *supra* note 38.

[237] *See id.*

[238] *See supra* Introduction.

188 member states surely hinders progress. Similarly, the International Whaling Commission has been dysfunctional for many years, due in part to its one-nation, one-vote decision structure, the recruitment of nations to membership (and participation in voting blocs) despite those nations' lack of real interest in the issues facing the organization, and super-majority voting requirements.[239] The failure to make progress in the latest round of international trade negotiations has been attributed to the WTO's consensus approach to decision making.[240]

There is a middle ground between "pay-to-play" and one-nation/one-vote that is best exemplified, in our view, by the Articles of Agreement of the International Monetary Fund ("IMF Agreement").[241] The IMF Agreement adopts a system that assigns votes to countries largely on the basis of their relative size in the world economy.[242] Most decision making is in the hands of a 24-person Executive Board whose members are appointed by the largest IMF members or elected by groups of Member States.[243] Each Executive Director casts the votes of the states he or she represents. Certain major decisions require an 85 percent vote, which effectively gives a veto to the United States or to the EU states acting jointly, but also ensures that substantial groups of smaller economies could, acting jointly, prevent significant actions that are adverse to their interests.[244] Placing responsibility for day-to-day IMF operations in the hands of a relatively small Executive Board can promote consensus-based decision making and has the potential to strengthen the voice of smaller countries, which are guaranteed a role in the decision-making process and can form coalitions to elect Executive Directors to cast their votes and represent their interests.[245]

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[239] *See* Jonathan C. Carlson, Geoffrey W.R. Palmer, & Burns H.Weston, *Editors' Comment: To Preserve Whales or to Slaughter Them?, in* INTERNATIONAL ENVIRONMENTAL LAW AND WORLD ORDER: A PROBLEM-ORIENTED COURSEBOOK 497, 504–06 (Jonathan C. Carlson, Geoffrey W.R. Palmer & Burns H. Weston, eds. 3d ed. 2012).

[240] *See* Richard A. Gardner, *The Bretton Woods-GATT System after Sixty-five Years: A Balance Sheet of Success and Failure,* 47 COLUM. J. TRANSNAT'L L. 31, 61 (2008) ("The WTO's large and diverse membership coupled with the unanimity rule is one reason the Doha Round has stalled."); *see generally* JOHN H. JACKSON, SOVEREIGNTY, THE WTO, AND CHANGING FUNDAMENTALS OF INTERNATIONAL LAW 24, 50, 113–116 (2006) (arguing that the formal equality of nations in WTO voting hinders effective decision making).

[241] *See* Articles of Agreement of the International Monetary Fund, Dec. 27, 1945, art. XII, § 5, 60 Stat. 1401, 1418–19, 2 U.N.T.S. 39, 86–88, *amended by* May 31, 1968, 20 U.S.T. 2775, *amended by* Apr. 30, 1976, 29 U.S.T. 2203,.

[242] S. Brock Blomberg & J. Lawrence Broz, *The Political Economy of IMF Voting Power and Quotas*, 1 (Aug. 23, 2007) (unnumbered working paper), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1080316.

[243] *Id.* at 5.

[244] *Id.* Because weights are voted, however, the 85 percent voting requirement is not as great an obstacle as it would be in a one-nation/one-vote system.

[245] *See generally* Ngaire Woods & Domenico Lombardi, *Uneven Patterns of Governance: How Developing Countries Are Represented in the IMF,* 13 REV. INT'L POL. ECON. 480 (2006)

We believe a similar approach should be taken to geoengineering governance. Each state that joins a geoengineering agreement should be assigned a base number of votes (as in the IMF Agreement). Additional votes could then be assigned in a manner that reflects what we regard as a fundamental political reality: states with the capacity and incentive to engage in geoengineering activity are not likely to surrender their freedom of action and join an effective, future-oriented international regulatory structure unless they are guaranteed a major role in the operation and decision making of the international organization.[246] Required financial contributions to the organization should parallel voting power, as in the IMF Agreement.

There are a number of criteria that could be used to determine a state's financial contribution and voting power within a geoengineering agreement. We believe the most obvious approach is to weigh votes and apportion financial responsibility by a state's contribution to global greenhouse gas emissions.[247] Such an approach would place financial responsibility on the states that are most responsible for our global failure to mitigate climate change. It would focus power and responsibility within the organization on the states with the largest economies and largest populations in the world.[248] It would also ensure that the decision-making body was globally representative, as the top fifteen GHG-emitting nations (accounting for 80 percent of global emissions) include states from every continent and at widely varying levels of development.[249] Finally, a governance mechanism of this sort would help promote sound decisions by placing leadership responsibility on those states whose scientific expertise and economic capacity make them

(discussing how voting power and other factors can adversely affect the ability of developing countries to protect their interests within the IMF structure).

[246] Leonardo Martinez-Diaz, *Executive Boards in International Organizations: Lessons for Strengthening IMF Governance*, Independent Evaluation Office of the International Monetary Fund (2008), at 28–29, *available at* http://imf-ieo.org/ieo/files/completedevaluations/05212008BP08_08.pdf; *cf.* Victor, *supra* note 29, at 331 (predicting that potential geoengineers "would balk" at a treaty that sought to ban geoengineering.)

[247] *Climate Analysis Indicators Tool (CAIT)*, WORLD RES. INSTITUTE (last updated May 2012), www.wri.org/project/cait/.

[248] Ariel Buira, *The Governance of the IMF in a Global Economy*, *in* CHALLENGES TO THE WORLD BANK AND IMF: DEVELOPING COUNTRY PERSPECTIVES 13 (Ariel Bund ed., 2003), *available at* http://www.g24.org/TGM/buiragva.pdf.

[249] LARRY PARKER & JOHN BLODGETT, CONG. RESEARCH SERV., RL 32721, GREENHOUSE GAS EMISSIONS: PERSPECTIVES ON THE TOP 20 EMITTERS AND DEVELOPED VERSUS DEVELOPING NATIONS 14 (2010), *available at* http://op.bna.com/hl.nsf/id/thyd-7zhq46/$File/CRS%20-%20Comparing%20GHG%20Emissions.pdf. Treating the EU as a single entity, the top fifteen emitters are: China, United States, European Union, Russia, India, Japan, Brazil, Canada, Mexico, Indonesia, South Korea, Australia, Iran, Ukraine, and South Africa.

most able to carry out the difficult and costly assessments that should be undertaken prior to implementation of any geoengineering plan.[250]

It might seem perverse to suggest weighted voting at a time when the IMF itself is pursuing reform of its voting structure in response to critiques of its legitimacy.[251] Indeed, there are obvious objections in principle to weighted voting governance. Weighted voting is a stark departure from the "one-nation, one-vote" paradigm that dominates international environmental agreements.[252] It is in obvious tension with the principle of the "sovereign equality" of states.[253] In addition, weighted voting systems are open to the objection that they can weaken the voice of those most affected by a particular international action.[254] Furthermore, the calculation of financial responsibility on the basis of current contributions to greenhouse emissions does not fully reflect either the historic contribution of developed states to rising atmospheric greenhouse gas concentrations or the notion that developed countries should "take the lead in combating climate change and the adverse effects thereof."[255] Despite these problems, we think the approach we have outlined is far more likely to lead to effective international governance of geoengineering than a "one-nation, one-vote" governance structure. To increase the influence of smaller countries in decision making, a

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[250] It may also be the case that decisions in an IMF-type structure will be more likely to be based on non-political, technical considerations than decisions made in the setting of a large diplomatic conference (which is the forum for critical decision making in many environmental treaties). Though the IMF makes important and closely watched decisions with global economic implications, "the limited occurrence of political decisions in the IMF has been remarkable." LEO VAN HOUTVEN, GOVERNANCE OF IMF: DECISION MAKING, INSTITUTIONAL OVERSIGHT, TRANSPARENCY AND ACCOUNTABILITY 43–44 (2002), *available at*http://www.imf.org/external/pubs/ft/pam/pam53/pam53.pdf. On the other hand, there is a widespread perception that IMF decisions are political in nature, and that perception may be due to the weight given to a handful of nations in its decision-making process. *See generally* Carlo Cottarelli, *Efficiency and Legitimacy: Trade-Offs in IMF Governance, in* IMF-SUPPORTED PROGRAMS: RECENT STAFF RESEARCH 103, 107 (Ashoka Mody & Alessandro Rebucci eds., 2006).

[251] *See generally* David P. Rapkin & Jonathan R. Strand, *Reforming the IMF's Weighted Voting System*, 29 WORLD ECON. 305 (2006). The reform, however, is not aimed at abolishing weighted voting. Rather, it seeks to adjust the votes to increase the voting power of certain key developing countries. Our weighted voting proposal would give significant voting authority to developing countries.

[252] See Joseph E. Stiglitz, *Democratizing the International Monetary Fund and the World Bank: Governance and Accountability*, 16 GOVERNANCE 111, 120 (2003), *available at* http://policydialogue.org/files/publications/Democratizing_International_Monetary_Fund_Stiglitz.pdf.

[253] U.N. Charter art. 2, para 1; *see also* Draft Principles of Conduct in the Field of the Environment for Guidance of States in the Conservation and Harmonious Utilization of Natural Resources Shared by Two or More States, UNEP Governing Council Decision 12/2, ¶ 1, U.N. Doc. UNEP/IG12/2 (May 19, 1978) (Cooperation on environmental matters would "take place on an equal footing and taking into account the sovereignty, rights and interests of the States concerned.").

[254] *See* Daniel D. Bradlow, *Rapidly Changing Functions and Slowly Evolving Structures: The Troubling Case of the IMF,* 94 AM. SOC'Y INT'L L. PROC. 152, 153 (2000).

[255] UNFCCC, *supra* note 178, art. 3, para.1

"double-majority" voting rule (requiring both a majority of weighted votes and a majority of countries for decisions) could be adopted to ensure that the largest countries could not proceed without taking account of, and gaining support from, smaller countries. [256] This would reduce, but not eliminate, the advantages of efficiency and congruence with interests and power that the IMF model provides.

One important advantage of the model we have proposed is that it gives the large GHG emitters from the group of developing nations—e.g. China and India—a major role in geoengineering governance and, consequently, in addressing the problem of climate change. Their contribution to the climate change threat, along with their growing economic power and their ability to engage in unilateral geoengineering, is sufficient reason to ensure that they are full participants in all efforts to address climate change.[257]

E. The Scientists

Decisions concerning geoengineering must be based on sound science. Proponents of geoengineering propose to make massive, possibly planetary-wide, changes to the earth's climate system. Before any such proposals are allowed to move forward, they must be subject to a careful, independent, and neutral scientific assessment of their feasibility, likely effectiveness, and risks. If geoengineering is a necessary part of the solution to our climate problem (and we fear it may be), then international decisions about approving geoengineering must be structured to ensure that approved projects are those that are most likely to succeed, that the projects do not conflict with one another, and that special pleading or political influence does not trump science in the approval process.[258]

International environmental treaties seek to secure scientific input into the international policy-making process in a variety of ways.[259] We think the concerns noted above require a very strong mechanism for science advice in any geoengineering agreement. A scientific advisory committee should be

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[256] Martinez-Diaz, *supra* note 246; Woods & Lombardi, *supra* note 232.

[257] *See* Buira, *supra* note 248.

[258] Financial muscle and political influence is already lining up behind certain geoengineering solutions, and leading scientists are acquiring financial stakes in particular techniques that may influence their future advocacy of particular geoengineering proposals. *See generally* Vidal, *supra* note 132.

[259] *See*, *e.g.*, Convention on Long Range Transboundary Air Pollution [LRTAP], art. 7, Nov. 13, 1979, 1302 U.N.T.S. 217 (encouraging research and research cooperation with respect to air pollution); Montreal Protocol on Substances that Deplete the Ozone Layer art. 7, Sept. 16, 1987, 1522 U.N.T.S. 3 (establishment of expert panels to conduct scientific assessment of measures to control ozone-depleting substances); UNFCCC art. 5, *supra* note 178 (research support and cooperation); *id.*, art. 9 (establishment of intergovernmental body for scientific assessment); Rotterdam Convention on Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade art. 5–7 & 18, Sept. 11, 1998, 2244 U.N.T.S. 337 (establishing a Chemical Review Committee, consisting of experts in chemical management, to advise parties on listing of chemicals in treaty annexes).

created and given power to review and make recommendations concerning any geoengineering proposal that is presented to the international governing body.[260] Ideally, no action could be taken without the concurrence of this body, but such a requirement might overly politicize the group and would certainly complicate negotiations concerning its composition. Therefore, it may be preferable to make its decision recommendatory only. With respect to composition, the minimum requirements should be that the individuals serving on the panel are persons of recognized scientific standing with expertise in climate change, geoengineering, weather modification, or the human/social impacts of climate instability. To ensure the independence of members, they must be expressly authorized to serve in their individual capacities and not as government representatives.[261] A scientist's home state should be expressly precluded from giving the scientist instructions or seeking to influence the scientist's decision.[262] Finally, reports and recommendations of the body should be publicly available, which will allow for scrutiny and analysis by other independent scientists.[263]

V. CONCLUSION

We have no illusions that the governance roadmap we have provided in this paper is comprehensive; we know that many details must be worked out in negotiations. Nevertheless, we believe that the principles and basic governance structure sketched out above could provide the foundation for a workable agreement to bring geoengineering under coherent and effective international control. We hope in a future paper to offer more detailed suggestions about the content of a treaty on this subject.

In her 1957 novel, *Atlas Shrugged,* Ayn Rand described a composer named Richard Halley who, like many of Rand's protagonists, was a man of transcendent and unappreciated genius. Halley wrote an opera based on the myth of Phaëthon. As anyone familiar with Rand's work will probably guess,

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[260] *See* Long & Winickoff, *supra* note 214.

[261] A model for this approach at the international level can be found in the World Trade Organization ("WTO")'s provisions for dispute settlement. *See* WTO, DISPUTE SETTLEMENT, art. 8, para. 9 (1994), *available at* www.wto.org/english/tratop_e/dispv_e/dsv_e.htm. "Panelists shall serve in their individual capacities and not as government representatives, nor as representatives of any organization. Members shall therefore not give them instructions nor seek to influence them as individuals with regard to matters before a panel." *Id.*

[262] Again, the WTO Dispute Settlement Understanding provides a model. *See id.*

[263] David Victor argues that international assessment of geoengineering solutions should "enlist multiple strong assessment institutions rather than a single, global, and weak institution. A few competent groups could prepare assessments in parallel—ideally groups that are connected to active scientific research in the area—and then compare the assessments." Victor, *supra* note 29, at 330. We are in basic agreement with Victor's belief that "multiple strong assessment institutions" are desirable, and our proposal for a treaty-based advisory group is not intended to, nor would it, preclude rigorous assessment by scientific experts at the national level. To the contrary, we would expect research and assessment activities to be ongoing, and we would expect international comparison of the results of those assessments, pursuant to the information-sharing and related norms discussed earlier in this paper.

Halley's operatic version of the myth departs from the Greek story in one significant way: Phaëthon controls the chariot and completes his flight; humankind triumphs even against the forces of gods and nature.[264]

We think it is almost inevitable that humankind will seek to fly Phaëthon's chariot. We must hope that Rand's optimistic and utopian modern mythology is more prophetic than the fatalistic vision of the Greeks and Romans. We must also work as best we can to ensure the enterprise's success.

[264] For an analysis, see Kirsti Minsaas, *Ayn Rand's Recasting of Ancient Myths in* Atlas Shrugged, *in* AYN RAND'S ATLAS SHRUGGED: A PHILOSOPHICAL AND LITERARY COMPANION 131 (Edward W. Younkins ed., 2007).