Article

The Missing Pieces of Geoengineering Research Governance

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INTRODUCTION

Geoengineering research is at a crossroads.[1] With growing urgency, scientists have expressed interest in moving beyond computer modeling and laboratory trials.[2] However, recent efforts to conduct field experiments have encountered strong opposition. The intensifying controversy points to the need to establish a system of geoengineering research governance. Two research projects that received substantial media attention—the Stratospheric Particle Injection for Climate Engineering (SPICE) project, and an ocean fertilization experiment sponsored by a native Haida village in British Columbia—illustrate the concerns that geoengineering field research raises.

The U.K. Research Councils commissioned the SPICE project in 2010 to investigate the potential release of aerosols into

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1. Geoengineering is a catch-all term for various proposed climate change policy responses that do not constitute reduction of greenhouse gas emissions or adaptation. *See* Albert C. Lin, *Geoengineering*, *in* GLOBAL CLIMATE CHANGE AND U.S. LAW 715, 715 (Michael B. Gerrard & Jody Freeman eds., 2d ed. 2014); *see also infra* Part I.A (defining geoengineering and discussing examples).

2. *See, e.g.*, NAT'L RESEARCH COUNCIL, CLIMATE INTERVENTION: REFLECTING SUNLIGHT TO COOL EARTH 152 (2015) (recommending development of a research program on methods to modify the Earth's reflectivity, including small-scale field experiments); Jane C.S. Long et al., *Start Research on Climate Engineering*, 518 NATURE 29, 30 (2015) (urging commencement of small-scale outdoor experiments).

the stratosphere to block solar radiation.[3] The project originally involved a modest field component in addition to desk-based and computer modeling work.[4] In the field component, scientists planned to spray 150 liters of water from a tethered balloon and to observe the contraption's movements under varying wind conditions.[5] The experiment would have blocked virtually no solar radiation and carried little if any physical risks.[6] Furthermore, the experiment was subject to typical university research oversight as well as additional review by a panel of scientists and social scientists.[7] Two key concerns nonetheless led to the field experiment's cancellation.[8] First, several project researchers had filed a patent application for the experimental mechanism, prompting objections regarding their motives.[9] Second, and more importantly, critics worried that the experiment signified a growing commitment to geoengineering deployment.[10] In contrast to the investigation of basic scientific principles, research regarding a specific geoengineering technique takes place with an operational objective in mind: deployment of the technique. Hastily moving forward with research, it is feared, could enable eventual deployment without sufficient public discussion or informed deliberation by policy makers.[11]

3. *See Aims and Background*, SPICE, http://www.spice.ac.uk/about-us/aims-and-background (last visited Feb. 21, 2016); *see also* Nick Pidgeon et al., *Deliberating Stratospheric Aerosols for Climate Geoengineering and the SPICE Project*, 3 NATURE CLIMATE CHANGE 451, 452 (2013). Aerosols are minute particles suspended in the atmosphere. *See Atmospheric Aerosols: What Are They, and Why Are They So Important?*, NASA, http://www.nasa.gov/centers/langley/news/factsheets/Aerosols.html (last updated July 31, 2015).

4. Pidgeon et al., *supra* note 3.

5. *See* David E. Winickoff & Mark B. Brown, *Time for a Government Advisory Committee on Geoengineering Research*, ISSUES SCI. & TECH., Summer 2013, at 79, 80; *see also* Pidgeon et al., *supra* note 3.

6. *See* Winickoff & Brown, *supra* note 5; *see also* Pidgeon et al., *supra* note 3.

7. *See* Phil Macnaghten & Richard Owen, *Good Governance for Geoengineering*, 479 NATURE 293, 293 (2011); Winickoff & Brown, *supra* note 5. This additional "Stagegate" review included a deliberative workshop with selected members of the public to gauge their response to the field experiment. Pidgeon et al., *supra* note 3.

8. *See* Winickoff & Brown, *supra* note 5; *see also* Jack Stilgoe et al., *Public Engagement with Biotechnologies Offers Lessons for the Governance of Geoengineering Research and Beyond*, 11 PLOS BIOLOGY, no. 11, 2013, 1, at 2–5.

9. *See* Winickoff & Brown, *supra* note 5.

10. *See id.*; *see also* Stilgoe et al., *supra* note 8, at 3.

11. *See* Stilgoe et al., *supra* note 8, at 5.

In the Haida experiment, the Haida tribe provided financial backing for an American businessman, Russ George, to dump over 100 tons of iron powder into international waters off the British Columbia coast.[12] The Haida hoped that fertilizing the oceans with iron would stimulate the growth of plankton and in time boost the local salmon fishery.[13] However, George's comments and his history of promoting geoengineering revealed a further, more controversial motive: to test whether ocean fertilization can sequester carbon from the atmosphere.[14] Once George publicly announced what he had done, experts expressed grave concerns.[15] The experiment not only lacked proper measurement and controls, but also took place without formal international sanction.[16] Although it is contested whether the experiment violated domestic or international law, the incident triggered a Canadian government investigation, as well as allegations that the Canadian government itself was complicit in the experiment.[17] The controversy has magnified the reluc-

12. *See* David Biello, *Can Controversial Ocean Iron Fertilization Save Salmon?*, SCI. AM. (Oct. 24, 2012), http://www.scientificamerican.com/article/fertilizing-ocean-with-iron-to-save-salmon-and-earn-money.

13. *See* Joshua Learn, *Are Record Salmon Runs in the Northwest the Result of a Controversial CO2 Reduction Scheme?*, E&E PUB. (Nov. 12, 2014), http://www.eenews.net/stories/1060008722.

14. *See* Henry Fountain, *A Rogue Climate Experiment Has Ocean Experts Outraged*, N.Y. TIMES, Oct. 19, 2012, at A1 (noting that George had previously proposed a similar iron fertilization project for the purpose of selling carbon offsets); Mark Hume & Ian Bailey, *Businessman Russ George Defends Experiment Seeding Pacific with Iron Sulphate*, GLOBE & MAIL (Oct. 19, 2012), http://www.theglobeandmail.com/news/british-columbia/businessman-russ-george-defends-experiment-seeding-pacific-with-iron-sulphate/article4622528 (reporting George's statements that "he is out to save the world's oceans and demonstrate how to halt global warming").

15. *See* Fountain, *supra* note 14. The Haida experiment followed earlier and similarly controversial ocean fertilization experiments. *See* Aaron Strong et al., *Ocean Fertilization: Time To Move On*, 461 NATURE 347, 348 (2009).

16. Edward A. Parson & David W. Keith, *End the Deadlock on Governance of Geoengineering Research*, 339 SCIENCE 1278, 1278 (2013).

17. *See* Joshua Learn, *Legal Mess Hampers Understanding of a Major CO2 Sequestration Test*, E&E PUB. (Nov. 13, 2014), http://www.eenews.net/stories/1060008800 (discussing a search of Haida offices); Dene Moore, *Ocean Fertilization Experiment Loses in B.C. Court; Charges Now Likely*, GLOBE & MAIL (Feb. 3, 2014), http://www.theglobeandmail.com/news/british-columbia/ocean-fertilization-experiment-loses-in-bc-court-charges-now-likely/article16672031 (reporting that the court dismissed Haida's application to declare the alleged offenses unenforceable and to enjoin further investigation by the Canadian environmental agency); *West Coast Ocean Fertilization Project Defended*, CBC NEWS (Oct. 19, 2012), http://www.cbc.ca/news/canada/british-columbia/west-coast-ocean-fertilization-project-defended-1.1226125 (recounting project leaders' contentions that they did not violate Canadian or international laws);

tance of potential funders to support basic research in this area and raised anxieties regarding rogue geoengineering field experiments.[18]

The fact that these field experiments generated substantial controversy despite their limited scope suggests various concerns. A number of these concerns cluster around the theme of a growing distrust of geoengineering researchers. The Haida incident reinforces the stereotype of the mad scientist who presses forward with his desired experiments, the public and environment be damned. Indeed, both the Haida and SPICE experiments resonate with a vigorous online discourse that supposes the existence of an ongoing secret program of large-scale climate modification.[19] Moreover, the possible role of personal financial motivations in both experiments exacerbates the public distrust. These incidents only seem to confirm the fears of some that professional and financial gain, not scientific merit, are driving a rush to geoengineering experimentation.

Lack of control is a second theme reflected in concerns surrounding geoengineering field experiments. The controversy that the SPICE experiment provoked, notwithstanding the trivial physical risk associated with the experiment itself, suggests that public worries extend beyond the hazards or scientific integrity of individual field experiments. These experiments possess an operational and symbolic significance that becomes apparent when the experiments are considered in their historical and social contexts. One might sensibly wonder what these experiments portend for further geoengineering research—or even deployment—and how they might alter humanity's relationship to the environment.[20]

see also Fountain, *supra* note 14 (reporting commentator's conclusion that the project had apparently contravened international agreements); Parson & Keith, *supra* note 16 (asserting that the experiment "violated no international law").

18. *See* Fountain, *supra* note 14; Andrew C. Revkin, *A Fresh Look at Iron, Plankton, Carbon, Salmon, and Ocean Engineering*, N.Y. TIMES: DOT EARTH (July 18, 2014), http://dotearth.blogs.nytimes.com/2014/07/18/a-fresh-look-at-iron-plankton-carbon-salmon-and-ocean-engineering. Preliminary accounts suggest positive effects on the salmon fishery. *See id.*

19. *See* Rose Cairns, *Climates of Suspicion: "Chemtrail" Conspiracy Narratives and the International Politics of Geoengineering*, 182 GEOGRAPHICAL J. 70, 75–76 (2014) (discussing the chemtrail conspiracy narrative, consisting of belief that trails left by airplanes are being deliberately sprayed for various ends, including climate modification or population control).

20. *See* Lisa Dilling & Rachel Hauser, *Governing Geoengineering Research: Why, When and How?*, 121 CLIMATIC CHANGE 553, 555 (2013), http://sciencepolicy.colorado.edu/admin/publication_files/2013.21pdf; Stefan Schäfer

In light of these developments, this Article finds a pressing need for greater governance of geoengineering research. Governance refers broadly to the making and implementation of rules through laws, decisions, and other mechanisms.[21] Existing proposals for geoengineering research governance concentrate on the physical risks associated with individual research projects. Generally overlooked, and more difficult to address, are the systemic concerns geoengineering research raises: technological lock-in—the danger that sustained research efforts will predetermine geoengineering deployment decisions; moral hazard—the danger that increased attention to geoengineering will undermine efforts to reduce greenhouse gas (GHG) emissions; and the potential for geoengineering research to contribute to future global conflict. This Article tackles the difficult but essential task of developing mechanisms to address these systemic concerns in addition to the physical risks of geoengineering research.

Part I of this Article addresses preliminary issues, makes the case for governance of geoengineering research, and surveys examples of research governance in other fields. Part II reviews existing proposals for geoengineering research governance and finds that they fail to address important, systemic concerns regarding technological lock-in, moral hazard, and potential military conflict. Part III discusses the desired characteristics of a prospective geoengineering research governance regime and offers specific recommendations. An ongoing programmatic technology assessment can analyze systemic concerns and promote public deliberation on geoengineering research and deployment. Policy makers can use the results of such an assessment to inform decisions and institute safeguards against the physical and systemic hazards of geoengineering research.

et al., *Correspondence: Field Tests of Solar Climate Engineering*, 3 NATURE CLIMATE CHANGE 766, 766 (2013).

21. *See* RALPH BODLE ET AL., FED. ENVT'L AGENCY, GER., OPTIONS AND PROPOSALS FOR THE INTERNATIONAL GOVERNANCE OF GEOENGINEERING 13 (Section I 1.3 Environmental Law & Friederike Domke eds., 2014) (defining governance to include "formal and informal, implicit and explicit processes, procedures and institutions"); Daniel Bodansky, *The Who, What, and Wherefore of Geoengineering Governance*, 121 CLIMATIC CHANGE 539, 541–45 (2013) (discussing basic issues of governance); *see also* NAT'L RESEARCH COUNCIL, *supra* note 2, at 10 (noting the wide variety of forms research governance may take).

I. BACKGROUND

A. PRELIMINARY ISSUES

There are several preliminary issues that merit attention before delving into the case for and design of geoengineering research governance.

First, what is geoengineering? Developing a working definition of geoengineering will help to establish a common baseline for discussion and a predictable governance regime.[22] Although the term lacks an undisputed meaning, most accounts include elements of scale and intent: geoengineering is large if not planetary in scale, and it is intended to counter elevated GHG concentrations or their impacts.[23] Proposals for geoengineering fall into two broad categories: carbon dioxide removal (CDR) and solar radiation management (SRM). CDR techniques strive to remove carbon dioxide (CO_2) from the atmosphere and to store it elsewhere.[24] Examples include ocean fertilization, direct capture, biochar, and enhanced weathering.[25] SRM techniques attempt to reduce the amount of radiation absorbed by the Earth but do not reduce atmospheric GHG concentrations.[26] Examples of SRM techniques include stratospheric aerosol release, cloud whitening, and space-based deflectors.[27] Stratospheric aerosol release, which would deploy tiny particles in the stratosphere to reflect sunlight into space, has been the subject of much attention because some perceive it as a relatively quick and inexpensive global response to climate

22. *See* BODLE ET AL., *supra* note 21, at 137.

23. *See id.* at 14, 43–46; David W. Keith, *Box 1: Geoengineering*, 409 NATURE 420, 420 (2001); PHILLIP WILLIAMSON ET AL., GEOENGINEERING IN RELATION TO THE CONVENTION ON BIOLOGICAL DIVERSITY: TECHNICAL AND REGULATORY MATTERS 23 (Technical Series No. 66, 2012), https://www.cbd.int/doc/publications/cbd-ts-66-en.pdf (summarizing selected definitions of geoengineering and defining the term as "a deliberate intervention in the planetary environment of a nature and scale intended to counteract anthropogenic climate change and its impacts").

24. *See* NAT'L RESEARCH COUNCIL, *supra* note 2, at 2, box S.1; Lin, *supra* note 1, at 716–19.

25. *See* Lin, *supra* note 1, at 716–17. For a more detailed description of each of these examples, see generally NAT'L RESEARCH COUNCIL, CLIMATE INTERVENTION: CARBON DIOXIDE REMOVAL AND RELIABLE SEQUESTRATION (2015).

26. *See* Lin, *supra* note 1, at 717–19; *see also* NAT'L RESEARCH COUNCIL, *supra* note 2, at 2, box S.1 (referring to SRM as "albedo modification").

27. *See* Lin, *supra* note 1, at 717–19. *See generally* NAT'L RESEARCH COUNCIL, *supra* note 2, at 66–132 (describing in detail these and other SRM techniques).

change.[28] Presently, no proposed geoengineering technique is ready for deployment at a scale that would substantially address the impacts of climate change.[29]

The techniques falling under the rubric of geoengineering differ significantly in their methodologies, levels of risk, and feasibility.[30] Of course, any characterization of specific techniques at this time is preliminary and rests on untested assumptions. Several general observations nevertheless seem reasonable. Some techniques could be implemented incrementally at a modest scale and within national boundaries, whereas others would require global implementation. Relatedly, some techniques—such as ocean fertilization and stratospheric aerosol release—would pose greater transboundary risks than others.[31] Because they are aimed directly at atmospheric GHGs, CDR techniques would generally be slower acting, and aside from the technique of ocean fertilization, potentially less risky.[32] SRM techniques, in contrast, would involve greater risks and uncertainties because they would only alleviate some of climate change's symptoms rather than address its root causes.[33] Proposed geoengineering techniques also differ in their apparent feasibility, as each technique faces various economic, technical, and political challenges. The inclusion of all geoengineering techniques within a system of research governance would promote coordination, priority setting, and public trust. At the same time, design of oversight should take into account relevant differences between techniques. SRM techniques warrant particular scrutiny not only because of their greater potential risks, but also because of the systemic concerns they tend to raise.

28. *See, e.g.*, ROYAL SOC'Y, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE, AND UNCERTAINTY 31 tbl.3.4 (2009) (preliminarily evaluating stratospheric aerosols as high in terms of effectiveness, affordability, and timeliness, but low in terms of safety); Parson & Keith, *supra* note 16 (commenting that "attention and controversy have centered on methods to reduce incoming sunlight," including stratospheric aerosol release).

29. *See* ROYAL SOC'Y, *supra* note 28, at 57 (concluding that various geoengineering methods "are unlikely to be ready for deployment in the short to medium term").

30. BODLE ET AL., *supra* note 21, at 40.

31. *See id.* at 20.

32. *See* NAT'L RESEARCH COUNCIL, *supra* note 2, at 2–4; Edward A. Parson & Lia N. Ernst, *International Governance of Climate Engineering*, 14 THEORETICAL INQUIRIES L. 307, 313, 316 (2013).

33. *See* NAT'L RESEARCH COUNCIL, *supra* note 2, at 3, 5–7; Lin, *supra* note 1, at 715, 718.

A second question regards whether governance should focus on geoengineering research, deployment, or both. The controversy generated by the Haida and SPICE experiments suggests a growing urgency in the need for governance of field experimentation. In contrast to the case for governance of research, which is discussed more thoroughly below, the case for governance of deployment is less pressing, with any deployment likely to be decades or more away.[34] Whether adequate governance of research is possible without also governing deployment presents a difficult question. A governance structure established for research may establish a precedent for later governance of deployment.[35] Moreover, to the extent that geoengineering research efforts have the ultimate aim of deployment, research governance arguably would serve as an indirect form of deployment governance. Any attempt to separate governance functions may be further complicated by the difficulty of distinguishing large-scale field experiments from full-scale deployment.[36] For stratospheric aerosol release, for example, the most informative way to test efficacy and risks—and perhaps the only reliable way to do so—may involve full-scale and extended deployment.[37]

Notwithstanding these points, focusing on research governance is appropriate. Attempting to establish governance of both deployment and research could prove to be a distraction. If governance of both deployment and research are grouped together, policy makers and stakeholders might perceive geoengineering governance to be less urgent generally and thus less worthy of action. Although geoengineering deployment raises important and challenging governance issues, many of these issues are distinct from those posed by field research.[38] Resolving

34. *See* Parson & Ernst, *supra* note 32, at 331 (distinguishing long-term tasks of regulatory and security governance from "near-term tasks of research, technology development, and risk assessment[, which] may remain the principal governance needs for a decade or more"); *cf.* DAVID KEITH, A CASE FOR CLIMATE ENGINEERING 87–88 (2013) (projecting deployment of stratospheric aerosols no earlier than 2025 or "more realistically, 2035 with missteps and surprises").

35. *See* BODLE ET AL., *supra* note 21, at 21; *cf.* Parson & Ernst, *supra* note 32, at 329 ("[T]here will not be a clean boundary between an early period of 'scientific' [geoengineering] governance and some later period of 'operational' governance").

36. *See* Alan Robock et al., *A Test for Geoengineering?*, 327 SCIENCE 530, 530–31 (2010).

37. *See id.*

38. *See infra* text accompanying notes 347–49.

these issues at this time is unlikely, and seeking to do so would unnecessarily complicate governance efforts.[39]

A governance effort focused on research would need to settle on an approach for determining which research projects require oversight. An effects-based approach would regulate research projects whose environmental impacts potentially exceed a certain threshold.[40] Research projects below the threshold would not receive particular geoengineering-related scrutiny, though they would have to comply with any otherwise applicable laws. However, an approach centered on individual projects would tend to overlook cumulative effects and the ways in which seemingly insignificant projects could contribute to the overall development of a geoengineering technique. A purpose-based approach would regulate all research activities that have a geoengineering purpose. A project's purpose could be defined subjectively or objectively. A subjective definition of purpose—based on a researcher's declared objective or justification for a project—would rely on the good faith of researchers to identify geoengineering experiments.[41] Such an approach, which would create an incentive to conceal the actual purpose of a geoengineering experiment, may fail to earn the public trust.[42] An objective definition of purpose—based on an independent determination of whether research might reasonably advance a geoengineering technique—may more readily garner public confidence. At the same time, it would be more difficult to administer, potentially necessitating the burdensome and politically fraught screening of numerous climate-related research projects.[43] Ultimately, these difficulties, along with the desirability of accounting for cumulative and systemic concerns, argue for an approach that combines a subjective definition of purpose with a list of objectively defined specific activities.[44] Under this approach, research activities would be subject

39. *See* Parson & Ernst, *supra* note 32, at 331 (suggesting that it "may . . . be possible to defer most high-stakes and potentially divisive questions of regulatory and security governance").

40. *See* Parson & Keith, *supra* note 16, at 1279.

41. *Cf.* Dilling & Hauser, *supra* note 20, at 562 (proposing that research "justified by investigators or programs as informing the idea of intentionally manipulating the earth's climate . . . be classified as geoengineering research").

42. *See* Parson & Keith, *supra* note 16.

43. *See* Bronislaw Szerszynski et al., *Why Solar Radiation Management Geoengineering and Democracy Won't Mix*, 45 ENV'T & PLANNING A 2809, 2813 (2013).

44. *Cf.* BODLE ET AL., *supra* note 21, at 136 (suggesting a geoengineering

to governance if they either incorporate a geoengineering purpose as a declared objective or fall within designated categories of geoengineering research activities.

B. THE CASE FOR RESEARCH GOVERNANCE

But is governance of geoengineering research even necessary? Scientists generally enjoy freedom of research, subject to informed consent and other ethical limits on human and animal experimentation.[45] This freedom, which is recognized or supported in various laws and treaties,[46] encompasses the autonomy to decide on research projects and approaches without political interference.[47] Underlying the principle is the presumption that research generates knowledge, and knowledge is socially desirable, both as an inherent matter and because it enables informed democratic choices.[48] In the United States, freedom of research is reflected in the "social contract for science": in exchange for public funding, scientists provide knowledge to society while themselves determining the aims of

definition be sufficiently broad to cover a wide range of methods and also include a list that expressly mentions specific techniques).

45. *See* Gary E. Marchant & Lynda L. Pope, *The Problems with Forbidding Science*, 15 SCI. & ENGINEERING ETHICS 375, 377 (2009) ("There is a strong presumption in modern industrialized democracies, endorsed by most scientists, in favor of minimal government interference in the content of basic scientific research."); Peter Singer, *Ethics and the Limits of Scientific Freedom*, 79 MONIST 218, 218–20 (1996). While some assert that scientists have a right to research, the U.S. Supreme Court has recognized no such right, and any such right arguably rests on the extent to which a research inquiry supports democratic governance. *See* Mark B. Brown & David H. Guston, *Science, Democracy, and the Right to Research*, 15 SCI. & ENGINEERING ETHICS 351, 362 (2009).

46. *See* BODLE ET AL., *supra* note 21, at 140; Jesse Reynolds, *Climate Engineering Field Research: The Favorable Setting of International Environmental Law*, 5 WASH. & LEE J. ENERGY CLIMATE & ENV'T 417, 430–31 (2014) (noting various multilateral environmental treaties that encourage scientific research); *see also* Ralph Cicerone, *Geoengineering: Encouraging Research and Overseeing Implementation*, 77 CLIMATIC CHANGE 221, 224 (2006) ("Freedom of inquiry itself has moral value."). Indeed, detailed formal international regulation of any area of research is unprecedented. *See* SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, SOLAR RADIATION MANAGEMENT: THE GOVERNANCE OF RESEARCH 33 (2011).

47. *See* Torsten Wilholt, *Scientific Freedom: Its Grounds and Their Limitations*, 41 STUD. HIST. & PHIL. SCI. 174, 174–75 (2010); *Scientific Freedom and the Public Good*, Union of Concerned Scientists, (2008), http://www.ucsusa.org/sites/default/files/legacy/assets/documents/scientific_integrity/scientific_freedom.pdf.

48. *See* Wilholt, *supra* note 47, at 175–78.

research as well as its governing standards.[49] Although the social contract for science has come under attack in recent years, it continues to dominate popular conceptions of scientists' role.[50]

Against the tradition of scientific freedom, calls for governance of geoengineering research require justification. The case for such governance is rooted in the frustration of what some scientists perceive as increasingly urgent field research. Geoengineering research is growing rapidly, and interest in conducting field experiments is on the rise.[51] Most research to date has been confined to computer modeling or indoor research, prompting various expert bodies, scientists, and commentators to contend that field research is necessary.[52] A research agenda could address the feasibility of specific techniques, their interaction with changing climate conditions, the geographic distribution of effects, the controllability and effects of regional interventions, and the identification and attribution of harmful

49. *See* Sheila Jasanoff, *Technologies of Humility: Citizen Participation in Governing Science*, 41 MINERVA 223, 227–28 (2003).

50. *See id.* at 228–29.

51. *See* NAT'L RESEARCH COUNCIL, *supra* note 2, at 155–56 (recommending small-scale field studies to investigate potential viability of albedo modification techniques); *see also* CLIVE HAMILTON, EARTHMASTERS: THE DAWN OF THE AGE OF CLIMATE ENGINEERING 17 (2013) (noting growth of the geoengineering research network); M. Granger Morgan et al., *Needed: Research Guidelines for Solar Radiation Management*, 29 ISSUES SCI. & TECH. 37, 41 (2013) (discussing "calls for a significantly expanded research program on SRM"); Parson & Ernst, *supra* note 32, at 309 (noting the "sharp increase in attention to climate engineering (CE) technologies"); Rob Bellamy, *Safety First! Framing and Governing Climate Geoengineering Experimentation* 14 (Climate Geoegineering Governance Working Paper Series, No. 014, 2014) http://www.geoengineering-governance-research.org/perch/resources/workingpaper14bellamysafetyfirst.pdf (identifying the "need to know more" as a prevalent theme in geoengineering discourse).

52. *See, e.g.*, GOV'T ACCOUNTABILITY OFFICE, GAO 11-71, TECHNOLOGY ASSESSMENT: CLIMATE ENGINEERING: TECHNICAL STATUS, FUTURE DIRECTIONS, AND POTENTIAL RESPONSES 49 (2011) (reporting that the majority of experts consulted in the study "advocated starting significant climate engineering research now or in the very near future"); BIPARTISAN POLICY 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 20 (2011) [hereinafter BPC] ("time is of the essence in establishing a thoughtful research program"); ROYAL SOCIETY, *supra* note 28, at 61 ("Research is urgently needed for evaluating which methods are feasible, and to identify potential risks."); Parson & Ernst, *supra* note 32, at 322 (asserting that a consensus exists that research into the feasibility, effects, and potential risks of CE technologies "should begin immediately").

effects.[53] SRM field research, for example, could take the form of small-scale experiments to increase understanding of physical, chemical, and radiative properties in the atmosphere; atmospheric studies across a range of scales to determine the applicability of models at different scales; global-scale experiments to measure risks and climate response; and tests of technologies for deploying SRM.[54]

A commonly proffered rationale for geoengineering research is for society to be well-informed of the effectiveness and risks of various techniques "if and when geoengineering becomes necessary."[55] Current geoengineering proposals are sometimes described as "speculative,"[56] and years or decades of research would likely be needed before deployment of any technique.[57] In the absence of sufficient research, some commentators warn, society could find itself in a "policy train wreck" in which "only unrefined, untested, and excessively risky approaches will be available" should a climate emergency occur.[58] Even some who are more skeptical of the need for geoengineering believe that research can inform discussions and decisions regarding its potential use.[59] Research might be valuable even

53. *See* BPC, *supra* note 52, at 24–26; Parson & Ernst, *supra* note 32, at 328.

54. *See* David W. Keith et al., *Field Experiments on Solar Geoengineering: Report of a Workshop Exploring a Representative Research Portfolio*, PHIL. TRANSACTIONS ROYAL SOC'Y A, Nov. 17, 2014, at 1 2–4.

55. Bodansky, *supra* note 21, at 546; *see also* BPC, *supra* note 52, at 14; Parson & Keith, *supra* note 16.

56. Steve Rayner et al., *The Oxford Principles*, 121 CLIMATIC CHANGE 499, 501 (2013) (noting the need for "extensive research" into the "technical, environmental, socio-political, ethical and economic characteristics" of all geoengineering technologies).

57. *See* GOV'T ACCOUNTABILITY OFFICE, *supra* note 52; Parson & Ernst, *supra* note 32, at 322 (noting present ignorance regarding "how well specific interventions and delivery methods would work").

58. Parson & Keith, *supra* note 16, at 1279. The use of "emergency" rhetoric in connection with geoengineering, let alone the determination of what might constitute a climate emergency, poses serious difficulties. *See* Nils Markusson et al., *"In Case of Emergency Press Here": Framing Geoengineering as a Response to Dangerous Climate Change*, 5 WIRES CLIMATE CHANGE 281, 284, 288 (2014).

59. *See* BPC, *supra* note 52, at 3; NAT'L RESEARCH COUNCIL, *supra* note 2, at 8–9; ROYAL SOCIETY, *supra* note 28, at 49, 52; Alan Robock, *Stratospheric Aerosol Geoengineering*, *in* GEOENGINEERING OF THE CLIMATE SYSTEM 162, 181 (R.E. Hester et al. eds., 2014); David G. Victor et al., *The Geoengineering Option: A Last Resort Against Global Warming?*, FOREIGN AFF., Mar./Apr. 2009, at 64, 74 (contending that research "would transform the discussion about geoengineering from an abstract debate into one focused on real risk assessment").

if nations or the international community ultimately reject geoengineering, as it can facilitate the detection and countering of unauthorized geoengineering efforts.[60]

Notwithstanding scientists' increasing interest in geoengineering research, overall funding for research remains modest and funding for field experimentation is especially limited.[61] Exact funding data is difficult to gather in the absence of a clear operational definition of geoengineering,[62] but estimates generally characterize research amounts as "very low."[63] The most prominent national funding effort, the SPICE project, consists of £1.6 million in total research support spread out over several years.[64] The United States lacks a dedicated research program, with existing geoengineering research efforts occurring largely as part of broader climate and atmospheric science programs.[65] Private individuals, including Bill Gates, provide a significant share of research support.[66] Yet even this support is relatively modest in terms of the scale of research it enables.[67] Gates, for example, has contributed $4.6 million to a

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60. *See* NAT'L RESEARCH COUNCIL, *supra* note 2, at 10; Mark G. Lawrence, *The Geoengineering Dilemma: To Speak or Not To Speak*, 77 CLIMATIC CHANGE 245, 246 (2006).

61. A 2010 GAO report estimated total U.S. government spending on direct geoengineering research at less than $2 million. GOV'T ACCOUNTABILITY OFFICE, GAO-10-903, CLIMATE CHANGE: A COORDINATED STRATEGY COULD FOCUS FEDERAL GEOENGINEERING RESEARCH AND INFORM GOVERNANCE EFFORTS 19 (2010) [hereinafter GAO-10-903]. A 2013 estimate of the total amount worldwide being spent on ongoing SRM research projects was $20–25 million. *Geoengineering Research,* GIVEWELL, http://www.givewell.org/labs/causes/geoengineering#footnoteref21_nhq5rn9 (last visited Oct. 9, 2014).

62. *See* GAO-10-903, *supra* note 61, at 23.

63. *See, e.g.*, Bodansky, *supra* note 21, at 546.

64. *See* Daniel Cressey, *Cancelled Project Spurs Debate over Geoengineering Patents*, 485 NATURE 429 (2012).

65. *See* GAO-10-903, *supra* note 61, at 23; Morgan et al., *supra* note 51.

66. *See* HAMILTON, *supra* note 51, at 77 (characterizing Gates as "the world's leading financial supporter of geoengineering research" and discussing Richard Branson's offer of a $25 million prize for developing a plan to extract carbon from the atmosphere); Bodansky, *supra* note 21, at 546; John Vidal, *Bill Gates Backs Climate Scientists Lobbying for Large-Scale Geoengineering*, GUARDIAN, Feb. 6, 2012, http://www.guardian.co.uk/environment/2012/feb/06/bill-gates-climate-scientists-geoengineering.

67. *See* Alan Robock, *Is Geoengineering Research Ethical?*, 4 SICHERHEIT & FRIEDEN 226, 228 ("[A] larger fraction of current geoengineering research funding comes from the US$1,000,000 per year that Bill Gates gives to David Keith and Ken Caldeira."); *see also* Vidal, *supra* note 66 (reporting that Gates has funded $4.6 million worth of geoengineering research).

fund administered by two leading geoengineering researchers.[68]

Potential funders have shied away particularly from field research because of its controversial nature. As the Haida and SPICE incidents suggest, concerns extend beyond any immediate physical risks that experiments might pose. The case for oversight rests equally on the goal-directed nature of geoengineering research and on the contested nature of that goal. The primary aim of such research is not to generate pure scientific knowledge nor to develop innovations that could be applied in the market, but rather to create specific deployable mechanisms for deliberately altering the climate.[69] Geoengineering research warrants external governance and public engagement because the research itself carries significant and controversial policy implications and can alter the policy environment in which decisions are made.[70] In the absence of legitimate and effective governance, additional field research will lead to further controversy,[71] which in turn could stymie transparent and accountable research efforts while spawning a rise in furtive experimentation.

At present, there is no general system of oversight for geoengineering field experimentation. Nor do mechanisms exist to ensure attention to concerns regarding the broader implications of research. As one analysis concludes, "almost none of [international environmental law] was developed with climate engineering in mind."[72] Indeed, that analysis suggests that international law "favor[s]" geoengineering research because it could develop methods for reducing climate risk to humans and the environment.[73] While the reduction of climate risks indeed would be consistent with several environmental agreements,[74] international environmental law provides no definitive guid-

68. The researchers, David Keith and Ken Caldeira, "select projects that receive support from the fund." *See* FUND FOR INNOVATIVE CLIMATE & ENERGY RESEARCH, http://dge.stanford.edu/labs/caldeiralab/FICER.html (last visited Mar. 7, 2016).

69. *See* Dilling & Hauser, *supra* note 20 ("This intentionality of the research program places geoengineering clearly in the sphere of science for policy, or usable science.").

70. *See id.*

71. *See* Rayner et al., *supra* note 56 ("[C]ontroversies will only increase over time if research is allowed to continue.").

72. Reynolds, *supra* note 46, at 480.

73. *Id.*

74. *See id.* at 480–81.

ance in this regard. For example, the precautionary principle, which some characterize as an emerging customary principle of international environmental law,[75] could be interpreted as either encouraging or discouraging geoengineering research.[76] Likewise, the U.N. Framework Convention on Climate Change's objective of avoiding "dangerous anthropogenic interference" with the climate system[77] leaves open the question of whether geoengineering itself might constitute dangerous anthropogenic interference.

To date, two international treaty regimes have specifically addressed the issue of geoengineering research. The parties to the London Convention and London Protocol (LC/LP) have developed an incipient oversight system for field research on ocean fertilization and other marine-based geoengineering techniques. As a general matter, the LC/LP prohibit the deliberate disposal of waste at sea, but allow placement of matter for purposes other than disposal.[78] In 2008, the parties to these agreements adopted a resolution opposing "ocean fertilization activities other than legitimate scientific research."[79] The resolution encourages member-states to review proposed ocean fertilization activity under an assessment framework to determine whether it constitutes legitimate scientific research and to assess its environmental impacts.[80] The assessment framework also recommends a process to notify potentially affected countries, explain potential impacts, encourage scientific coopera-

75. A leading articulation of the precautionary principle declares that "[w]here there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." United Nations Conference on Environment and Development, June 3-14, 1992, Rio Declaration on Environment and Development, U.N. Doc. A/CONF.151/26.

76. *See* Lin, *supra* note 1.

77. United Nations Framework Convention on Climate Change, art. 2, May 9, 1992, 1771 U.N.T.S. 164.

78. 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, arts. 1.4.1, 1.4.2.2, 4, Nov. 7, 1996, 36 I.L.M. 1; *see* Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, art. III.1(a), Dec. 29, 1972, 1046 U.N.T.S. 140 (referring to "deliberate disposal at sea," as opposed to "deliberate disposal into the sea").

79. London Convention and Protocol, Resolution LP-LP.1 (2008) on the Regulation of Ocean Fertilization, LC 30/16 (Oct. 31, 2008).

80. London Convention and Protocol, Resolution LC-LP.2 (2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization (Oct. 14, 2010).

tion, and provide for ongoing consultation.[81] Building on the 2008 resolution, the parties to the London Protocol later adopted an amendment to the protocol. If ratified, the amendment would make the assessment and permitting process binding and expand its application to other marine geoengineering activities.[82] Permits would issue only if a proposed activity is not contrary to the aims of the London Protocol and an environmental assessment determines that pollution and detriment would be prevented or minimized.[83]

Field experiments outside the marine environment lie beyond the scope of the LC/LP. Of particular concern are SRM techniques, which could involve experimentation and deployment on a global scale.[84] The most frequently discussed SRM techniques, stratospheric aerosol release and cloud brightening, would involve field trials in the atmosphere, where there is no existing treaty regime possessing obvious oversight responsibility.[85] The parties to the Convention on Biological Diversity (CBD), a treaty that promotes biodiversity primarily through national laws and policies,[86] have attempted to fill this void. Specifically, the CBD parties adopted a decision discouraging geoengineering activities potentially affecting biodiversity, with the exception of "small scale scientific research studies . . . in a controlled setting."[87] Such research, the decision cautions, should occur only if subject to a prior environmental assessment and justified by the need to gather specific scientific data.[88] Notably, the decision is nonbinding and has no force in the United States, which is not a party to the CBD.[89] Moreover, the

81. The Assessment Framework can be found at Report of the Thirty-Fifth Consultative Meeting and the Eighth Meeting of Contracting Parties to the London Convention, LC 35/15, annex 6 (2013).

82. Resolution LP.4(8) on the Amendment to the London Protocol to Regulate the Placement of Matter for Ocean Fertilization and Other Marine Geoengineering Activities, LC 35/15, annex 4, at 8–9 (Oct. 18, 2013) [hereinafter Resolution 4.8].

83. *Id.* at 8.

84. *See* SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 14–16.

85. *See* Lin, *supra* note 1, at 730–31 (discussing international legal regimes governing air pollution).

86. Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 143 [hereinafter CBD], http://www.cbd.int/convention/convention.shtml.

87. Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity, X/33: Biodiversity and Climate Change, ¶ 8(w), Oct. 29, 2010, UNEP/CBD/COP/DEC/X/33.

88. *Id.*

89. The CBD does not authorize its Conference of the Parties to adopt le-

decision does not define critical terms such as "small scale scientific research studies" and "controlled setting," and in contrast to the LC/LP's assessment framework, provides little guidance to member-states regarding implementation.[90]

To sum up, support for and concern about geoengineering research are both on the rise. On the one hand, the worsening climate situation and dim prospects for meaningful GHG mitigation efforts make increasingly important the exploration of a variety of responses to climate change. Geoengineering research can generate valuable information for deciding whether geoengineering options might be viable and how they might be used.[91] On the other hand, the field experimentation that would be necessary to evaluate geoengineering options or to deploy them has largely been stymied. Geoengineering research is in a state of "deadlock" where even publicly sponsored and seemingly harmless field experiments are unable to proceed.[92]

Should this deadlock remain unresolved, one can expect further controversy, a continued reluctance to fund even publicly accountable tests, and a rise in furtive experimentation. As climate change's effects become more pronounced, the pressure to explore and ultimately deploy geoengineering will only intensify.[93] At the same time, increased attention to geoengineering is unlikely to dissipate public discomfort and uncertainties

gally binding decisions. Accordingly, one commentator characterizes CBD decisions as "'soft law' of a primarily political nature." ALEXANDER PROELSS, LEGAL OPINION ON THE LEGALITY OF THE LOHAFEX MARINE RESEARCH EXPERIMENT UNDER INTERNATIONAL LAW 9 (2009), http://www.internat-recht.uni-kiel.de/de/forschung/opinions/LOHAFEX_en.pdf. For a list of parties that have ratified the CBD, see *List of Parties*, CONVENTION ON BIOLOGICAL DIVERSITY, http://www.cbd.int/convention/parties/list/ (last visited Mar. 25, 2016).

90. For further discussion of the shortcomings of the CBD decisions, see BODLE ET AL., *supra* note 21, at 59, 152–53.

91. *See* BPC, *supra* note 52, at 29; Bodansky, *supra* note 21, at 546.

92. Parson and Keith use the term "deadlock" to characterize the current governance of geoengineering research: namely, the increasingly polarized debate regarding such questions as whether government regulation is needed and whether large-scale research requires greater oversight. Parson & Keith, *supra* note 16. *But cf.* Schäfer et al., *supra* note 20 (contending that "there is no deadlock on climate engineering governance"). In my view, the term deadlock better characterizes the present state of geoengineering field experimentation.

93. *See* Bodansky, *supra* note 21, at 540 (observing that "grim outlook" regarding rising global GHG emissions "has led many to take a second look at geoengineering"); *see also* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: IMPACTS, ADAPTATION, AND VULNERABILITY 1065 (2014) (discussing geoengineering and noting the "increasing attention" it has received in the scientific literature).

associated with many geoengineering proposals.[94] In such circumstances, states will remain hesitant to openly undertake or sponsor field experiments. Polarized views on the subject may make it difficult for states to adopt any policy on geoengineering whatsoever.[95] And without a clear system of governance, projects lacking external oversight and peer review may become more common. The establishment of a credible research governance structure could break the deadlock by providing assurance that geoengineers are not performing uncontrolled experiments or embarking on a course leading to full-scale deployment without official sanction.

C. MODELS FOR RESEARCH GOVERNANCE

International law provides little guidance for establishing a system of research oversight. International environmental law generally favors scientific research, and precedents for governing field experimentation, particularly in its early stages, are limited.[96] For instance, the UN Convention on the Law of the Sea, which contains relatively detailed provisions on research, affirms the right of states and "competent international organizations" "to conduct marine scientific research subject to the rights and duties of other States" and encourages the exercise of this right.[97] The right to conduct research is subject to procedural and substantive obligations designed to protect other states from transboundary harm.[98] Beyond such obligations,

94. *See* Nick Pidgeon et al., *Exploring Early Public Responses to Geoengineering*, 370 PHIL. TRANSACTIONS ROYAL SOC'Y A 4176, 4177 (2012); *cf.* Adam Corner et al., *"Experiment Earth?" Reflections on a Public Dialogue on Geoengineering* 18, http://psych.cf.ac.uk/understandingrisk/docs/experiment_earth.pdf (last visited Mar. 25, 2016) (reporting a weak positive correlation between knowledge about CDR and support for CDR and a negative correlation between knowledge about SRM and support for SRM).

95. *See* BODLE ET AL., *supra* note 21, at 131.

96. *See* Reynolds, *supra* note 46.

97. United Nations Convention on the Law of the Sea, arts. 238, 239, Dec. 10, 1982, 1833 U.N.T.S. 397 [hereinafter UNCLOS], http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm. The Convention on the Law of the Sea is one of the few treaties potentially relevant to geoengineering that contains detailed provisions governing research. *See* Reynolds, *supra* note 46, at 431.

98. *See, e.g.*, UNCLOS art. 242(1) (describing obligation of state conducting research to provide other states an opportunity to obtain information necessary to prevent and control damage to human health and marine environment); *id.* art. 246 (describing right of coastal states to regulate research in their exclusive economic zone and continental shelf); Reynolds, *supra* note 46, at 475–78 (discussing customary law obligations to prevent or control trans-

though, the convention contains no provisions for comprehensive oversight of research.

Experience under another environmental treaty, the International Convention for the Regulation of Whaling, warns against excessive deference to treaty members in the oversight of scientific research. This convention's governing body established an indefinite moratorium on commercial whaling in 1982.[99] However, parties to the convention may issue permits authorizing the killing of whales for purposes of scientific research "subject to such restrictions as to number and . . . such other conditions as [each party] thinks fit."[100] Contending that the killing of hundreds of whales per year is necessary for research purposes, Japan has made liberal use of these permits to circumvent the moratorium.[101] Japan vows to continue its whaling program even in the face of strong international condemnation and an International Court of Justice finding that it lacks scientific merit.[102] The ongoing conflict illustrates not only the difficulty of defining and policing research, but also the inability to avoid value-laden policy determinations by deferring to scientific expertise.[103]

Perhaps the most instructive precedent for geoengineering research governance comes from the field of recombinant DNA (rDNA) research. In the early 1970s, rDNA researchers faced a research deadlock resembling that confronting geoengineering researchers today. Scientists, policy makers, and the public worried that rDNA experiments might wreak havoc if they accidentally released genetically altered organisms into the environment.[104] Such concerns led researchers to impose a volun-

boundary harm and to cooperate in doing so).

99. *See* DAVID HUNTER ET AL., INTERNATIONAL ENVIRONMENTAL LAW & POLICY 1050–54 (4th ed. 2011) (noting that the moratorium took effect in 1986).

100. International Convention for the Regulation of Whaling, Dec. 2, 1946, art. VIII, 161 U.N.T.S. 72.

101. *See* HUNTER ET AL., *supra* note 99, at 1058–59.

102. *See* Editorial, *Japan Is Back in the Hunt for Whales*, N.Y. TIMES, Nov. 29, 2014, at SR8; *see also* HUNTER ET AL., *supra* note 99, at 1059 (noting that "[E]very IWC meeting adopts a resolution condemning [Japan's] practice.").

103. *See* Daniel Bodansky, *Legitimacy*, *in* THE OXFORD HANDBOOK OF INTERNATIONAL ENVIRONMENTAL LAW 704, 720 (Daniel Bodansky et al. eds., 2007).

104. *See* Paul Berg et al., *Potential Biohazards of Recombinant DNA Molecules*, 185 SCIENCE 303, 303 (1974) ("There is serious concern that some of these artificial recombinant DNA molecules could prove biologically hazardous.").

tary moratorium on further research.[105] The purpose of the moratorium was to preserve the status quo while the scientific community undertook a more considered evaluation of the new technology and its risks.[106] That evaluation took place at the 1975 Asilomar Conference, where an international gathering of scientists developed recommendations designed to address the potential hazards of rDNA experiments.[107] Deeming societal concerns to be adequately addressed, the scientists ended the research moratorium. The Asilomar recommendations subsequently proved influential, serving as the foundation for government guidelines on publicly funded rDNA research.[108]

Although the Asilomar recommendations enabled rDNA research to proceed, the effort offers a flawed model for governing research in an emerging technology. The Asilomar conference involved a limited range of participants, predominantly scientists who favored moving forward with research.[109] Moreover, the scope of discussions was narrow, focusing on technical issues of risk management.[110] Discussions largely omitted broader societal concerns as well as ethical and legal issues because their consideration was seen as "premature" and "speculative."[111] Asilomar was viewed as a success at the time, but its failure to incorporate the public and its concerns at an early stage of technology development contributed to a resistance to biotechnology that continues today.[112] Geoengineering researchers interested in proceeding with field experiments would do well to be more inclusive and more sensitive to nontechnical concerns.

Another illustration of self-guided oversight comes from the governance of genetics research and research involving human subjects. Such research is often subject to domestic laws and restrictions, but at the international level, soft law devel-

105. *See id.*

106. *See* Paul Berg & Maxine F. Singer, *The Recombinant DNA Controversy: Twenty Years Later*, 92 PROC. NAT'L ACAD. SCI. U.S. 9011, 9011 (1995).

107. *See* ALBERT C. LIN, PROMETHEUS REIMAGINED: TECHNOLOGY, ENVIRONMENT, AND LAW IN THE TWENTY-FIRST CENTURY 52–53 (2013).

108. *See id.* at 54.

109. *See* Paul Berg, *Meetings That Changed the World: Asilomar 1975*, NATURE (Sept. 18, 2008), http://www.nature.com/nature/journal/v455/n7211/full/455290a.html ("[M]ost researchers, like me, acknowledged that the new technology opened extraordinary avenues for genetics and could ultimately lead to extraordinary opportunities in medicine, agriculture, and industry.").

110. *See* LIN, *supra* note 107, at 53.

111. Berg & Singer, *supra* note 106, at 9012.

112. *See* LIN, *supra* note 107, at 72, 78.

oped by expert bodies predominates.[113] The leading code of ethical principles for medical research involving human subjects is the Declaration of Helsinki.[114] Developed by the World Medical Association and aimed at securing respect for individuals and their right to make informed decisions,[115] the Declaration encourages physicians to conduct research under the oversight of independent research committees and with the informed consent of research subjects.[116] The Declaration provides an example of voluntary, self-governing oversight analogous to the measures that rDNA researchers adopted at Asilomar and is subject to similar limitations and critiques.

Geoengineering research governance might also draw lessons from beyond international environmental law. Perhaps the most obvious examples of international restrictions on research involve biological, chemical, and nuclear weapons. Each of these dual use technologies relies on skills, information, and equipment that may be used for both peaceful and military purposes, complicating efforts to restrict weapons research.[117] Determining the actual or primary purpose of research is rarely straightforward, and perhaps futile when a technology can be readily converted from peaceful to military use.

The experience of the 1972 Biological Weapons Convention (BWC) illustrates some of the difficulties of regulating research for dual use technologies. The BWC forbids parties from *developing*, producing, stockpiling, or acquiring biological weapons.[118] However, the treaty allows research for defensive purposes even though it "can involve pathogens and technologies that may be little different from the work needed to develop of-

113. Reynolds, *supra* note 46.

114. *Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects*, WORLD MED. ASS'N, http://www.wma.net/en/30publications/10policies/b3 (last visited Mar. 25, 2016); *see* Soren Holm, *Declaration of Helsinki*, *in* INT'L ENCYCLOPEDIA OF ETHICS 1232 (Hugh La Follette ed. 2013) [hereinafter *Declaration of Helsinki*] (describing the Declaration as "an important normative document in international discussions about research ethics," despite the fact that the World Medical Association is only an umbrella organization for medical associations across the world).

115. Declaration of Helsinki, arts. 7–9, 25–32.

116. *Id.* arts. 2, 23; *see* Holm, *supra* note 114.

117. *See* David P. Fidler, *International Law and Weapons of Mass Destruction: End of the Arms Control Approach?*, 14 DUKE J. COMP. & INT'L L. 39, 66 (2004).

118. Convention on the Prohibition of the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on Their Destruction, Apr. 10, 1972, art. I, 26 U.S.T. 583, 1015 U.N.T.S. 163 (emphasis added).

fensive weapons."[119] The treaty lacks a verification system, moreover. Parties were unable to agree on a mechanism for distinguishing between prohibited research aimed at developing offensive weapons and other, permissible biological research.[120] In the absence of a verification mechanism, Iraq and the former Soviet Union have committed substantial violations of the treaty's provisions, calling into question the treaty's effectiveness.[121]

The 1993 Chemical Weapons Convention (CWC) similarly forbids parties from *developing*, producing, stockpiling, or acquiring chemical weapons.[122] In contrast to the BWC, the CWC incorporates a detailed verification system that includes recordkeeping and inspection requirements.[123] While this verification system promises to make the CWC more effective than the BWC, the potential for dual use remains. For instance, those chemicals most susceptible to weapons use are generally prohibited, but parties may still produce and use such chemicals for research purposes.[124] In addition, technological advances in neuroscience and nanotechnology that offer potential benefits for medical treatment also may find application in new chemical weapons.[125]

119. Leonard S. Spector, *Slowing Proliferation: Why Legal Tools Matter*, 34 VT. L. REV. 619, 621 (2010).

120. *See id.* at 620–21. In rejecting a draft protocol that would have established a verification regime, the United States explained that detecting violations would be nearly impossible because of the potential dual use of biological weapon components. John R. Bolton, Under Secretary for Arms Control and International Security, Remarks at the Tokyo America Center: The U.S. Position on the Biological Weapons Convention: Combating the BW Threat (Aug. 26, 2002), http://2001-2009.state.gov/t/us/rm/13090.htm.

121. *See* Fidler, *supra* note 117, at 63–64.

122. Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, Jan. 13, 1993, art. I.1, S. Treaty Doc. No. 103-219, 1974 U.N.T.S. 317 (emphasis added).

123. Annex on Implementation and Verification, Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, http://www.opcw.org/index.php?eID=dam_frontend_push&docID=6357 (last visited Mar. 25, 2016) [hereinafter CWC Verification Annex); *see also* Timothy K. Webster, *The Future of the Chemical and Biological Weapons Conventions*, 16 NAT. RESOURCES & ENV'T 187, 188–90 (2002) (discussing verification scheme).

124. CWC Verification Annex, *supra* note 123, pt. VI.

125. Alistair Burt, *We Must Wake Up to the Threats of New Chemical Weapons*, NEW SCIENTIST (Apr. 15, 2013) http://www.newscientist.com/article/mg21829125.900-we-must-wake-up-to-the-threats-of-new-chemical-weapons.html.

Nuclear technology presents further dual use challenges. Under the Treaty on the Non-Proliferation of Nuclear Weapons, states without nuclear weapons pledge not to manufacture or acquire such weapons.[126] In exchange, these states receive assistance in developing peaceful uses of nuclear energy.[127] Indeed, the treaty explicitly recognizes "the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes."[128] The nuclear activities of non-nuclear-weapon states are subject to inspection to ensure that the activities are only for peaceful purposes, and noncompliance can prompt a referral to the U.N. Security Council.[129] The treaty's monitoring and enforcement provisions are relatively detailed and forceful, but implementation has sometimes proved difficult.[130] As with the BWC and CWC, deliberate skirting of treaty provisions has revealed the difficulty of administering prohibitions that hinge on determining an activity's purpose.[131] Most notoriously, Iran has undertaken uranium enrichment and plutonium production for apparent military purposes while asserting peaceful intentions.[132]

Each of the just-discussed weapons regulatory regimes distinguishes between prohibited and permitted research based on the purpose of such research. The challenges of implementing these regimes offer several cautionary points for prospective geoengineering governance. A ban on research having a specific purpose will incentivize efforts to disguise the true purpose of otherwise prohibited research projects. Restrictions on research may require verification mechanisms to be effective. And much

126. Treaty on the Non-Proliferation of Nuclear Weapons, July 1, 1968, art. II, T.I.A.S. No. 6839, 21 U.S.T. 483. Other treaties governing nuclear weapons research include the Partial Test-Ban Treaty, which bans nuclear weapons tests in the atmosphere, outer space, and under water, and the Comprehensive Nuclear Test Ban Treaty, which has not entered into force. Comprehensive Nuclear Test Ban Treaty, Sept. 24, 1996, S. Treaty Doc. No. 105-28 (1997), 35 I.L.M. 1439; Treaty Banning Nuclear Weapons in the Atmosphere, in Outer Space, and Under Water, Aug. 5, 1963, 14 U.S.T. 1313, 480 U.N.T.S. 43.

127. Treaty on Non-Proliferation of Nuclear Weapons, *supra* note 126, at art. V.

128. *Id.* at art. IV.1.

129. *Id.* at art. III.1.

130. Joseph Cirincione, *Enforcing Compliance with the Non-Proliferation Treaty*, CARNEGIE ENDOWMENT FOR INT'L PEACE (Mar. 24, 2005), http://carnegieendowment.org/2005/03/24/enforcing-compliance-with-non-proliferation-treaty.

131. *Id.*

132. Spector, *supra* note 119, at 624–25.

technical knowledge, including that produced by geoengineering research, has dual use potential.

II. EXISTING PROPOSALS TO GOVERN GEOENGINEERING RESEARCH—AND WHAT'S MISSING FROM THEM

The deadlock on geoengineering research—and the corresponding need to establish some form of governance for geoengineering research—is widely acknowledged.[133] Various commentators have set forth governance proposals ranging from self-regulation to formal international oversight. A survey of these proposals identifies common elements and functions, and also reveals a shared neglect of systemic concerns.

A. EXISTING PROPOSALS

1. Overview of Selected Proposals

A "widespread but quietly expressed" view in the geoengineering community advocates that governance of geoengineering research be left to ordinary scientific research governance processes, with no additional oversight by government or other actors.[134] Drawing on conventional notions of scientific freedom, this view assumes that peer review, scientific community norms, and existing regulations will adequately account for risks and other concerns. However, this view is not universally held, even among scientists, and is often overshadowed by declarations calling for closer scrutiny and broader participation in governance.[135] Leading proposals for governance of geoengineering research generally incorporate a wide range of actors, including national governments or international organizations. Underlying these proposals is a recognition that geoengineering research differs from basic scientific research in important ways that warrant additional external oversight. For one,

133. *See* Bellamy, *supra* note 51, at 21.

134. Parson & Keith, *supra* note 16; *see* Cicerone, *supra* note 46, at 223, 225 (urging that geoengineering research proceed as "on any other scientific problem at least for theoretical and modeling studies," while suggesting a moratorium "on large-scale field manipulations").

135. *See, e.g.*, Schäfer et al., *supra* note 20 (describing a letter to the editor noting that proposals for field testing generally "acknowledge a need for some form of governance"); Karen N. Scott, *International Law in the Anthropocene: Responding to the Geoengineering Challenge*, 35 MICH. J. INT'L LAW 309, 355 (2013) (contending that self-regulation "does not represent an appropriate governance mechanism").

large-scale field experiments, which might ultimately be necessary to assess effectiveness and risks, could affect millions of people. For another, the primary aim of geoengineering research is to develop and implement specific technologies. If undertaken without sufficient oversight and accountability, such goal-directed research could unwittingly commit the global community to an undesirable course of action.

Perhaps the foremost effort to focus attention on the specific issue of governing geoengineering research is the Solar Radiation Management Governance Initiative (SRMGI).[136] As its name suggests, the SRMGI concentrates on SRM, and its initial purpose was "to develop specific governance recommendations for SRM research."[137] However, the initiative has since modified its orientation toward "open[ing] up" discussions of SRM governance by exploring and recording different perspectives, rather than preemptively "closing down" discussions and producing definitive prescriptions.[138]

In 2011, the SRMGI organized a conference to explore the challenges raised by SRM research.[139] Although organizers disclaimed any effort to reach a consensus, a summary report identified general governance considerations, including possible functions and alternative approaches.[140] The report suggested categorizing research into five groups according to potential risk: (1) computer and desk studies involving no potential environmental impact; (2) laboratory studies or passive observations of nature; (3) small field trials having no significant large scale effects; (4) medium and large-scale field trials; and (5) deployment.[141] The report characterized the first three categories as involving "negligible direct risk" and the latter two categories as involving "potentially direct risk."[142] While noting that physical risk is "not the only consideration" relevant to govern-

136. *See* SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 11. The SRMGI is an ongoing partnership between the Royal Society, Environmental Defense Fund, and The World Academy of Science (TWAS). *See id.* at 7.

137. *Id.* at 12.

138. *Id.* at 12, box 1.1.

139. *See id.* at 11–12.

140. *Id.* at 29–44.

141. *Id.* at 25–26. The report recognized that SRM research activities could be organized in other ways, but explained that the categorization described above was used and developed in conference discussions and "has the advantages of being clear, accessible, and reflecting the full range of potential SRM research activities." *Id.* at 25, 27.

142. *See id.* at 26.

ance, the report described general agreement among conference participants on the need for "differentiated governance arrangements for different kinds of SRM activity."[143] A more limited approach might increase oversight in proportion to the physical risks of research, whereas a more proactive approach might consider more broadly the indirect risks of research and "pursue early progress towards a more comprehensive governance framework."[144]

The SRMGI has refrained from advocating a specific proposal for geoengineering research governance, but others have not. Proposals vary in their details but frequently contain the following elements: a coordinating role for governments, a government advisory committee on geoengineering research, a moratorium on some or all field experiments, a permitting system to govern allowed field experiments, and compensation for harms.

Governments could take an active role in organizing or promoting geoengineering research, as some proposals advocate.[145] Government leadership would address concerns that current research is insufficient or poorly prioritized. On a national basis, governments can coordinate existing research, set research priorities, and help ensure that policy makers make informed decisions.[146] Internationally, cost-sharing arrangements or cooperative research programs can stimulate national spending and promote more cost-effective research.[147] International cooperation can also coordinate field experiments so that they do not interfere with one another.[148] More generally, formal government involvement can provide legitimacy to research activities, which might otherwise be perceived as rogue experiments.[149]

Under several proposals, an advisory committee on geoengineering research would provide expert advice to governments regarding oversight, policies, and practices.[150] A 2011 proposal

143. *Id.* at 25, 27.

144. *Id.* at 55.

145. *See* Bodansky, *supra* note 21, at 546.

146. *See* GAO-10-903, *supra* note 61, at 39; GOV'T ACCOUNTABILITY OFFICE, *supra* note 52, at 55.

147. *See* Bodansky, *supra* note 21, at 546.

148. *See* BODLE ET AL., *supra* note 22, at 128.

149. *See* Bodansky, *supra* note 21, at 546.

150. In addition to the proposals discussed above, see Jane C.S. Long & Dane Scott, *Vested Interests and Geoengineering Research*, ISSUES SCI. & TECH., 2013, 45, at 45–52 (suggesting that an independent advisory board

from the Bipartisan Policy Center's (BPC) Task Force on Climate Remediation Research advocates a committee to provide advice on setting up an adequate research program, regulating the risks of field experiments, and conducting public outreach.[151] This proposal takes the perspective that present research efforts are an insufficient response to climate change and thus anticipates "little, if any, special scrutiny on a project-by-project basis" for "low-risk early research."[152] Another proposal for an advisory committee, from David E. Winickoff and Mark B. Brown, urges a generally more cautious approach than the BPC. Winickoff and Brown's proposed advisory committee would "provide detailed advice to the Executive Branch and government agencies on an oversight framework *before* the conception and funding of geoengineering research."[153] Emphasizing the importance of developing trusted institutions and procedures for addressing this controversial subject, Winickoff and Brown describe "promot[ion of] public deliberation and debate about values and goals" as a critical function of their proposed committee.[154]

A moratorium on some or all field experiments is an element of many proposals. Edward A. Parson and David W. Keith suggest, for example, distinguishing between projects based on two thresholds of scale and risk: geoengineering projects and field experiments beyond a "large" threshold would be subject to a moratorium, whereas field experiments below a "small-scale" threshold would be allowed to proceed if they comply with transparency requirements and environmental, health, and safety rules.[155] Parson and Keith sidestep the issue of how

could develop standards and norms for transparency and research management), and Parson & Ernst, *supra* note 32, at 335 (suggesting a "World Commission on Climate Engineering" to advise governments and international organizations, elicit stakeholder and citizen input, and undertake other tasks).

151. BPC, *supra* note 52, at 19.

152. *Id.* at 20.

153. Winickoff & Brown, *supra* note 5, at 83 (emphasis added). In contrast, another proposal would insist on a governance framework as a precondition only for field research outside an "'allowed zone' of experimental parameters and expected effects." Morgan et al., *supra* note 51, at 37, 41.

154. Winickoff & Brown, *supra* note 5, at 84.

155. Parson & Keith, *supra* note 16, at 1279. Overall, Parson and Keith recommend that research be subject to governance "backed by government authority and coordinated internationally," perhaps through "informal consultation and coordinated decisions by research-funding and regulatory agencies of participating governments." *Id; cf.* Ian D. Lloyd & Michael Oppenheimer, *On the Design of an International Governance Framework for Geoengineering*, GLOBAL ENVTL. POL., May 2014, at 45, 53–57 (proposing a similar approach in

to govern experiments falling between these two thresholds and focus instead on creating operating space for "small, low-risk research." To that end, they contend the proposed moratorium should "be long and firm enough to allay concern that small research will slide unexamined into deployment."[156] Other commentators urge a broader moratorium on all field testing to allow further public deliberation on geoengineering to occur first.[157]

Various proposals also include a permitting system or some other form of external control. Some proposals would require a permit for all geoengineering field experiments,[158] whereas others would require a permit only for experiments exceeding specified thresholds of scale or risk.[159] Permitting is commonly contemplated at the national level, but international oversight for field experiments having international significance or transboundary effects is also possible.[160] A permit requirement can ensure prior assessment, mitigation, and monitoring of a field experiment's environmental impacts.[161] Such a requirement would build on actions already taken under the LC/LP and CBD.[162] As noted above, the permitting contemplated un-

which small-scale experiments would be frequently permitted, large-scale experiments with potential transboundary effects would be banned initially but occasionally permitted as knowledge increases, and large-scale deployment would be permitted only with consensus approval).

156. Parson & Keith, *supra* note 16, at 1279.

157. *See* ETC GRP., GEOPIRACY: THE CASE AGAINST GEOENGINEERING 40 (2010) (urging a moratorium "on all geoengineering activities outside the laboratory" "[u]ntil there has been a full debate on the course all countries wish to go"); Clive Hamilton, *No, We Should Not Just "At Least Do the Research*,*"* 496 NATURE 139, 139 (2013) (identifying various questions to be answered before further research is undertaken); Michael Zürn & Stefan Schäfer, *The Paradox of Climate Engineering*, 4 GLOBAL POL'Y 266, 274 (2013) (proposing a "time-limited moratorium" on field testing).

158. *See, e.g.*, BODLE ET AL., *supra* note 21, at 142.

159. *See, e.g.*, Parson & Ernst, *supra* note 32, at 326; *cf.* ROYAL SOC'Y, *supra* note 28, at 41 (contending "[t]here is a clear need for governance of research involving large-scale field testing," without specifying the form such governance might take).

160. *See* HOUSE OF COMMONS SCI. & TECH. COMM., THE REGULATION OF GEOENGINEERING 38 (2010) (U.K.) (suggesting that "small tests of SRM geoengineering" having negligible or predictable environmental impacts and no transboundary effects be allowed if in accordance with internationally accepted principles, and that larger scale tests be regulated).

161. *See* Resolution LP.4(8), *supra* note 82, annex 4, at 8; Parson & Ernst, *supra* note 32, at 327.

162. *See* Till Markus & Harald Ginzky, *Regulating Climate Engineering: Paradigmatic Aspects of the Regulation of Ocean Fertilization*, 4 CARBON & CLIMATE L. REV. 477, 484–86 (2011) (discussing how assessment framework

der the LC/LP is limited to scientific research on ocean fertilization and other marine geoengineering techniques.[163] Meanwhile, the decision by the CBD parties allows for small-scale scientific research studies "conducted in a controlled setting," but does nothing to establish a permitting scheme.[164]

Finally, some proposals suggest the creation of a liability and compensation system to address harms that might result from field experiments.[165] Geoengineering deployment raises liability concerns most pointedly,[166] but field experiments also could have adverse environmental consequences warranting compensation.[167] Designing a compensation system would require the resolution of difficult questions of harm, causation, and responsibility.[168]

2. Existing Proposals Focus on Physical Risks

Viewed collectively, existing proposals for governing geoengineering research focus on physical risks.[169] This focus is

for evaluating ocean fertilization experiments could serve as a model for other geoengineering regulatory efforts).

163. Resolution LP.4(8), *supra* note 82.

164. CBD, *supra* note 87, at 5.

165. *See* Joshua B. Horton et al., *Liability for Solar Geoengineering: Historical Precedents, Contemporary Innovations, and Governance Possibilities*, 22 N.Y.U. ENVTL. L.J. 225, 237–45 (2015); Parson & Ernst, *supra* note 32, at 326; Jesse L. Reynolds, *An Economic Analysis of Liability and Compensation for Harm from Large-Scale Field Research in Solar Climate Engineering*, 5 CLIMATE L. 182, 192–202 (2015).

166. *See, e.g.*, Toby Svoboda & Peter J. Irvine, *Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering*, 17 ETHICS POL'Y & ENV'T 157 (2014); Joshua B. Horton et al., *Solar Geoengineering and the Problem of Liability*, GEOENGINEERING OUR CLIMATE? (Nov. 19, 2013), http://geoengineeringourclimate.files.wordpress.com/2013/11/horton-et-al-2013-solar-geoengineering-and-the-problem-of-liability-click-for-download.pdf; Pak-Hang Wong et al., *Compensation for Geoengineering Harms and No-Fault Climate Change Compensation*, (Apr. 8, 2014) http://geoengineering-governance-research.org/perch/resources/workingpaper8wongdouglassavulescucompensationfinal-.pdf.

167. *See* Dilling & Hauser, *supra* note 20, at 557.

168. *See id.*; Parson & Ernst, *supra* note 32, at 326; Svoboda & Irvine, *supra* note 166, at 161–70.

169. *Cf.* Rob Bellamy, *Beyond Climate Control: "Opening Up" Propositions for Geoengineering Governance* (Climate Geoengineering Governance Working Paper Series No. 11, 2014), http://www.geoengineering-governance-research.org/perch/resources/workingpaper11bellamybeyondclimatecontrol.pdf (observing that geoengineering appraisals "have largely taken the form of reductive 'expert-analytic' approaches such as computer modelling, cost-benefit analysis, expert review and multi-criteria analysis that treat the issue as one of simple 'risk' rather than one of indeterminate uncertainty, ambiguity or ignorance"

apparent from what these proposals do—and do not—contain. First, no proposals call for oversight of indoor research. Such research poses virtually no threat of physical harm, and their regulation in any case is politically unlikely.[170] Second, proposals to regulate field experiments generally tailor the amount of scrutiny to the scale of the experiment and expected effects.[171] The most stringent oversight would correspond to experiments posing the greatest potential physical risk, whereas experiments posing little potential physical risk would likely escape oversight altogether. The scope of proposed moratoria on field experiments further illustrates the emphasis on physical risk. For instance, Parson and Keith's proposed moratorium would apply only to those field experiments whose effects surpass defined thresholds of damage or risk. In sum, each of these features reflects a desire to strike a balance between the information that field tests might offer and the environmental harm that may result.[172]

Undoubtedly, the physical risks of geoengineering warrant substantial attention. Ocean fertilization could wreak havoc on marine ecosystems.[173] The release of stratospheric aerosols could interfere with monsoon patterns and exacerbate depletion of the ozone layer.[174] Similarly, enhancing cloud albedo could alter regional precipitation and temperature patterns.[175] Thanks to the uncertainties associated with individual geoen-

(internal citations omitted)).

170. *See, e.g.*, HOUSE OF COMMONS SCI. & TECH. COMM., *supra* note 160, at 37.

171. *Cf.* NAT'L RESEARCH COUNCIL, *supra* note 2, at 13 (recommending that research governance "consider the need for increasing supervision as the scope and scale of the research and its potential implications increase").

172. *See* Parsons & Ernst, *supra* note 32, at 328 (contending that governance decisions "must have a substantially scientific character" because "[d]ecisions whether to authorize proposed research interventions will need to be informed by judgments of their scientific promise and the balance between the knowledge they offer and the scale of environmental disruption they impose").

173. *See* ROYAL SOC'Y, *supra* note 28, at 17–18; Mary W. Silver et al., *Toxic Diatoms and Domoic Acid in Natural and Iron Enriched Waters of the Oceanic Pacific*, 107 PROC. NAT'L ACAD. SCI. 20,762, at 20,763–64 (2010).

174. *See* ROYAL SOC'Y, *supra* note 28, at 31; Simone Tilmes et al., *The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes*, 320 SCIENCE 1201, 1203–04 (2008).

175. *See* ROYAL SOC'Y, *supra* note 28, at 28; John Latham et al., *Global Temperature Stabilization Via Controlled Albedo Enhancement of Low-Level Maritime Clouds*, 366 PHIL. TRANSACTIONS ROYAL SOC'Y A. 3969, 3982–83 (2008).

gineering techniques and the Earth's climate systems, other, as-yet unanticipated physical risks also may emerge. Moreover, physical risks are not confined to full-scale deployment. Field experiments, too, may be of sufficient scale or effect to present significant physical hazards, thereby warranting concern and close scrutiny.

Physical risks are not the only concerns that geoengineering research raises, however. Transparency and public deliberation—or a lack thereof—are two concerns that some geoengineering research governance proposals acknowledge as well. Potential mechanisms to foster transparency include education, media outreach, and a public registry that would give advance notice of geoengineering field trials and disclose research results.[176] Mechanisms to engage the public in decision making, as opposed to merely providing information, might include discussion groups, citizen panels, or public comment processes.[177] The principles of transparency and deliberation feature prominently in the Oxford Principles, a widely cited set of general principles for geoengineering governance. With respect to transparency, the Oxford Principles encourage "complete disclosure of research plans and open publication of results."[178] And to promote public deliberation, the principles counsel that "those conducting geoengineering research . . . be required to notify, consult, and ideally obtain the prior informed consent of, those affected by the research activities."[179]

176. *See* Dilling & Hauser, *supra* note 20, at 559; Parson & Keith, *supra* note 16, at 1279; *see also* BPC, *supra* note 52, at 14 (recommending development of "transparency protocols for all potentially risky forms of climate remediation research"); Morgan et al., *supra* note 51, at 42 (recommending a code of best practices that would include a commitment to publicize SRM research activities on a common website).

177. *See* Dilling & Hauser, *supra* note 20, at 559–60; *see also* Winickoff & Brown, *supra* note 5, at 84 (suggesting that a proposed government advisory committee promote public deliberation regarding geoengineering goals).

178. Rayner et al., *supra* note 56, at 503; *cf.* ASILOMAR SCI. ORG. COMM., THE ASILOMAR CONFERENCE RECOMMENDATIONS ON PRINCIPLES FOR RESEARCH INTO CLIMATE ENGINEERING TECHNIQUES 9 (2010) (recommending that geoengineering research "be conducted openly and cooperatively," with "[p]ublic participation and consultation in research planning and oversight"); BPC, *supra* note 52, at 14 (identifying transparency as an important basic principle that should govern geoengineering research).

179. Rayner et al., *supra* note 56, at 502.

B. WHAT'S MISSING: OTHER CONCERNS RAISED BY RESEARCH

Ensuring that geoengineering field experiments do not present unacceptable physical risks is essential, as is informing and engaging the public regarding such experiments that do occur. Geoengineering research governance proposals typically seek to address these concerns on a project-by-project basis. Through the review of individual field experiments, society presumably can guard against physical harm to humans or the environment. A review process for individual experiments also would provide a concrete setting for implementing measures to promote transparency and public engagement.

Merely attending to physical risks and providing avenues for public participation are not sufficient, however. Existing governance proposals largely fail to address the big-picture concerns geoengineering research raises. I refer to these concerns as systemic concerns, as they arise from the sum of geoengineering research efforts rather than any individual experiment. Systemic concerns are apparent in the public response to the SPICE project—which engaged stakeholders and posed virtually no physical risks yet triggered pointed opposition.[180] The public, sensitive to the project's significance within a broader developmental trajectory, worries that such research will lead society down a slippery slope to deployment. The slippery slope concern and the related phenomenon of technological lock-in are not the only systemic concerns associated with geoengineering research. Other systemic concerns include the potential for geoengineering to undermine mitigation efforts (often referred to as a "moral hazard"), and the heightened prospects for military conflict as geoengineering experimentation and deployment proceed. Ultimately, research does not produce knowledge in a vacuum; rather, it alters the context in which society makes policy decisions and may predispose society to particular courses of action.[181]

1. Lock-in

Through its co-evolution with social, institutional, cultural, and political systems, a technology can become dominant and

180. *See supra* note 10 and accompanying text.

181. *See* Rayner et al., *supra* note 56, at 502 ("These considerations suggest that the issue of social control over the technologies is vital in deciding whether to proceed with geoengineering research. Public resistance to new technology is seldom only about the probability of death or physical injury from a technology.").

difficult to dislodge, or "locked in."[182] Lock-in often results not from obvious technical superiority but rather from processes of path-dependence. Self-reinforcing processes can amplify minor but early advantages or chance circumstances into subsequent dominance.[183] Specifically, a technology may benefit from economic factors such as economies of scale, learning effects, and other positive feedback processes.[184] Political and social factors also may contribute to lock-in, as politicians, agencies, firms, and other parties become invested in establishing and perpetuating a particular technology,[185] and as social paradigms and everyday practices contribute to a technology's acceptance.[186]

To some degree, lock-in is a necessary and unavoidable feature of innovation.[187] Sizable investments and commitments are essential for technologies to take root. Society faces a fundamental dilemma in deciding whether to adopt an emerging technology, however, because its negative consequences often are not known or salient at the outset. Once a technology is locked in, those consequences can be difficult to avoid or address.[188] The unavoidable delay in identifying a technology's adverse effects undermines rational decision making. A technology may achieve dominance not because it is optimal, but because it possessed an initial competitive advantage. As a re-

182. *See* Ivan Scrase & Gordon MacKerron, *Lock-In*, *in* ENERGY FOR THE FUTURE: A NEW AGENDA 89, 90 (Ivan Scrase & Gordon MacKerron eds., 2009); *see also* Rose C. Cairns, *Climate Geoengineering: Issues of Path-Dependence and Socio-Technical Lock-In*, 5 WIREs CLIMATE CHANGE 649, 650–51 (2014).

183. *See* Cairns, *supra* note 182, at 650.

184. *See id.*; Scrase & MacKerron, *supra* note 182, at 91; *see also* W. Brian Arthur, *Competing Technologies, Increasing Returns, and Lock-In by Historical Events*, 99 ECON. J. 116, 116 (1989) ("Modern, complex technologies often display increasing returns to adoption in that the more they are adopted, the more experience is gained with them, and the more they are improved."). Learning effects refer to product improvements and cost reductions resulting from the accumulation of specialized skills and knowledge. *See* Timothy J. Foxon, *Technological Lock-In and the Role of Innovation*, *in* HANDBOOK OF SUSTAINABLE DEVELOPMENT 140, 142 (Giles Atkinson et al. eds., 2007).

185. *See* Scrase & MacKerron, *supra* note 182, at 90, 94. Policies, regulatory frameworks, and political institutions can be resistant to change because of high start-up costs, complex and opaque interactions, and the ability to use political authority to enhance one's own power. *See* Foxon, *supra* note 184, at 144.

186. *See* Cairns, *supra* note 182, at 650.

187. *See* William Walker, *Entrapment in Large Technology Systems: Institutional Commitment and Power Relations*, 29 RES. POL'Y 833, 834, 846 (2000).

188. DAVID COLLINGRIDGE, THE SOCIAL CONTROL OF TECHNOLOGY 16–19 (1980); Cairns, *supra* note 182, at 650.

sult, "the unfit can attract huge investment and can survive long after they should have been sent to the grave."[189]

Global dependence on fossil fuel-based energy systems provides a straightforward illustration of lock-in.[190] Existing energy systems are deeply resistant to change because of their long-lived and extensive infrastructure, as well as their complex and interrelated components.[191] In addition, these systems are operated by powerful stakeholders whose interests are tied to perpetuating the status quo.[192] As a result of lock-in, fuel use in future decades "is *already* determined by investment decisions made over the last decade and more."[193] Rapid and widespread adoption of alternative energy systems to mitigate climate change or reduce fossil fuel dependence is difficult, if not impossible.

Although economists developed the concept of lock-in to explain the dominance of inferior technologies in competitive markets,[194] the concept can apply in other contexts as well. In geoengineering policy discussions, lock-in refers to a variety of concerns—social and cognitive—regarding premature and suboptimal commitments to one or more geoengineering techniques.[195] Social lock-in describes the concern that some geoengineering technologies would require sizable capital investments and physical infrastructure and thus foster the creation of vested interests in their continuation.[196] Even substantial

189. Walker, *supra* note 187, at 834.

190. *See* Gregory C. Unruh, *Understanding Carbon Lock-in*, 28 ENERGY POL'Y 817, 818 (2000); *see also* Simon Shackley & Michael Thompson, *Lost in the Mix: Will the Technologies of Carbon Dioxide Capture and Storage Provide Us with a Breathing Space as We Strive To Make the Transition from Fossil Fuels to Renewables?*, 110 CLIMATIC CHANGE 101, 103–12 (2012) (discussing a concern that carbon capture and storage will reinforce carbon lock-in).

191. *See* Albert C. Lin, *Lessons from the Past for Assessing Energy Technologies for the Future*, 61 UCLA L. REV. 1814, 1820 (2014).

192. *See id.*

193. Scrase & MacKerron, *supra* note 182, at 95.

194. *See* Arthur, *supra* note 184, at 126–27 (suggesting adoption of the QWERTY typewriter keyboard and other examples).

195. *See* Cairns, *supra* note 182, at 651. In addition to the lock-in concerns associated with geoengineering research discussed above, deployment of geoengineering raises a further lock-in concern regarding the drastic climate consequences of terminating an SRM scheme once it has been in place. *See infra* text accompanying notes 329–31.

196. *See* Cairns, *supra* note 182, at 651. David Keith, a leading proponent of field research on stratospheric aerosol release, acknowledges institutional lock-in to be a "strong argument" against experiments posing little risk. *See* KEITH, *supra* note 34, at 151.

research into a specific technique could create scientific and commercial interests favoring further research and perhaps implementation.[197] Cognitive lock-in characterizes the worry that the social framing of geoengineering can conceal value judgments and unduly influence assessments of geoengineering.[198] For example, a focus on certain geoengineering proposals could prematurely foreclose consideration of other geoengineering options. The disproportionate attention currently being devoted to stratospheric aerosols is of particular concern.[199] More generally, the discussion of any geoengineering technique could steer attention away from non-geoengineering alternatives for responding to climate change—a moral hazard concern discussed below.[200] Further, the mere study of geoengineering could even make its deployment more likely.[201] Thus, one report on SRM worries that "[e]ven very basic and safe research . . . could be a first step onto a 'slippery slope,'" creating momentum and a scientific lobbying constituency for development and eventual deployment.[202]

2. Moral Hazard

Geoengineering research presents a second systemic concern, commonly referred to as moral hazard. Geoengineering can offer no more than a partial response to climate change. SRM techniques would "fail to precisely undo the environmental disruptions caused by elevated GHGs" and would do nothing to combat the ocean acidification that rising carbon levels cause.[203] CDR techniques would require intense and protracted efforts to remove relatively modest amounts of carbon from the atmosphere.[204] Accordingly, even if geoengineering were to be

197. *See* David R. Morrow et al., *Toward Ethical Norms and Institutions for Climate Engineering Research*, 4 ENVTL. RES. LETTERS, Oct. 2009, at 3.

198. *See* Rob Bellamy et al., *A Review of Climate Geoengineering Appraisals*, 3 WIREs CLIMATE CHANGE 597, 610–11 (2012); Cairns, *supra* note 182, at 651–52.

199. *See* Bellamy et al., *supra* note 198, at 608.

200. *See id.* at 609. Bellamy et al. further caution that the contextual framing of geoengineering as a response to a climate emergency could "artificially enhance the perceived acceptability of geoengineering proposals." *Id.*

201. *See* Cairns, *supra* note 182, at 652.

202. SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 21.

203. *See* Parson & Ernst, *supra* note 32.

204. *See* Albert C. Lin, *Does Geoengineering Present a Moral Hazard?*, 40 ECOLOGY L.Q. 673, 676–77 (2013); Parson & Ernst, *supra* note 32, at 313 (discussing "low leverage" characteristics of CDR techniques).

deployed, GHG emissions reductions (commonly referred to as mitigation) would remain essential.[205] In this context, moral hazard refers to the potential for geoengineering research and development activities to undermine mitigation efforts and public support for such efforts.[206] Specifically, geoengineering—or the prospect of geoengineering—may divert attention and resources away from mitigation, undermine incentives to reduce behaviors that generate carbon emissions, or encourage political inaction.[207] The moral hazard concern has both psychological and political components. Psychologically, people may misperceive geoengineering as a simple yet comprehensive solution to climate change and thereby view mitigation as less urgent or even unnecessary.[208] The extent of this effect is open to debate as an empirical matter, but psychological tendencies toward overconfidence and procrastination suggest its plausibility.[209] Politically, geoengineering might offer elected officials an easy excuse for avoiding difficult choices that could impose significant costs or require substantial changes in current lifestyles and the global economy.[210] Why pay the price of mitiga-

205. Geoengineering researchers generally agree on this point. *See, e.g.*, NAT'L RESEARCH COUNCIL, *supra* note 2, at 13; ROYAL SOCIETY, *supra* note 28, at ix ("No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change."); Martin Bunzl, *Researching Geoengineering: Should Not or Could Not?*, 4 ENVTL. RES. LETTERS, 045104, at 2 (2009); Michael MacCracken et al., Asilomar International Conference on Climate Intervention Technologies, Statement from the Conference's Scientific Organizing Committee, (Mar. 26, 2010), http://www.whoi.edu/fileserver.do?id=62483&pt=10&p=39472.

206. *See* Lin, *supra* note 204, at 674; David R. Morrow, *Ethical Aspects of the Mitigation Obstruction Argument Against Climate Engineering Research*, 372 PHIL. TRANSACTIONS ROYAL SOC'Y A, Nov. 17, 2014, at 2.

207. *See* Stefan Schäfer et al., *Earth's Future in the Anthropocene: Technological Interventions Between Piecemeal and Utopian Social Engineering*, 2 EARTH'S FUTURE 239, 242 (2014). For a discussion regarding whether decreased mitigation would lead to a worse outcome, see Morrow, *supra* note 206, at 3–11.

208. *See* Lin, *supra* note 204, at 678.

209. *Compare* Lin, *supra* note 204, at 694–701 (discussing psychological influences on risk perception), *with* Jesse Reynolds, *A Critical Examination of the Climate Engineering Moral Hazard and Risk Compensation Concern*, 2 ANTHROPOCENE REV. 174, 185 (2015) (arguing that empirical evidence of moral hazard and risk compensation is "not fully conclusive").

210. *See* STEPHEN M. GARDINER, A PERFECT MORAL STORM: THE ETHICAL TRAGEDY OF CLIMATE CHANGE 364 (2011) (warning that a policy of modest geoengineering research, but not deployment, "is the approach most compatible with continued intergenerational buck-passing" because it would impose minimal costs and risks to the present generation); Lin, *supra* note 204, at 707; Robert L. Olson, *Soft Geoengineering: A Gentler Approach to Addressing Cli-*

tion today, politicians might contend, if a seemingly inexpensive technological fix lies just over the horizon?

Like lock-in, moral hazard is a systemic concern in that it arises from the overall course of geoengineering research rather than from any individual field trial. An ongoing research program, including advancing field experimentation, might offer political cover for officials to sustain claims that a technological fix is on the way and that mitigation is unnecessary.

3. Increased Conflict

Geoengineering research—especially research into the faster-acting SRM techniques—raises a further systemic concern: the potential use of such techniques in military conflict. The military, appreciating the importance of weather to battlefield success, has a deep and long-standing interest in weather and climate control.[211] It is thus not surprising that the U.S. military has expressed interest in the subject of geoengineering.[212] Current geoengineering research has a peaceful aim of countering the effects of climate change, and it is not at all certain that geoengineering-based applications would have sufficient precision to be useful in war.[213] Nonetheless, as experi-

mate Change, ENVIRONMENT, Sept./Oct. 2012, at 29, 30 ("Another key concern is that if politicians come to believe that geoengineering provides a low-cost 'tech fix' for climate change, it could give them a perfect excuse to back off from efforts to cut emissions."); Edward A. Parson, *Reflections on Air Capture: The Political Economy of Active Intervention in the Global Environment*, 74 CLIMATIC CHANGE 5, 8 (2006).

211. *See generally* JAMES RODGER FLEMING, FIXING THE SKY: THE CHECKERED HISTORY OF WEATHER AND CLIMATE CONTROL 165–88 (2010) (detailing military interest in cloud seeding, hurricane modification, and other forms of weather modification). The ENMOD Convention prohibits the "military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury" to other states. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques art. I, opened for signature May 18, 1977, 31 U.S.T. 333, 1108 U.N.T.S. 151.

212. *See* Morrow et al., *supra* note 197.

213. *See* Achim Maas & Jürgen Scheffran, *Climate Conflicts 2.0? Climate Engineering as a Challenge for International Peace and Security*, 20 SICHERHEIT & FRIEDEN 193, 196 (2012) (reasoning deliberate military use of geoengineering is unlikely because of potential for large collateral damage, time delay between deployment and results, and highly indirect effects); Steve Rayner, *To Know or Not To Know? A Note on Ignorance as a Rhetorical Resource in Geoengineering Debates* 8, (Climate Geoengineering Governance, Working Paper Series No. 10, 2014), http://geoengineering-governance-research.org/perch/resources/workingpaper10raynertoknowornottoknow-1.pdf (noting tension between assertions that solar geoengineering is uncontrollable and the high degree of control that successful weaponization would require).

ence with other dual-use technologies suggests, the military might use the information generated from such research to develop weapons and other wartime applications.[214] Geoengineering technologies with regional effects may be of particular interest because of their potential for altering the weather or climate of potential enemies.[215]

Aside from direct military applications, geoengineering research also could foster global conflict by creating a new bone of geopolitical contention. For one, states might view another country's unilateral pursuit of geoengineering research as contrary to their interests and as a precursor to unilateral deployment.[216] Field tests could heighten tensions or lead to preemptive strikes, and deployment could provoke retaliatory measures.[217] Moreover, even if geoengineering techniques were successfully and peacefully developed, a slate of difficult if not ungovernable issues regarding their potential deployment would arise. The metaphor of a global thermostat, though misleading in the degree of control it suggests, captures some of the likely conflict.[218] Just as individuals may disagree over a thermostat setting, nations may disagree over whether to deploy geoengineering at all; if so, when and how deployment should occur; and how to make such decisions.[219] If these issues are inherently ungovernable, perhaps the prudent course would be to avoid developing a technology that would only sow the seeds of future conflict.[220] Ignorance, in this instance, could be a virtue.[221]

214. *See supra* Part I.C (discussing the dual use of biological research for offensive and medical purposes).

215. *See* Morrow et al., *supra* note 197; Robock, *supra* note 67, at 227.

216. *See* Adam Corner & Nick Pidgeon, *Geoengineering the Climate: The Social and Ethical Implications*, ENVIRONMENT, Jan./Feb. 2010, at 24, 30.

217. *See* Bodansky, *supra* note 21, at 549 (suggesting that retaliation might include measures to warm the climate back up).

218. *See* Albert Lin, *Geoengineering's Thermostat Dilemma*, *in* THE LAW OF THE FUTURE AND THE FUTURE OF LAW: VOLUME II 173–74 (Sam Muller et al. eds., 2012).

219. *See* MIKE HULME, CAN SCIENCE FIX CLIMATE CHANGE?: A CASE AGAINST CLIMATE ENGINEERING 60 (2014); Lin, *supra* note 218, at 175; Phil Macnaghten & Bronislaw Szerszynski, *Living the Global Social Experiment: An Analysis of Public Discourse on Solar Radiation Management and Its Implications for Governance*, 23 GLOBAL ENVTL. CHANGE 465, 472 (2013); Parson & Ernst, *supra* note 32, at 330.

220. *Cf.* HULME, *supra* note 219, at 81–82 (contending that stratospheric aerosol deployment should not be researched if it cannot be governed in an acceptable manner).

221. *See* Rayner, *supra* note 213, at 12–13.

A counterargument can be made, however, that ignorance may not be an option if would-be geoengineering researchers are determined to press forward. Furthermore, ignorance regarding a geoengineering technique or its risks might not prevent *poorly informed* deployment.[222] As climate change becomes more severe, the international community or an individual nation might turn in desperation to an unproven geoengineering technique. Such a move could lead to international disputes as well as unexpected consequences.[223] The critical premise underlying this argument is that research will yield adequate information to support prudent, consensus-based decision making. Even if research is done, however, substantial uncertainties regarding the effects of possible climate interventions are likely to remain.[224] In any case, disagreements regarding how to proceed will persist, and research may create a false sense of security that exacerbates such disagreements.[225]

III. A PROPOSAL FOR GEOENGINEERING RESEARCH GOVERNANCE

Governance should address both the systemic concerns and physical risks associated with geoengineering research. This Part sketches out the desired characteristics of a research governance structure, surveys issues of governance design, and then sets forth a specific proposal.

A. DESIRED CHARACTERISTICS OF RESEARCH GOVERNANCE

What characteristics should a geoengineering research governance regime have? First, governance should be legitimate and perceived as such. Second, governance should effectively address the concerns raised by geoengineering research.

1. Legitimacy

Efforts by the scientific community and by nongovernmental institutions to develop governance mechanisms, however well-intended, have been lacking in legitimacy. The SPICE field

222. *See, e.g.*, SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 20.

223. *See id.* at 20–21.

224. *See* Rayner, *supra* note 213, at 7; Szerszynski et al., *supra* note 43, at 2811 (suggesting that SRM "[d]eployment will thus always have the character of research").

225. *See* Rayner, *supra* note 213, at 12–13 (describing such concern among opponents of geoengineering research).

experiment ran into trouble, but not for lack of conventional scientific oversight. Indeed, the experiment was subject to review processes beyond those typically applied to university research.[226] This oversight nevertheless was perceived as inadequate to account for the broader social concerns surrounding SRM.[227] Laypersons questioned the experiment's justification, given the limited information the experiment would provide and the subsequent research it seemed to presume.[228] They also voiced strong support for international regulatory structures to shape this and any subsequent SRM field experiments.[229] The conflict-of-interest concerns that ultimately sank the experiment only underscore the need for external oversight that would be widely accepted as legitimate.

The incorporation of various features—independence, transparency, public participation, and accountability—all can contribute to a governance structure's legitimacy.[230] Independence requires that overseers make decisions in the public interest and free from the undue influence of researchers, research sponsors, and private interests.[231] Accordingly, individual researchers cannot be left to police themselves, and there should be some form of external oversight. Even peer review by other geoengineering researchers may not assure impartiality.[232] Participation by geoengineering experts will be necessary to enable informed oversight, but to ensure independence, a governing institution should also include diverse perspectives and interests from outside the geoengineering research community.[233]

Transparency is inherent to legitimacy in the sense that openness demonstrates respect for the persons over whom

226. *See* Pidgeon et al., *supra* note 3 (discussing "Stagegate" evaluation process, in which researchers were asked to satisfy five evaluation criteria, including the description of future potential applications and impacts).

227. *See id.* at 454–55.

228. *See id.*

229. *See id.*

230. *See* BODLE ET AL., *supra* note 21, at 20; Rayner et al., *supra* note 56, at 505, 508; Winickoff & Brown, *supra* note 5, at 81 ("An advisory committee on geoengineering will be more effective and legitimate to the extent that it is independent, transparent, deliberative, publicly engaged, and broadly framed.").

231. *See* Winickoff & Brown, *supra* note 5, at 81.

232. *See id.* (warning that an expert institution, to avoid being seen as an advocate for geoengineering deployment, must include people without direct involvement in geoengineering research).

233. *See id.*

democratic authority is exercised.[234] Equally important, transparency furthers legitimacy by exposing vested interests and fostering public confidence in governance processes.[235] To promote transparency, the public should have detailed notice of research plans in advance, as well as access to the information generated by research.[236] Transparency also should apply to research agendas: researchers and policy makers should explain the role of individual research projects within their broader context and communicate overall research goals.[237] The technical nature of geoengineering demands special attention to presenting information to the public in an understandable manner.[238] Perhaps most importantly, governance processes themselves should be transparent.[239] Given the distrust that already attends geoengineering, a governance regime for geoengineering research will command public confidence only if the public can see how governance decisions are made.

Through public participation, persons affected by a decision can have a say in its making.[240] Participation can advance democratic governance, foster support for decisions, and generate substantively better outcomes.[241] In the context of geoengineering governance, Dane Scott and Jane C.S. Long argue that "[p]ublic deliberation can highlight inappropriate profit-making concerns, point out unbalanced scientific positions, call attention to hubris and institutional bias, and counter the influence of partisan positioning on decisionmaking."[242] Determining how to operationalize public participation presents a difficult matter, however, particularly when the relevant public consists of the entire global population. Ensuring that public engagement serves as more than an empty exercise presents a further chal-

234. *See* Neil Craik & Nigel Moore, *Disclosure-Based Governance for Climate Engineering Research* 4 (Ctr. for Int'l Governance Innovation, CIGI Paper No. 50, 2014), https://www.cigionline.org/sites/default/files/no.50.pdf.

235. *See id.* at 4–5; *see also* Winickoff & Brown, *supra* note 5, at 81.

236. *See* Dilling & Hauser, *supra* note 20, at 559 (recommending "public registries that include information on funding sources, personnel, research plans, project outcomes, etc.").

237. *Cf.* Pidgeon et al., *supra* note 3, at 454 (characterizing communication about research as "obligatory").

238. *See* Dilling & Hauser, *supra* note 20, at 556–57.

239. *See* Parson & Keith, *supra* note 16, at 1279; Winickoff & Brown, *supra* note 5, at 81.

240. *See* Rayner et al., *supra* note 56, at 505.

241. *See* LIN, *supra* note 107, at 20.

242. Scott & Long, *supra* note 150, at 51.

lenge.[243] Affording public access to the information generated by research provides a starting point;[244] public comment processes and deliberative exercises offer avenues for acting on that information.[245] The public engagement associated with the SPICE project provides an example of the influence that public input can have on decision making processes: the results of that engagement were delivered to a panel which in turn instructed the researchers to reflect on the concerns raised before proceeding.[246]

Accountability overlaps with the values of transparency and participation. Transparency promotes accountability when those engaged in oversight explain or justify their decisions to the public.[247] Similarly, public participation can be a means of holding governance institutions accountable for their decisions.[248] A focus on accountability highlights the importance of developing mechanisms for overseeing the overseers.[249] These mechanisms, which may include reporting requirements, funding conditions, and formal government participation, ideally would ensure that geoengineering research governance is responsive to the international community, stakeholders, and the public.

2. Effectiveness

A second essential characteristic of geoengineering research governance is effectiveness. Governance must effectively address not only the physical risks associated with individual field experiments, but also the systemic concerns attendant to geoengineering research in general. Addressing these two sets of issues poses formidable yet distinct challenges. The difficul-

243. *See* Rayner et al., *supra* note 56, at 505.

244. Winickoff & Brown, *supra* note 5, at 81.

245. *See* Dilling & Hauser, *supra* note 20, at 560.

246. Pidgeon et al., *supra* note 3, at 455.

247. *See* Rayner et al., *supra* note 56, at 508; Rick Stapenhurst & Mitchell O'Brien, *Accountability in Governance*, WORLD BANK, http://siteresources.worldbank.org/PUBLICSECTORANDGOVERNANCE/Resources/AccountabilityGovernance.pdf (last visited Feb. 29, 2016).

248. *See* Rayner et al., *supra* note 56, at 508; Stapenhurst & O'Brien, *supra* note 247, at 1–2 (discussing "vertical accountability[,] . . . through which citizens, mass media and civil society seek to enforce standards of good performance on officials").

249. *See* Stapenhurst & O'Brien, *supra* note 247, at 1 ("[A]ccountability exists when there is a relationship where an individual or body, and the performance of tasks or functions by that individual or body, are subject to another's oversight . . . ." (emphasis omitted)).

ties of analyzing physical risks arise largely because field tests are inherently experimental and thus may generate unexpected effects. Scientists can try to reduce this uncertainty by conducting careful modeling, studying natural analogues, and gradually scaling up field experiments.[250] The process of assessing physical risks would be a familiar one for scientists, just as the subsequent process of risk management would be familiar to policy makers. It is perhaps unsurprising, then, that extant proposals for geoengineering research oversight focus on physical risks.

By contrast, concerns regarding lock-in, moral hazard, and future military conflict differ from worries about physical risks in two important ways. First, these concerns are beyond the scope of hard scientific inquiry. Social scientists can contribute useful insights on these matters and offer instructive analogies, but can provide no ready quantitative assessments. Policy decisions regarding geoengineering research will require an uneasy merger of qualitative analysis of these concerns with quantitative risk data. Second, these concerns are systemic and cumulative—they arise not so much from any individual research project as from the overall trajectory of geoengineering research. Thanks to the cumulative nature of these concerns, they are unlikely to be given much weight in the review of single research projects and are prone to omission from research governance proposals. Effective consideration of systemic concerns will require holistic rather than piecemeal review of geoengineering research.

B. DESIGN OPTIONS

Governance can be undertaken by different actors, through different institutions, at different scales, and via different tools.[251] The following discussion identifies key considerations in designing a governance system for geoengineering research.

First, who should be involved in governance? The technical nature of geoengineering demands the involvement of scientists in governance, most importantly independent experts who can impartially evaluate research proposals and results.[252] Scholars

250. *See, e.g.*, KEITH, *supra* note 34, at 80–88 (advocating gradual ramping up of research and field experimentation).

251. *E.g.*, SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 30 (identifying different scales of regulation, ranging from individual regulation by researchers themselves to international regulation).

252. *See* Parson & Ernst, *supra* note 32, at 328.

outside the hard sciences also can provide important contributions regarding the social and ethical implications of field experiments. Yet experts alone should not decide whether or how geoengineering research proceeds. Humanity has a common interest in a stable climate, as reflected in various calls for geoengineering to be regulated as a "public good."[253] Because decisions regarding geoengineering research will have important ramifications for public policy, democratically accountable institutions should participate in making these decisions. Legitimacy further demands that potentially affected persons have a voice. The systemic concerns posed by even relatively limited field experiments make it essential to integrate the public into the governance process early on, rather than waiting until experiments have significant physical impacts.[254]

Second, through what institutions and at what scale should governance occur? Governance need not necessarily occur through government. Various entities could participate in geoengineering research governance, including professional associations and other peer-based organizations, nongovernmental organizations, national governments, and international treaty organizations. The scientific community's core mechanism for promoting accuracy in research is peer review. More generally, professional associations can ingrain values into members of a research or occupational community through codes of conduct and the like.[255] These forms of governance offer potential advantages of flexibility and adaptability.[256] But geoengineering research governance requires far more than the promotion of research accuracy or the inculcation of ethical practices among geoengineering researchers. Society has a strong interest in determining the course of geoengineering research, and governance must incorporate its values and concerns. One means of incorporating social values into an oversight regime is through the participation of nongovernmental

253. Rayner et al., *supra* note 56, at 505; *see also* ASILOMAR SCI. ORG. COMM., *supra* note 178 (listing "[p]romoting the collective benefit of humankind and the environment" as the primary purpose of geoengineering research).

254. This would be in contrast to proposals to expand participation as the scale of research expands. SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 38.

255. *See* LIN, *supra* note 107, at 167; Lorna Weir & Michael J. Selgelid, *Professionalization as a Governance Strategy for Synthetic Biology*, 3 SYSTEMS & SYNTHETIC BIOLOGY 91, 94 (2009).

256. Marchant & Pope, *supra* note 45, at 389.

organizations, such as certification societies or nonprofit environmental monitors.[257] However, absent government sanction—and perhaps even in its presence—such governance may not be perceived as representative or legitimate.[258] Governance through national governments or international treaty organizations is more likely to offer the legitimacy essential to geoengineering research. International oversight requires a level of cooperation that national oversight does not. Climate change is a problem of the global commons, however, and the global implications of geoengineering research call for representation of those whom geoengineering would affect. There is a further, practical argument for international oversight or international coordination of oversight: research restrictions may have limited effect unless they extend beyond national boundaries.[259] Ultimately, broad, multilateral participation in an international governance regime can foster its reach and legitimacy,[260] though the involvement of large numbers of countries may diminish its effectiveness.[261]

International governance could take place through a single institution, but the breadth of potential geoengineering activities makes it more likely that a complex of multiple institutions would jointly govern the subject.[262] One observer has described the current state of international geoengineering governance, including actions taken under the CBD and LC/LP treaty regimes to address geoengineering research, as an "emerging in-

257. *See* Cathy C. Conrad & Krista G. Hilchey, *A Review of Citizen Science and Community-Based Environmental Monitoring: Issues and Opportunities*, 176 ENVTL. MONITORING & ASSESSMENT 273, 276–78 (2011) (discussing different forms of community-based monitoring); Ewald Rametsteiner & Markku Simula, *Forest Certification—an Instrument to Promote Sustainable Forest Management?*, 67 J. ENVTL. MGMT. 87, 89–90 (2003) (discussing implementation of forest certification schemes).

258. *See, e.g.*, Benjamin Cashore et al., *Forest Certification (Eco-Labeling) Programs and Their Policy-Making Authority: Explaining Divergence Among North American and European Case Studies*, 5 FOREST POL'Y & ECON. 225, 228–37 (2003) (discussing various forest certification schemes and their perceived legitimacy).

259. *See* Singer, *supra* note 45, at 227–28 (contending that national decisions not to research a subject "will not stop the knowledge emerging somewhere in the world"); *cf.* Marchant & Pope, *supra* note 45, at 381 (remarking that international regulation might in principle prevent off-shoring of research but is difficult to accomplish in practice).

260. BODLE ET AL., *supra* note 21, at 124.

261. Bodansky, *supra* note 21, at 544.

262. *See* BODLE ET AL., *supra* note 21, at 132.

stitutional complex."[263] These institutions eventually may merge into a single regime in which one institution dominates and sets a general policy direction.[264] Or they may evolve independently and continue to act without any coordination.[265] A single institution that takes the lead in geoengineering governance could fulfill various functions.[266] Most importantly, such an institution would be situated to take a broad, programmatic view of all geoengineering research and to do so in the context of other options for responding to climate change. It might also develop overarching principles and coordinate arrangements by other institutions.[267] The involvement of multiple institutions can offer benefits of expertise and specialization.[268] In addition, combining the efforts of a broad institution with more specialized institutions can avoid burdening policy makers with the minutiae of implementing a complex oversight regime.[269] Such a differentiated approach may suit the oversight of research into widely varying geoengineering techniques.

A third design question turns to the choice of specific tools of governance. Tools of governance can include formal "hard" regulation as well as "soft" governance processes.[270] Formal regulation includes prohibitions, restrictions, permitting systems, and notification and disclosure requirements.[271] Hard law obligations flow from recognized lawmaking processes and are generally binding.[272] Soft governance processes refer to other, nonbinding means of influencing activity, such as the establishment of guidelines, recommendations, or norms, as well as funding allocation decisions.[273]

263. *Id.*

264. *Id.* at 133.

265. *See id.*

266. *Id.* at 156–57.

267. *Id.*

268. *See* Bodansky, *supra* note 21, at 545 (suggesting "a broadly-inclusive international institution . . . for the development of general rules regarding geoengineering" but "a smaller group with technical expertise" or national decision-makers for applying such rules).

269. *See id.* at 544–45.

270. SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 29.

271. *See* BODLE ET AL., *supra* note 21, at 131–32.

272. *See* DANIEL BODANSKY, THE ART AND CRAFT OF INTERNATIONAL ENVIRONMENTAL LAW 13–14 (2010).

273. *See* SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 29; Bodansky, *supra* note 21, at 544.

To date, efforts to govern geoengineering research have primarily involved soft law. For example, decisions by governments to fund—or not to fund—geoengineering research have had a direct effect on research levels and have sent implicit messages regarding the acceptability of such research. Government funding decisions cannot carry out the full range of desired governance functions, however, nor do they directly control research funded by private parties. Soft governance efforts have also included bottom-up efforts to develop voluntary guidelines.[274] Although such efforts can be a relatively simple and flexible means of establishing norms, they have produced only "consensus statements . . . lacking the specificity needed to help any body—governmental or scientific—enact operational governance and assessment procedures" with respect to geoengineering research.[275] Indeed, the best known guidelines, the Oxford Principles, are described by their own authors as "high-level and abstract," "intended . . . to be interpreted and implemented in different ways, appropriate to the technology under consideration and the stage of its development, as well as the wider social context of the research."[276]

C. Putting Together the Missing Pieces

Governance of geoengineering research should address physical risks as well as systemic concerns. Because the existing literature already suggests various options for addressing physical risks,[277] the discussion below focuses on addressing systemic concerns. A governance regime might mitigate systemic risks through a variety of mechanisms, but should include several key elements. These elements are: programmatic technology assessment, analysis of the systemic risks posed by specific geoengineering techniques, prioritization of research into techniques involving lesser systemic risks, and institution of safeguards against systemic risks.

274. *E.g.*, SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46, at 36; *see also* BODLE ET AL., *supra* note 21, at 124 (discussing such efforts).

275. Parson & Keith, *supra* note 16.

276. Rayner et al., *supra* note 56, at 504.

277. *See supra* Part II.A.1.

1. Ongoing Programmatic Technology Assessment

a. *General Design Issues*

A developing consensus in the scientific community supports external review of geoengineering field research.[278] The oversight typically contemplated would involve project-by-project review to identify a particular experiment's physical risks and to provide an opportunity for public input. Such review is essential, but unlikely to account adequately for the cumulative effects of multiple research projects. More importantly, project-by-project review would miss the systemic concerns of geoengineering research—lock-in, moral hazard, and increased potential for conflict.

These shortcomings resemble a common flaw encountered in National Environmental Policy Act (NEPA) analysis: environmental impact statements (EISs) for individual projects often overlook indirect, cumulative, or programmatic effects. NEPA requires federal agencies to prepare an EIS for major federal actions significantly affecting the quality of the human environment.[279] Programmatic EISs offer one means of articulating and analyzing effects that extend beyond individual projects.[280] In contrast to piecemeal, project-specific assessments, programmatic analyses evaluate the environmental impacts of multiple facilities, multiple projects, or agency-wide policies or programs. These analyses consequently can identify and resolve difficult but important issues that might otherwise be avoided.[281] Programmatic EISs can be substantial undertakings, however, and judicial interpretations of NEPA require their preparation only in fairly narrow circumstances.[282] Not

278. Parson & Ernst, *supra* note 32, at 320, 324 (suggesting that one "point[] of strong consensus" is that "research itself needs governance"); *see also* Editorial, *A Charter for Geoengineering*, 485 NATURE 415, 415 (2012) (calling for regulation before geoengineering field experiments begin).

279. *See* 42 U.S.C. § 4332(C) (2012).

280. *See* Jon C. Cooper, *Broad Programmatic, Policy and Planning Assessments Under the National Environmental Policy Act and Similar Devices: A Quiet Revolution in an Approach to Environmental Considerations*, 11 PACE ENVTL. L. REV. 89, 94, 133–34 (1993).

281. *See id.* at 116 ("[A] programmatic/policy assessment is an attempt by high-level officials to examine the implications of the programs/policies from top to bottom."); *id.* at 136.

282. *See* Kleppe v. Sierra Club, 427 U.S. 390, 405–06 (1976) (holding that preparation of studies of possible resource development does not trigger obligation to prepare an EIS absent a specific proposal); Nat. Res. Def. Council v. U.S. Dep't of Navy, No. CV–01–07781 CAS (RZX), 2002 WL 32095131, at *13–

surprisingly, in analyzing similar but unrelated research projects, federal agencies often dodge the consideration of broader systemic concerns.[283]

The proposal here moves beyond NEPA's requirements and urges an ongoing programmatic technology assessment of geoengineering research activities. This assessment would consider the cumulative effects of multiple research projects, examine the developmental trajectory of specific techniques in light of ongoing research, and tease out scientific, social, and ethical issues.[284] As explained in more detail below, the proposed analysis would differ from conventional NEPA analysis in several ways. First, it would consider the effects of all geoengineering research activities and do so within the context of other strategies for responding to climate change. Analysis should encompass social and systemic effects in addition to physical effects. Second, the tools of analysis would include not only environmental impact analysis, but also scenario planning, vision assessment, and other future-oriented analyses. Third, the analytical process would be ongoing rather than discrete.

The proposed geoengineering technology assessment would extend more broadly than ordinary NEPA analysis. It would consider all geoengineering research activities, regardless of federal funding, approval, or involvement. Ideally, this analysis would account for research activities both inside and outside the United States. Such a broad-ranging analysis is feasible. While some research might occur beyond public scrutiny, most geoengineering researchers believe that transparency is essen-

17 (C.D. Cal. Sept. 17, 2002) (rejecting claim that Navy tests of anti-submarine technologies required programmatic NEPA review).

283. *See* Found. on Econ. Trends v. Lyng, 817 F.2d 882, 884–85 (D.C. Cir. 1987) (finding no programmatic EIS required for "diverse" and "discrete" animal productivity research projects); Found. on Econ. Trends v. Heckler, 756 F.2d 143 (D.C. Cir. 1985) (vacating lower court injunction of GMO deliberate release experiments in absence of programmatic EIS); Cooper, *supra* note 280, at 117–18 (discussing agencies' wide discretion in deciding whether to prepare programmatic EISs and their opposition to doing so). No law bars agencies from conducting programmatic EISs to analyze systemic concerns, and NEPA regulations encourage the preparation of EISs for research programs for new technologies. *See* 40 C.F.R. § 1502.4(c)(3) (2015) ("[A]gencies may find it useful to evaluate the proposal(s) . . . [b]y stage of technological development including federal or federally assisted research, development or demonstration programs for new technologies . . . .").

284. *Cf.* Rayner et al., *supra* note 56, at 507 (urging "[r]egular assessments of the impacts of geoengineering research" to address the environmental and socioeconomic impacts of research).

tial and are willing to make public their experiments and results.[285] Furthermore, the proposed assessment would give close attention to the policy context of geoengineering research. Agencies often limit the range of alternatives in NEPA analyses to fit their narrowly defined needs.[286] The assessment of geoengineering alternatives, in contrast, should be part of a broader discussion concerning the full range of climate change policy options.[287] Equally important, the analysis should extend beyond technical design issues and safety and environmental concerns to consider social, economic, and other relevant effects.[288] A comprehensive approach is necessary to assess lock-in, moral hazard, and other systemic effects, and to consider social acceptability as well as technical readiness. Indeed, the assessment process itself, if done in a careful and open manner, may mitigate these systemic concerns by identifying the limitations and flaws of geoengineering techniques.

The proposed assessment would identify trends and future technological developments, yet should endeavor to do more than predict the future. Another important function would be to envision *possible* future scenarios and stimulate public discourse regarding those scenarios. Accordingly, the assessment process should incorporate analytical techniques in addition to the risk analyses and impact assessments that typically dominate EISs. Scenario planning, vision assessment, and other innovative techniques would also be useful. In scenario planning,

285. *See* Dilling & Hauser, *supra* note 20, at 559 (noting that transparency "has repeatedly come up as a necessary component of a geoengineering governance framework"); Morgan et al., *supra* note 51 (recommending "guidelines to provide open access to SRM knowledge"); *see also* BPC, *supra* note 52, at 14 (affirming importance of transparency); ROYAL SOC'Y, *supra* note 28, at 52 ("Research activity should be as open . . . as possible . . . .").

286. *See* James Allen, *NEPA Alternatives Analysis: The Evolving Exclusion of Remote and Speculative Alternatives*, 25 J. LAND RESOURCES & ENVTL. L. 287, 300–09 (2005) (discussing case law); *cf.* City of Alexandria v. Slater, 198 F.3d 862, 867 (D.C. Cir. 1999) (reviewing agency's objectives and agency's evaluation of alternatives in light of these objectives "with considerable deference to the agency's expertise and policy-making role").

287. *Cf.* Rob Bellamy et al., *"Opening Up" Geoengineering Appraisal: Multi-Criteria Mapping of Options for Tackling Climate Change*, 23 GLOBAL ENVTL. CHANGE 926, 927 (2013) (contending that the failure of existing geoengineering appraisals to reflect mitigation and adaptation alternatives for responding to climate change has "closed down" debate and can lead to premature lock-in).

288. 42 U.S.C. § 4332(C) (2012); Metropolitan Edison Co. v. People Against Nuclear Energy, 460 U.S. 766, 774 (1983) (holding that agencies must consider only those effects where there is "a reasonably close causal relationship between a change in the physical environment and the effect at issue").

participants develop narratives that identify important decisions, events, and consequences of plausible future scenarios.[289] Policy makers can use these scenarios to conduct more effective strategic planning in the face of uncertainty.[290] These scenarios also can serve as the subject of public engagement exercises and thereby facilitate discussions about societal goals. Another technique, vision assessment, evaluates far-reaching yet plausible technological visions articulated by scientists and others. This analysis can provide strategic knowledge for bringing about—or preventing—such visions and shaping public debate about future technologies.[291]

Researchers are beginning to explore how these futuring techniques may inform geoengineering policy. A recent scenario-planning exercise concerning solar radiation management, for example, generated six scenarios premised on differing levels of stakeholder self-interest and technological controllability.[292] The conveners of the exercise suggested that the scenarios offer "insight into some of the dynamics that may shape how our world unfolds" and could assist in evaluating proposals for SRM governance across varying conditions.[293]

Any programmatic assessment of geoengineering should incorporate broad and meaningful public engagement.[294] At a

289. *See* JAMES A. OGILVY, CREATING BETTER FUTURES: SCENARIO PLANNING AS A TOOL FOR A BETTER TOMORROW 175–76 (2002); David N. Bengston, *Futures Research: A Neglected Dimension in Environmental Policy and Planning*, *in* ENVIRONMENTAL FUTURES RESEARCH: EXPERIENCES, APPROACHES, AND OPPORTUNITIES 4, 8 (2012). A recent scenario planning exercise focused on SRM. *See* GLOBAL GOVERNANCE FUTURES, HUMAN INTERVENTION IN THE EARTH'S CLIMATE: THE GOVERNANCE OF GEOENGINEERING IN 2025+ (2015).

290. *See* Bengston, *supra* note 289; Stephen R. Carpenter & Adena R. Rissman, *Scenarios and Decisionmaking for Complex Environmental Systems*, *in* ENVIRONMENTAL FUTURES RESEARCH, *supra* note 289, at 37–38 (noting that scenario planning helps policy makers deal with "profound uncertainty"); *cf.* OGILVY, *supra* note 289, at 176–77 (noting that scenario planning fosters "bottom-up innovation and creativity").

291. *See* Armin Grunwald, *Vision Assessment as a New Element of the FTA Toolbox*, EU-US SEMINAR: NEW TECHNOLOGY FORESIGHT, FORECASTING & ASSESSMENT METHODS 53, 56–60 (2004), http://foresight.jrc.ec.europa.eu/fta/papers/Session%204%20What's%20the%20Use/Vision%20Assessment%20as%20a%20new%20element%20of%20the%20FTA%20toolbox.pdf (explaining the role of visions and vision assessment in technology).

292. *See* YALE CLIMATE & ENERGY INST., SCENARIO PLANNING FOR SOLAR RADIATION MANAGEMENT 8 (2013).

293. *Id.* at 26. A prominent issue raised in discussions of the scenarios was the slippery slope concern that technologies, once developed, tend to be used. *Id.* at 6.

294. *See* Winickoff & Brown, *supra* note 5, at 82 (also suggesting the publi-

minimum, such engagement would raise public understanding of geoengineering and its limitations. Public hearings, deliberative exercises, and the like would not only provide information, but also encourage input, identify concerns, and stimulate debate. Without adequate public engagement, future geoengineering field experiments are likely to encounter opposition akin to that provoked by the SPICE experiment. Public engagement, in other words, can help establish the social license for field research and legitimize research governance.

Generating effective public engagement may not be easy. Technical descriptions of geoengineering proposals could exclude lay citizens from meaningful participation. Speculative accounts of relatively untested techniques could lead to unproductive discussions or irrational responses. In addition, the broad and general scope of a programmatic assessment may limit interest in participation. Assessments of specific proposed field experiments, in contrast, might stimulate immediate concern and more intense interest. Relatedly, geoengineering and climate change present long-term issues that must compete for attention with seemingly more urgent matters. The public reactions to the SPICE and Haida experiments nevertheless suggest that geoengineering's controversial nature will generate keen interest. Creative methods of outreach and attention from policy makers and opinion leaders may be necessary.

It is worth noting that public engagement is unlikely to lead to social consensus. Participatory processes often yield more questions than answers.[295] In the case of geoengineering, reconciling opposing views may be especially difficult because controversies touch on deeply-held values regarding humanity's capabilities and limitations and humanity's proper relationship to nature.[296] Rather than seeking to produce consensus, partic-

cation of accessible reports and outreach to mass media outlets).

295. *See* Andy Stirling, *"Opening Up" and "Closing Down": Power, Participation, and Pluralism in the Social Appraisal of Technology*, 33 SCI. TECH. & HUM. VALUES 262, 282 (2008) (noting that participatory appraisals of technology may not lead to "final consensus").

296. *See* Adam Corner et al., *Messing with Nature? Exploring Public Perceptions of Geoengineering in the UK*, 23 GLOBAL ENVTL. CHANGE 938, 942 (2013) (noting that the theme of "messing with nature" stood out in deliberative workshops involving the public on geoengineering); Dan M. Kahan et al., *Geoengineering and Climate Change Polarization: Testing a Two-Channel Model of Science Communication*, 685 ANNALS AM. ACAD. POLIT. & SOC. SCI. 192, 193 (2014) (noting that "cultural meanings influence public perceptions" of geoengineering risk); Rayner, *supra* note 213, at 12–13 (noting that geoengineering implicates "what it means to be human and our relationship with

ipatory processes ideally would "explor[e] systematic divergences of perspective" and provide insights to inform policy making on geoengineering and geoengineering research.[297]

b. Mechanics

When should a programmatic geoengineering technology assessment begin, and who should conduct it? The systemic concerns raised by geoengineering research argue for commencing the proposed assessment before further field experimentation gets underway. Putting in place an assessment process would provide some assurance that independent oversight of field research is taking place. Early assessment and public discussion would ease worries that the science is proceeding faster than society can control it and counter the danger of technological lock-in. Preferably, the assessment process would be ongoing or recurring rather than a one-time event. Ongoing analysis would enable consideration of new developments in geoengineering research, climate change science, and global events. Such a process also would facilitate a deepening understanding of geoengineering, promote continuing societal deliberation, and encourage the consideration of exit strategies should a once-promising technique prove to be problematic.[298]

In the United States, the federal government is the entity best situated to undertake the proposed assessment. The federal government has financial, technical, and other resources to support an assessment and could offer a more objective approach than private parties. Furthermore, the federal government has the general authority and means to act on the resulting information and recommendations. As a significant source of research funding, it can create and enforce conditions on geoengineering research grants.

Effectiveness and trust are important criteria in identifying a specific federal actor to carry out the assessment. Logical candidates include the Environmental Protection Agency, which has expertise in analyzing health and environmental consequences, and the Government Accountability Office, which has performed an increasing number of technology assessments in recent years.[299] Both agencies have experience in

nature").

297. Stirling, *supra* note 295.

298. *Cf.* Walker, *supra* note 187, at 844–45 (discussing importance of considering exit strategies as a defense to lock-in).

299. *See* LIN, *supra* note 107, at 25. One of the GAO's assessments con-

carrying out assessments, though on a smaller scale and a more discrete basis than envisioned here. Although the work of these agencies is increasingly subject to politicization and partisan attack, their involvement may be preferable to creating a new agency to carry out the assessment. An agency focused on geoengineering—whose existence may be contingent on continued research and eventual deployment[300]—may be more vulnerable to bias.

Regardless of the agency tasked with preparing the assessment, an important complementary role could be played by nongovernmental organizations (NGOs) or a government advisory committee composed of experts, representatives of potentially affected communities, and representatives of diverse political viewpoints.[301] NGOs such as World Wide Views could carry out citizen consultations and other participatory exercises to engage the public and explore public views on a global scale.[302] Furthermore, a government advisory committee could offer greater independence and flexibility than established government agencies and could provide advice on an oversight framework.[303] While such a committee could be a valuable source of input in structuring a programmatic assessment or project-specific oversight, a government agency should retain the responsibility for carrying out the assessment and engagement functions.

The proposed technology assessment would move beyond current ad hoc efforts to manage geoengineering research. These efforts include formal legal mechanisms (such as the amendments to the London Protocol), soft law mechanisms (such as the Oxford Principles), information gathering initiatives (such as prior reports prepared by the GAO), and outreach efforts (such as the SRMGI). None of these efforts purport to assess, let alone comprehensively govern, geoengineering field

cerned geoengineering and included a technical assessment of specific techniques, consultation with experts, and a public survey. GOV'T ACCOUNTABILITY OFFICE, *supra* note 52.

300. *See* Long & Scott, *supra* note 150, at 51 (noting that geoengineering faces hurdles to research and deployment).

301. *See* Winickoff & Brown, *supra* note 5, at 81.

302. *See* Bjørn Bedsted et al., *The Story of WWViews*, *in* CITIZEN PARTICIPATION IN GLOBAL ENVIRONMENTAL GOVERNANCE 30 (Mikko Rask et al. eds., 2012); WORLD WIDE VIEWS, http://wwviews.org (last visited Feb. 27, 2016).

303. Winickoff & Brown, *supra* note 5, at 83; *see also* Long & Scott, *supra* note 150 (discussing possible functions of an independent geoengineering advisory board).

research. Nor do extant efforts offer a broad forum for public input and engagement. A programmatic geoengineering technology assessment would make significant advances in these regards.

The proposed assessment nonetheless can build on existing efforts, such as the Integrated Assessment of Geoengineering Proposals (IAGP). The IAGP is a four-year multidisciplinary research project funded by British research agencies and carried out by several institutions.[304] The IAGP's "core research objectives" include evaluating the effectiveness and side-effects of geoengineering proposals and assessing the controllability of global climate using these proposals.[305] The IAGP emphasizes technical evaluation and arguably neglects the systemic concerns of geoengineering research. Nonetheless, researchers associated with the IAGP have undertaken several projects that are consistent with the programmatic assessment proposed here, such as a broadly-based appraisal of geoengineering options by two dozen specialists,[306] a similar appraisal by thirteen citizens,[307] and public discussion groups of climate change and geoengineering.[308]

Finally, although the proposal here is for the U.S. government to initiate the proposed assessment, it need not—and should not—have exclusive control over geoengineering research assessment. Rather, geoengineering is an issue that demands international participation in an ongoing global conversation. Other governments could undertake similar assess-

304. *Who We Are*, INTEGRATED ASSESSMENT GEOENGINEERING PROPOSALS, http://www.iagp.ac.uk/who-we-are (last visited Feb. 27, 2016); *see also* KAREN PARKHILL & NICK PIDGEON, PUBLIC ENGAGEMENT ON GEOENGINEERING RESEARCH: PRELIMINARY REPORT ON THE SPICE DELIBERATIVE WORKSHOPS 4 (2011) (detailing the history and aims of the IAGP).

305. *See* IAGP, *supra* note 304. The IAGP's central tasks include developing a framework for assessing the viability of various techniques and engaging various stakeholders and the public. *See Developing a Framework for the Evaluation of Geoengineering Proposals*, INTEGRATED ASSESSMENT GEOENGINEERING PROPOSALS, http://www.iagp.ac.uk/iagp-framework-development (last visited Feb 27, 2016); *Engaging with Member of the Public and Other Stakeholders*, INTEGRATED ASSESSMENT GEOENGINEERING PROPOSALS, http://www.iagp.ac.uk/engaging-publics-and-stakeholders (last visited Feb 27, 2016).

306. *See* Bellamy et al., *supra* note 287, at 928.

307. *See* Rob Bellamy et al., *Deliberative Mapping of Options for Tackling Climate Change: Citizens and Specialists "Open Up" Appraisal of Geoengineering*, PUB. UNDERSTANDING OF SCI., 2014, at 5, http://pus.sagepub.com/content/early/2014/09/12/0963662514548628.full.pdf+html.

308. *See* Corner et al., *supra* note 296, at 938.

ments on their own, participate in a U.S.-led assessment, or respond to specific issues raised by a U.S. assessment. The Kyiv Protocol to the Espoo Convention, which some twenty-six European nations have joined, requires parties to conduct a strategic environmental assessment of plans and programs likely to have significant environmental effects.[309] Such an assessment process could offer a framework for conducting the programmatic technology assessment suggested here.

Nor should any programmatic assessment serve as an endpoint for governance efforts. Ideally, a programmatic assessment would serve as a springboard for further analysis, debate, and policy making on geoengineering research. Perhaps most obviously, the programmatic assessment should inform the establishment of an oversight regime for individual field trials. Such oversight, which can build on existing governance efforts under the CBD and LC/LP as well as research governance proposals in the literature,[310] would focus on the physical risks associated with individual experiments.

2. Analyze Dangers and Set Research Priorities

The proposed assessment would analyze both the physical hazards and systemic dangers of prospective geoengineering techniques. In contrast to conventional assessments of physical risk, the assessment of systemic dangers would be a somewhat novel undertaking. For illustrative purposes, this section considers how the proposed assessment might identify techniques posing a greater danger of lock-in.

From studying technologies such as nuclear power, commentators have identified various technical and organizational indicators of technological inflexibility.[311] Technical indicators of inflexibility pertain to the inherent features of a technique, whereas organizational indicators pertain to how a technology

309. Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context, May 21, 2003, U.N. Doc. ECE/MP.EIA/2003/2, http://www.unece.org/fileadmin/DAM/env/eia/documents/legaltexts/protocolenglish.pdf. The Protocol has thirty-eight signatories as of Feb. 27, 2016. *Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context*, UNITED NATIONS TREATY COLLECTION, https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-4-b&chapter=27&lang=en (last visited Feb. 27, 2016).

310. *See supra* Parts I.B, II.A.1.

311. *See* Shackley & Thompson, *supra* note 190, at 115 (characterizing conventional nuclear power as “relatively inflexible” and renewable power as “relatively flexible”).

is likely to be framed and developed.[312] Technical indicators of inflexibility include high capital intensity, long lead times from idea to application, large-scale production units, substantial infrastructure requirements, and irreversibility.[313] Such characteristics lead to inflexibility because they generally call for large upfront commitments of effort, funding, political capital, or other resources. Once made, these commitments can be politically and psychologically difficult to undo. The momentum behind inflexible technologies derives not only from their scale but also from their tendency to create powerful constituencies and institutions having a vested interest in perpetuating or expanding existing commitments.

Organizational indicators of inflexibility arise from the institutional and social contexts surrounding a technology rather than from the technology itself. These indicators include hype, hubris, closure to criticism, and operation through organizations having a single mission.[314] Such features foster lock-in by suppressing critical inquiry, fashioning social expectations, and diminishing the possibility of changing course.[315] Although organizational indicators of inflexibility are not inherent to specific technologies, they often accompany technologies that have features of technical inflexibility. For example, the nuclear industry, which runs large-scale, capital-intensive facilities, historically has resisted critical scrutiny and operated through single-mission companies or organizations.[316]

How might the factors of technical and organizational inflexibility apply to various geoengineering proposals? A thorough analysis is beyond the scope of this Article, but several preliminary observations can be made. All geoengineering techniques are far from effective application and would require substantial effort and resources to ready them for deployment.[317] The long lead time to deployment indicates that each

312. *See id.* at 112, 115.

313. *See* DAVID COLLINGRIDGE, THE MANAGEMENT OF SCALE: BIG ORGANIZATIONS, BIG DECISIONS, BIG MISTAKES 14 (1992); ROYAL COMM'N ON ENVTL. POLLUTION, NOVEL MATERIALS IN THE ENVIRONMENT: THE CASE OF NANOTECHNOLOGY 8 (2008); Cairns, *supra* note 182, at 655; Shackley & Thompson, *supra* note 190, at 112.

314. *See* Shackley & Thompson, *supra* note 190, at 115.

315. *See id.*

316. *See id.* at 113–14 tbl.1 (presenting the flexibility characteristics of the nuclear industry in tabular form).

317. *See* GOV'T ACCOUNTABILITY OFFICE, *supra* note 52, at v–vi; *see also* Gordon MacKerron, *Costs and Economics of Geoengineering* 12 (Climate Geoengineering Governance, Working Paper Series, Paper No. 13, 2014),

technique is at some risk of lock-in if field experimentation proceeds.[318] Other indicators of inflexibility nonetheless suggest a higher risk of lock-in for some techniques than others. SRM techniques, which have attracted some support because of their potential to provide cheap and rapid cooling,[319] have been the focus of governance concerns because of the physical risks and international conflict they might cause.[320] SRM techniques also warrant careful scrutiny because their implementation would require sizable economic, social, and political commitments over extended periods of time.[321]

To take an example, consider stratospheric aerosol release. This often-cited SRM technique possesses several indicators of inflexibility. First, it faces a long lead time: a leading proponent estimates a deployable stratospheric aerosol system to be at least two decades away.[322] Second, significant hype surrounds the technique: popular accounts sometimes characterize it as a "cheap and simple solution[]" "to a "straightforward engineering problem."[323] The cost estimates on which such statements

http://geoengineering-governance-research.org/perch/resources/workingpaper13mackerroncostsandeconomicsofgeoengineering.pdf (noting that for all geoengineering options, "the state of technological development is exceptionally limited, and in most cases does not yet extend to any kind of even small-scale demonstration").

318. *See* Bellamy et al., *supra* note 198, at 611 (noting that geoengineering proposals, "[a]s an upstream suite of technology proposals . . . are particularly sensitive to . . . instrumental framing conditions and could easily be quickly and prematurely closed down, locking us in to certain technological trajectories but not others").

319. *See* Parson & Ernst, *supra* note 32, at 314 (describing the SRM techniques that "offer extremely high leverage" as "fast, cheap, and imperfect"). The cost of delivering aerosols with specially designed aircraft has been estimated to be in the range of $10 billion to $25 billion, a small fraction of global GDP. *See* GOV'T ACCOUNTABILITY OFFICE, *supra* note 52, at 31 tbl.3.2 (reporting estimated first-year cost of $35 billion to $65 billion and subsequent annual costs of $13 billion to $25 billion); Morgan et al., *supra* note 51, at 40 (reporting $10 billion estimate); Robock, *supra* note 59, at 166 (discussing various quantitative cost estimates).

320. *See, e.g.*, SOLAR RADIATION MGMT. GOVERNANCE INITIATIVE, *supra* note 46 (analyzing the physical and political risks of SRM); Morgan et al., *supra* note 51 (recommending development and implementation of a voluntary code for SRM research).

321. The use of space-based solar deflectors, for example, would involve the deployment of trillions of reflecting discs or tens of thousands of large mirrors. *See* ROYAL SOC'Y, *supra* note 28, at 32.

322. *See* KEITH, *supra* note 34, at 88; *see also* GOV'T ACCOUNTABILITY OFFICE, *supra* note 52, at 33 (rating stratospheric aerosol technology as very immature "because only basic principles have been reported").

323. STEVEN D. LEVITT & STEPHEN J. DUBNER, SUPERFREAKONOMICS 193–

rest are probably low, however. These estimates typically quantify only direct costs, omitting external costs to society or the environment.[324] Furthermore, optimism bias, structural incentives, and the need for unanticipated design changes consistently lead to underestimates of the costs of novel, large-scale technologies.[325] A third indicator of inflexibility is the substantial capital and infrastructure that stratospheric aerosol deployment would require. If aircraft are used, for example, a dedicated fleet of specialized planes would have to make hundreds or thousands of flights per day over perhaps hundreds of years.[326] Deployment of the technique would likely create powerful economic constituencies and necessitate a centralized structure designed to ensure its smooth and unhindered operation.[327] One final indicator of technology inflexibility for stratospheric aerosol release is its irreversibility, which would be two-fold. For one, it would be virtually impossible to recover released particles, which would be problematic if they turned out to be harmful.[328] Sulfur species are already present in the atmosphere in large quantities and pose relatively well-understood risks, but specially engineered aerosols could give rise to new or uncertain hazards. For another, it would be quite difficult to reverse any SRM scheme, including stratospheric aerosol release, once it is fully deployed.[329] This latter difficul-

94 (2009). Professor Scott Barrett similarly lauds its "incredible economics." Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. & RESOURCE ECON. 45 (2008); *see also* Alan Carlin, *Global Climate Change Control: Is There a Better Strategy Than Reducing Greenhouse Gas Emissions?*, 155 U. PA. L. REV. 1401, 1459–60 (2007).

324. *See* MacKerron, *supra* note 317, at 4. Indeed, MacKerron contends that the direct cost estimates of stratospheric aerosol release found in the literature "are simple to the point of being simplistic" and "generally far from contemporary good practice." *Id.* at 5.

325. *See id.* at 7–9, 12.

326. *See* Alan Robock et al., *Benefits, Risks, and Costs of Stratospheric Geoengineering*, GEOPHYSICAL RES. LETTERS, Oct. 2, 2009, at 1, 2–7 (discussing possible methods of delivering aerosols to the stratosphere); R. Turco, Geoengineering the Stratospheric Sulfate Layer from Aircraft Platforms: Scale, Engineering Constraints, and Estimated Costs 5 (unpublished manuscript); *see also* MacKerron, *supra* note 317, at 21 (suggesting that geoengineering technologies are large-scale in that they potentially involve multi-national or global efforts).

327. *See* Szerszynski et al., *supra* note 43, at 2812, 2814.

328. *Cf.* ROYAL COMM'N ON ENVTL. POLLUTION, *supra* note 313 (suggesting the widespread and uncontrolled release of substances into the environment as an indicator of technological inflexibility).

329. Relatedly, the inability to opt out of any global SRM scheme suggests the potentially "anti-democratic constitution of the technology and its incom-

ty—often referred to as the "termination problem"—arises from the fact that the sudden cessation of SRM would result in an extremely rapid rebound to ungeoengineered conditions.[330] Human societies and natural ecosystems would have little time to adapt to such a swift change in climate.

Further analyses of individual geoengineering techniques would identify techniques less susceptible to lock-in. Analyses also would consider the extent to which techniques may pose a moral hazard or heighten the risks of military conflict. A realistic and accessible assessment could itself counter moral hazard if it underscores the need to mitigate. And at the least, it could identify those techniques less likely to be misperceived as a magic bullet against climate change.[331]

Ultimately, research priority setting and resource allocation decisions should take these analyses into account. Resulting policies might resemble the "soft geoengineering" approach described by technology scholar Robert Olson. Cautioning against categorical rejection of geoengineering, Olson advocates prioritizing the development of techniques that "touch gently on biological and social systems."[332] Such techniques, he suggests, can be applied locally yet also be scaled up or rapidly reversed. In addition, these techniques ideally would offer multiple benefits, cause minimal negative impacts, resemble natural processes, and be cost-effective.[333] Among the techniques that fare well under Olson's criteria are the creation of microbubbles on water body surfaces to increase their reflectivity and the placement of light-colored material on ice to slow melting processes.[334] Such techniques might also do well in an analysis of systemic concerns: they appear to pose little risk of lock-in or of

patibility with liberal democracy." Macnaghten & Szerszynski, *supra* note 219.

330. *See* NAT'L RESEARCH COUNCIL, *supra* note 2, at 63–65; H. Damon Matthews & Ken Caldeira, *Transient Climate-Carbon Simulations of Planetary Geoengineering*, 104 PROC. NAT'L ACAD. SCI. U.S. 9949, 9951–52 (2007) (describing how temperatures, previously suppressed by aerosols, would quickly rebound to the levels they would have reached had no geoengineering been implemented).

331. *See* Lin, *supra* note 204, at 708.

332. Olson, *supra* note 210, at 30. The Royal Society report on geoengineering similarly advocates that CDR research prioritize those methods "that remove atmospheric CO_2 without affecting other natural systems and which do not require large-scale land-use changes." ROYAL SOC'Y, *supra* note 28, at 61.

333. Olson, *supra* note 210, at 30.

334. *See id.* at 30–33.

undermining mitigation efforts and are not obviously susceptible to military application.[335]

Using the information generated by a programmatic technology assessment, governments should set research priorities that reflect the public interest. Notwithstanding generally prevalent notions of scientific freedom, the geoengineering research agenda should be determined by governments, not scientists or private funders lacking public accountability.[336] Nations should coordinate research efforts, whether through existing international organizations, ad hoc agreements, or the establishment of nonbinding guidelines that may influence research agendas.[337] Ultimately, the goal-oriented nature of geoengineering research calls for a strategic yet accountable approach developed through public engagement and deliberation. Through technology assessment, funding decisions, and direct oversight, governments can steer the scientific community toward investigating options meriting further inquiry.

3. Institute Safeguards Against Systemic Concerns

As the public reactions to the SPICE and Haida field trials reflect, even modest experiments can represent symbolically important commitments along a path that has not received adequate public consideration. A programmatic technology assessment can serve as a vehicle for initiating public consideration and setting research priorities. Such an assessment would not provide definitive and permanent answers regarding how to proceed, however. As research advances, assessment should be ongoing, taking into account new information. Lock-in and other systemic concerns will continue to be at issue, and governments can take concrete measures in response. Measures to consider include a moratorium on field research or full-scale deployment, as well as the development of a diverse portfolio of options for combating climate change.

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335. *See id.* at 37–38.

336. *See* Long & Scott, *supra* note 150, at 50 (recommending that geoengineering research be conducted in a "collaborative mission-driven" manner rather than an "investigator-driven" manner).

337. *See, e.g.*, ORG. FOR ECON. CO-OPERATION & DEV., NANOSAFETY AT THE OECD: THE FIRST FIVE YEARS 2006–2010, at 7–12 (2011) (summarizing efforts by the Organisation for Economic Co-operation and Development (OECD) to coordinate environmental, health, and safety research on nanomaterials); Bodansky, *supra* note 21, at 543 (observing that decisions by international institutions, while binding only on states, can affect decisions by funding agencies or scientists).

a. *A Moratorium on Field Research?*

One option for combating lock-in and moral hazard is to limit or prohibit field research. A technology cannot become locked in, and is unlikely to undermine climate mitigation efforts, if it remains an abstract notion. A blanket ban on geoengineering field research is improbable, however. Through the LC/LP and CBD regimes, the international community has already decided that certain types of geoengineering field research may be authorized, subject to specific conditions. Moreover, key nations would likely oppose a ban on field experimen-experimentation. The British government sponsored the SPICE project, for example, and Russia has conducted field research to measure the effect of aerosols on sunlight.[338] In the United States, President Obama's chief scientific advisor once declared that geoengineering has "got to be looked at" as an option for responding to climate change.[339] And while China has not announced an official position on geoengineering, it lists the subject as an Earth science research priority and faces strong incentives to promote SRM research and its eventual use.[340] A broad ban on geoengineering field research would encounter opposition not only from powerful nations but also from would-be researchers.[341] Indeed, effective enforcement of a ban may not be possible, as some researchers might characterize their

338. *See* Martin Lukacs et al., *Russia Urges UN Climate Report To Include Geoengineering*, GUARDIAN (Sept. 19, 2013), http://www.theguardian.com/environment/2013/sep/19/russia-un-climate-report-geoengineering.

339. *See* Alok Jha, *Obama Climate Adviser Open to Geo-engineering To Tackle Global Warming*, GUARDIAN (Apr. 8, 2009), http://www.theguardian.com/environment/2009/apr/08/geo-engineering-john-holdren. The advisor, John Holdren, later clarified that such comments reflected his personal views rather than official policy. *See* Andrew C. Revkin, *Science Advisor Lays Out Climate and Energy Plans*, DOT EARTH (Apr. 9, 2009), http://dotearth.blogs.nytimes.com/2009/04/09/science-adviser-lists-goals-on-climate-energy/.

340. *See* Kingsley Edney & Jonathan Symons, *China and the Blunt Temptations of Geo-Engineering: The Role of Solar Radiation Management in China's Strategic Response to Climate Change*, 27 PAC. REV. 307, 309–10, 325 (2014) ("China may be unusually susceptible to the 'blunt temptations' of geoengineering: it is politically dependent on maintaining rapid economic growth, conceptualizes climate change as a form of environmental imperialism, is a self-proclaimed leader of developing countries and possesses a large landmass and an unrivalled existing weather manipulation programme that would enable unilateral implementation of SRM."); *see also* Clive Hamilton, *Why Geoengineering Has Immediate Appeal to China*, GUARDIAN (Mar. 22, 2013), http://www.theguardian.com/environment/2013/mar/22/geoengineering-china-climate-change.

341. *See* Parson & Keith, *supra* note 16; Rayner et al., *supra* note 56.

work in such a way as to circumvent a ban or relocate their projects to jurisdictions where no ban applies.[342]

In contrast to a broad prohibition on field experimentation, which might limit research that neither raises systemic concerns nor poses physical risks, more narrowly tailored restrictions can address concerns associated with specific techniques. The fierce reaction to the SPICE project, for instance, reveals the need to engage the public and grapple with broader concerns prior to field experiments on stratospheric aerosol release. A moratorium on field research in this area would buy time for the international community—and scientists—to attend to these concerns in a more satisfactory manner. The course followed by recombinant DNA researchers four decades ago, notwithstanding the shortcomings of the 1975 Asilomar conference, offers a model for stimulating governance of research in new technologies.[343] Namely, an explicit moratorium on stratospheric aerosol field experiments—whether self-imposed or government-based—could create room and support for a programmatic technology assessment that ideally would engage a wide range of stakeholders and the broader public.[344]

b. A Moratorium on Deployment

Although this Article focuses on the governance of geoengineering research, not deployment, an international moratorium on geoengineering *deployment* could contribute in several ways to more effective governance of geoengineering *research*. First, a moratorium on geoengineering deployment would counter the risk of lock-in.[345] Such a moratorium would expressly affirm that no decision to deploy geoengineering has been made. As long as a moratorium remains in place, deliberate action by the international community—or blatant violation of the moratorium—would be required for deployment to occur. Second, if its terms are sufficiently strong, a moratorium on deployment might also allay moral hazard concerns. To be sure, a temporary, short-term moratorium would do little to counter

342. *See* Marchant & Pope, *supra* note 45, at 381 (discussing the potential for scientists to relocate).

343. *See supra* Part I.C.

344. David Keith, a leading proponent of geoengineering research, has stated that "[t]aking a few years to have some of the debate happen is healthier than rushing ahead with an experiment." *Geoengineering: Lift-Off*, ECONOMIST, Nov. 6, 2010, at 99, 102.

345. *See* Zürn & Schäfer, *supra* note 157 (recommending "a time-limited moratorium" on field testing "[t]o limit the risk of a slippery slope effect").

the potential for geoengineering to be perceived as a substitute for mitigation. But a more permanent moratorium or an outright prohibition of specific geoengineering techniques "could serve as a political signal that emission reductions are the default climate policy."[346] Third, a moratorium on deployment could simplify the process of developing a research governance regime. Governance of geoengineering deployment would have to grapple with contentious issues such as whether to geoengineer, how and when to do so, and how to make these decisions.[347] As critical as these issues may eventually be, reaching agreement on them in the near term may be impossible. Close consideration of these issues would necessitate all manner of speculation regarding geoengineering techniques and hazards as well as future climate conditions.[348] A moratorium on deployment would bracket these issues and concentrate policy makers' attention on more pressing and concrete matters of research governance.

While some commentators argue for an absolute ban—and not just a moratorium—on geoengineering deployment,[349] a ban could go too far in discouraging research and development. A "prohibition of geoengineering activities as a general rule *combined with* exceptions under well-defined circumstances" offers a perhaps less problematic and more politically feasible approach.[350] As proposed in a report prepared for Germany's Federal Environmental Agency (Umweltbundesamt), such an approach would contemplate a mandatory permit for field experiments and other research activities and allow for the development of additional exceptions over time.[351] In any case, whether the international community establishes a formal pro-

346. BODLE ET AL., *supra* note 21, at 135; *cf.* Parson & Ernst, *supra* note 32, at 336 (suggesting that announcements by states that they are provisionally suspending the right to deploy geoengineering "would soothe alarm about rapid, unilateral, or reckless pursuit" of geoengineering and "create stronger incentives to negotiate serious measures on emissions" by "implying a potential future threat to proceed with [geoengineering] under certain conditions").

347. *See* Albert C. Lin, *Geoengineering Governance*, 8 ISSUES LEGAL SCHOLARSHIP, No. 3, 2009, at 1, 21, 24; Lin, *supra* note 218, at 176.

348. *See* BODLE ET AL., *supra* note 21, at 125 ("Regulation of research presents a natural first, and likely easier, step prior to consideration of deployment.").

349. *E.g.*, ETC GRP., THE CASE FOR TECHNOLOGY ASSESSMENT: GEOENGINEERING (2012), http://www.etcgroup.org/sites/www.etcgroup.org/files/TAF7_Geoengineering_042612.pdf.

350. BODLE ET AL., *supra* note 21, at 135.

351. *Id.*

hibition on deployment may make little practical difference in the immediate future. There already exists a general consensus that geoengineering deployment should not occur in the near term.[352] Indeed, the LC/LP and CBD pronouncements both take a position against geoengineering deployment and arguably are evidence of a nascent international norm in that regard.[353]

c. Diversification

Developing a diverse geoengineering research portfolio would be sensible for a number of reasons, including the alleviation of systemic concerns. Great uncertainty surrounds the effectiveness and acceptability of each geoengineering technique. Diversification offers resilience in coping with these uncertainties as well as uncertainties regarding the consequences of climate change.[354] Diversification also responds to the inability of any single geoengineering technique to tackle all climate concerns, even if technical challenges are resolved. As noted earlier, ocean fertilization could sequester no more than a modest fraction of annual anthropogenic carbon emissions, and SRM techniques would do nothing to combat ocean acidification.[355]

Importantly, diversification also counters the economic, political, and social forces that contribute to lock-in.[356] Investing in a variety of options makes it less likely that any one option will become dominant and lowers the barriers to switching away from a technology whose selection turns out to have been mistaken.[357] Furthermore, if alternative technologies are viable, politicians, firms, and other stakeholders are less likely to be vested in establishing and continuing with a particular technology.[358] Cultivating alternatives also serves an important

352. *See* GOV'T ACCOUNTABILITY OFFICE, *supra* note 52, at 13; ROYAL SOC'Y, *supra* note 28, at 57; Rayner et al., *supra* note 56.

353. *See supra* Part I.B.

354. *See* Andy Stirling, *Direction, Distribution, and Diversity! Pluralising Progress in Innovation, Sustainability and Development* 25–26 (Soc., Tech. & Envtl. Pathways to Sustainability, Working Paper No. 32, 2009) http://steps-centre.org/anewmanifesto/wp-content/uploads/stirling-paper-32.pdf.

355. *See supra* text accompanying note 203–04.

356. *See* Cairns, *supra* note 182, at 651; *cf.* COLLINGRIDGE, *supra* note 313, at 18 (recommending that government promote diverse views and plural interests in developing and choosing technologies); KEITH, *supra* note 34, at 151 ("Competition and diversity are the best defense against lock-in.").

357. *See* Cairns, *supra* note 182, at 651.

358. *See* Stirling, *supra* note 354, at 26 ("[D]iversity helps resist associated concentrations of institutional power . . . ."); Walker, *supra* note 187, at 834–

expressive function by declaring publicly that policy makers have not chosen to deploy any specific geoengineering technique. Opening up the appraisal of geoengineering alternatives would ideally be part of a broader process in which society develops a diverse set of options for addressing climate change—and not just a diverse set of geoengineering options.[359] Situating geoengineering within the broader context of an overall climate response strategy would facilitate useful comparisons, reduce the systemic risks of lock-in and moral hazard, and perhaps accommodate fundamentally divergent perspectives regarding risk, science, and society.[360]

Insulated from competition and backed by politically powerful forces, government research institutions tend to become committed to a narrow course of action.[361] To reduce the risk of lock-in, a research diversification strategy should distribute grants to a range of researchers, including those outside government. Funding programs should balance competing interests in incentivizing research and avoiding entrenchment of specific techniques. While funding must be sufficient to attract the interest of the scientific community, large and long-term commitments can create political and economic constituencies that lock in favored technologies.[362] Limited grants and short-term contracts, combined with a diverse research portfolio, can preserve the space for society to make deliberate decisions regarding whether to proceed with a technology.

A strategy of diversification would not be costless.[363] It could slow the development of a specific geoengineering technique by diluting support. In addition, such a strategy could exacerbate the moral hazard problem if it fosters the mistaken impression that there are many possible technological fixes for climate change. Notwithstanding these concerns, a diversified

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36, 845–46 (discussing lock-in of nuclear reprocessing technology in the United Kingdom as alternative technological options were eliminated).

359. *See generally* Stirling, *supra* note 295, at 280–81 (advocating for social appraisal as a means of maintaining a transparent and objective process for evaluating climate change solutions).

360. *See* Bellamy, *supra* note 51, at 33–34.

361. *See* KEITH, *supra* note 34, at 151–52 (recommending that we "avoid dominance by single government research institutions and instead build a culturally diverse set of research and management efforts"); *cf*. Walker, *supra* note 187, at 841–44 (discussing how British Nuclear Fuels, a state-owned enterprise, exercised influence to preclude consideration of policy alternatives).

362. *See* Walker, *supra* note 187, at 839.

363. *See* Stirling, *supra* note 354, at 26 (noting possible costs of diversification).

approach can buy time for society to debate how or whether to proceed with geoengineering. Notably, a diversification strategy need not fund all techniques on an equal basis. Rather, it should prioritize research into those techniques that are less problematic in terms of their physical and systemic risks.

CONCLUSION

Amid growing scientific interest in geoengineering field experimentation, rising public discomfort with geoengineering research has stymied open and responsible field trials. Such experimentation could yield valuable information regarding the viability of geoengineering techniques and diffuse the pressure to conduct rogue field tests. Establishing a governance regime for geoengineering research can address the deadlock, but such a regime must consider more than the physical risks of field experimentation. Geoengineering research governance also must analyze and address systemic concerns of lock-in, moral hazard, and increased risk of conflict, for these concerns lie at the heart of the unease that geoengineering field research engenders.

To gain the public's trust, governance must be independent, transparent, participatory, and accountable. And to effectively oversee the hazards of geoengineering research, governance must draw on a wide range of expertise and be comprehensive and reflexive. In pursuit of these goals, the U.S. government should initiate an ongoing programmatic technology assessment and invite the input of stakeholders and the general public. Such an assessment can serve as a foundation for establishing an oversight system for individual field experiments. A programmatic assessment can also inform policies to prioritize research into techniques involving lesser systemic and physical risks and to incorporate safeguards against these risks.