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# RESEARCH GOVERNANCE

*A CHAPTER IN CLIMATE ENGINEERING AND THE LAW:  
REGULATION AND LIABILITY FOR SOLAR RADIATION  
MANAGEMENT AND CARBON DIOXIDE REMOVAL (MICHAEL B.  
GERRARD AND TRACY HESTER, EDS., FORTHCOMING)*

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## CHAPTER 6

## RESEARCH GOVERNANCE

Michael Burger and Justin Gundlach

There is a broad consensus on several basic points pertaining to the relationship between climate engineering research and its governance. First, governance should precede deployment of climate engineering technology<sup>1</sup> even if governance does not precede all research.<sup>2</sup> Second, governance will be prompted by research efforts.<sup>3</sup> Third, useful research is unlikely to advance steadily without adequate governance.<sup>4</sup> And fourth, neither climate engineering research nor

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<sup>1</sup> Committee on Geoengineering Climate, National Research Council, *Climate Intervention: Reflecting Sunlight to Cool Earth* (2015) [hereinafter NRC, *Reflecting Sunlight*]; Stefan Schäfer et al., *The European Transdisciplinary Assessment of Climate Engineering (EuTRACE): Removing Greenhouse Gases from the Atmosphere and Reflecting Sunlight away from Earth 111* (2015), [bit.ly/20JsJB8](http://bit.ly/20JsJB8); John Shepherd et al., Royal Society, *Geoengineering the Climate: Science, Governance and Uncertainty* (2009) [hereinafter Royal Society]; see also *Geoengineering I: Assessing the Implications of Large-Scale Climate Intervention: Hearing Before the H. Comm. on Sci. & Tech.*, 111<sup>th</sup> Cong. 83 (Statement of Chairman Gordon: “I think we can submit unanimously that this panel would say that there should be no deployment, only research. I don’t think you are going to find anybody that is going to disagree with that.”).

<sup>2</sup> Compare Edward A. Parson & David W. Keith, *End the Deadlock on Governance of Geoengineering Research*, 339 *Science* 1279, Mar. 15, 2013 (proposing technical threshold for categories of field research to be subject to or exempt from governance), with Clive Hamilton, *Geoengineering: Governance Before Research Please, Our World-United Nations University* (Sept. 27, 2013), <http://bit.ly/1NXs697>, and Editorial: A Charter for Geoengineering, 485 *Nature* 415 (May 2012) (“Geoengineers should . . . come together and draft detailed, practical actions that need to be taken to advance governance in the field.”).

<sup>3</sup> See, e.g., Government Response to the House of Commons Science and Technology Committee 5th Report of Session 2009-10: *The Regulation of Geoengineering* 4 (Sept. 2010) (“The Government considers it too early to be able to establish appropriate regulatory frameworks for geoengineering research or deployment on a comprehensive basis without a clear view of what needs to be regulated and how.”); David G. Victor, *On the Regulation of Geoengineering*, 24 *Oxford Rev. Econ. Pol’y* 322, 323–24 (2008).

<sup>4</sup> See Editorial: *A Charter for Geoengineering*, 485 *Nature* 415, May 24, 2012, [bit.ly/1mFihma](http://bit.ly/1mFihma) (“More troubling is the lack of an overarching governance framework. \* \* \* Geoengineers should keep trying. They should come together and draft detailed, practical actions that need to be taken to advance governance in the field.”); Parson & Keith, *supra* note 2, at 1278; Daniel Bodansky, *The Who, What, and*

institutions engaged in its governance currently exist to a substantial degree.<sup>5</sup> As the U.S. Government Accountability Office (GAO) wrote in its 2010 review of the U.S. federal government's role in climate engineering research efforts, "a general lack of significant efforts to pursue geoengineering is a contributing factor to why geoengineering governance has not been pursued further to date."<sup>6</sup> The consensus that surrounds these conclusions is remarkable, if only because it indicates a fundamental confusion over what comes first, research or governance.

The five years since GAO made the above statement have seen a handful of forays into climate engineering field research, a stack of new articles and reports recommending that climate engineering research proceed, others recommending approaches to its governance, multiple articulations of principles relevant to such governance, and few if any steps toward actual, purposive governance. Thus, in 2016 as in 2010, governance of climate engineering research is still nascent and inchoate. Notably, however, the intervening years saw the launch of "the first coordinated geoengineering research project supported by the National Key Basic Research Program of China,"<sup>7</sup> and a recommendation by the National Research Council that the U.S. undertake its own climate engineering research program.<sup>8</sup>

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*Wherefore of Geoengineering Governance*, 121 *Climatic Change* 539, 546 (Dec. 2013) ("The rationale for international governance in this scenario is to encourage national spending, develop cost-sharing arrangements, and incentivize private investment.").

<sup>5</sup> Piers Forster, *Not enough time for geoengineering to work?*, *Bulletin Atomic Scientists*, Feb. 2 2015, <http://bit.ly/1NRN2Ox> ("None of the proposed technologies really exist on anything other than paper"); David W. Keith et al., *Field Experiments on Solar Geoengineering: Report of a Workshop Exploring a Representative Research Portfolio*, 372 *Phil. Transactions Royal Soc'y* 175 (Dec. 2014) (setting out taxonomy of proposed research projects). The article generally credited as incipient of broader discussions of geoengineering was published in 2006. See Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections*, 77 *Climatic Change* 211 (2006).

<sup>6</sup> GAO, GAO-10-903, *Climate Change: A Coordinated Strategy Could Focus Federal Geoengineering Research and Inform Governance Efforts* 34 (2010); see also Jane C. S. Long et al., *Start Research on Climate Engineering*, 518 *Nature* 29 (Feb. 5, 2015) ("governance and experimentation must co-evolve.").

<sup>7</sup> Cao Long et al., *Geoengineering: Basic Science and Ongoing Research Efforts in China*, *Advances in Climate Change Res.* 188, 193 (2015), <http://bit.ly/22wOUmr>.

<sup>8</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at 6 (recommending investment into R&D for carbon removal and sequestration), 10 (recommending launch of albedo modification research program).

This Chapter approaches the complex topic of climate engineering research governance in four Parts. Part I describes the forms research has taken so far and those that are expected in the future. It also offers short summaries of five instances of climate engineering field research conducted since 2009. Part II considers the key issues and concerns that have prompted calls for governance and that have inspired sometimes heated debate of what it should involve. Part III discusses governance directly, including its goals and functions, as well as issues arising from implementation. This Part also surveys the institutional landscape and classifies bodies with potential jurisdiction into three groups: those that are currently serviceable for the governance of research into particular climate engineering technologies, those that seem capable of adapting to the task, and those that will need to be created anew in order to fill critical gaps. Part IV concludes.

## I. WHAT IS CLIMATE ENGINEERING RESEARCH?

Climate engineering research has been characterized as “more than simply a scientific procedure: it is a socially constructed and contested phenomenon.”<sup>9</sup> The importance of this point is underscored by the fact that knowledge of the climate will always be partial and imperfect, such that any decision to deploy climate engineering technologies will follow not from precise understanding and effective control but from a gamble—possibly a gamble informed by research but necessarily a gamble—that deployment will do more good than harm, at least to the parties participating in the decision.

To date, the bulk of research bearing the “geoengineering” label has involved comparing the outputs of computer models to historical data and conducting laboratory tests.<sup>10</sup> For

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<sup>9</sup> Rob Bellamy, *Safety First! Framing and Governing Climate Geoengineering Experimentation*, Climate Geoengineering Governance Working Paper No. 14, at 33 (2014).

<sup>10</sup> See Kelsi Bracmort & Richard K. Lattanzio, Cong. Res. Serv., *Geoengineering: Governance and Technology Policy* 3 (Nov. 2013) (“Little research has been done on most geoengineering methods, and no major directed research programs are in place. Peer reviewed literature is scant. . . .”); see also Committee on Geoengineering Climate, National Research Council, *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration* 86 (2015) [hereinafter NRC, *Carbon Removal*] (indicating that nearly all CDR technologies exist only pre-prototype or prototype form).

instance, a number of models have drawn on data gathered in the aftermath of the 1991 eruption of Mount Pinatubo, which launched a large volume of particulates into the stratosphere and was followed by a period of reduced global temperatures and disruption to precipitation patterns.<sup>11</sup> Such modeling is generally understood to be the first step on any of the paths climate engineering research would take.<sup>12</sup> Subsequent steps on that path have been described as “laboratory” or “indoor” testing, followed by “field” or “outdoor” testing on small, medium, and large scales.<sup>13</sup> However, there is disagreement about whether field testing of some climate engineering technologies can be meaningfully distinguished from deployment for governance purposes.<sup>14</sup>

Although the issues discussed in this Chapter relate to all climate engineering research activities, we devote particular attention to issues arising from field testing. The following brief summaries of field tests conducted since 2009 illustrate what the term “small-scale field testing” has described to date. These field tests, which have generally proven controversial, also provide

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<sup>11</sup> See, e.g., Kevin E. Trenberth & Aiguo Dai, *Effects of Mount Pinatubo Volcanic Eruption on the Hydrological Cycle as an Analog of Geoengineering*, *Geophysical Res. Letters*, Aug. 2007, at 1.

<sup>12</sup> See, e.g., Ben Kravitz et al., *The Geoengineering Model Intercomparison Project (GeoMIP)*, *12 Atmospheric Sci. Letters* 162 (2011) (reporting results of comparison how each of several climate models predicts effects of stratospheric geoengineering with sulfate aerosols).

<sup>13</sup> See NRC, *Reflecting Sunlight*, *supra* note 1, at 188 (recommending that, for some approaches, “[s]mall-scale field experiments” will help reduce uncertainty, verify modeling, and validate theory); Bellamy, *supra* note 9, at 13–14 (reporting research steps anticipated by several authors: non-field experiments, field experiments, and “de facto experiments in deployment”); Jane C.S. Long et al., *Bipartisan Pol’y Ctr., Task Force on Climate Remediation Research* 29 (2012) [hereinafter “BPC Task Force”] (anticipating “large-scale field tests” will occur “at some point”); Solar Radiation Management Governance Initiative, *Solar Radiation Management: the Governance of Research* 45–53 (2011) (listing steps or successive “categories” of research activity).

<sup>14</sup> See Edward A. Parson & Lia N. Ernst, *International Governance of Climate Engineering*, 14 *Theoretical Inquiries in Law* 307, 329 (2013) (“there will not be a clean boundary between an early period of ‘scientific’ governance and some later period of ‘operational’ governance.”); M. Granger Morgan and Katharine Ricke, *Cooling the Earth Through Solar Radiation Management: The need for research and an approach to its governance* 19 (2010) (“one of the first objectives of an SRM research programme should be to give more precise meaning to the phrase ‘modest low-level [field testing].’”); Royal Society, *supra* note 1, at 41 (“In some cases...it is not clear that field trials can usefully be conducted on a limited scale, or without appreciable and widespread environmental impacts.”).

a useful illustration of features that inform definitions and categories relevant to climate engineering research.

## A. Examples

### 1. LOHAFEX

The LOHAFEX project was a collaboration between India's Council of Scientific Industrial Research and the German Alfred Wegener Institute for Polar and Ocean Research, first agreed to in 2007 and carried out in January 2009. "Loha" is the Hindi word for iron, and the project plan involved spreading six tons of iron sulfate dust on the surface of a patch of the Southern Ocean in a planktonic algae fertilization experiment – hence "FEX."<sup>15</sup> This action would test the hypothesis, described in more detail in Chapter 2 of this book, that ocean iron fertilization (OIF) can sequester CO<sub>2</sub> in the deep ocean by promoting algae blooms that absorb CO<sub>2</sub> from the ambient air before dying and taking that CO<sub>2</sub> with their remains below the ocean's surface level.<sup>16</sup> (The hypothesis was not novel,<sup>17</sup> and multiple small-scale field tests had explored it since 1993.<sup>18</sup>) The LOHAFEX investigators sought and received authorization for their experiment from the parties to the Convention on the Prevention of Marine Pollution by

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<sup>15</sup> Press Release, Alfred-Wegener-Institute for Polar and Marine Research, The Indo-German Iron Fertilization Experiment LOHAFEX (Jan. 13, 2009), [bit.ly/23JLBZN](http://bit.ly/23JLBZN).

<sup>16</sup> NRC, Carbon Removal, *supra* note 10, at 58.

<sup>17</sup> See, e.g., Fortunat Joos & Ulrich Siegenthaler, *Possible Effects of Iron Fertilization in the Southern Ocean on Atmospheric CO<sub>2</sub> Concentration*, 5 *Global Biogeochemical Cycles* 135 (1991).

<sup>18</sup> Phillip Williamson et al., *Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance*, 90 *Process Safety & Env'tl. Protection* 475 (Nov. 2012) (listing 13 ocean fertilization field experiments conducted between 1993 and 2009: IronEx I (1993); IronEx II (1995); SOIREE (Southern Ocean Iron Enrichment Experiment, 1999); EisenEx (2000); SEEDS I (Subarctic Pacific Iron Experiment for Ecosystem Dynamics Studies, 2001); SOFeX North and SOFeX South (Southern Ocean Iron Experiment, 2002); SERIES (Subarctic Ecosystem Response to Iron Enrichment Study, 2002); CYCLOPS (Cycling of Phosphorus in Eastern Mediterranean, 2002); EIFEX, European Iron Fertilization Study, 2004); SEEDS II (2004); SAGE (SOLAS Air–Sea Gas Exchange experiment, 2004); FEED (2004); and LOHAFEX (2009)).

Dumping of Wastes and Other Matter (the London Convention) in October 2008,<sup>19</sup> and, after a two-week emergency delay, from the German Ministry for Education and Research.<sup>20</sup> But the authorization followed announcements of disapproval by the German Ministry of Environment and condemnation by a Canadian NGO,<sup>21</sup> which both noted the OIF moratorium issued by the (nonbinding) UN Convention on Biological Diversity in May 2008 (discussed in Chapter 3 of this book).<sup>22</sup> On January 27, 2009—the day after the investigators began depositing iron sulfate dust in the Southern Ocean—the German Ministry for Education and Research explained its approval of the project in a statement that referred to the test as an “oceanographic research experiment” and said that “fears of this being a step toward geoengineering are unjustified.”<sup>23</sup> Though the Environment Ministry had not backed down,<sup>24</sup> the German Government, citing the London Convention Scientific Group’s January 16, 2009 Risk Assessment, endorsed the reasoning of the Ministry for Education and Research.<sup>25</sup> The experiment’s findings contributed

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<sup>19</sup> Resolution LC-LP.1 (2008); *see also* Scientific Group of London Convention and London Protocol, Int’l Maritime Org., Statement of Concern Regarding Iron Fertilization of the Oceans to Sequester CO<sub>2</sub> at 1, IMO Ref. T5/5.01, LC-LP.1/Circ. (14) (July 13, 2007).

<sup>20</sup> Press Release, Statement von Bundesforschungsministerin Annette Schavan zum deutsch-indischen LOHAFEX-Experiment im Südatlantik, Jan. 27, 2009, [bit.ly/1PiSQxW](http://bit.ly/1PiSQxW).

<sup>21</sup> *See* UN Convention on Biological Diversity Decision XI/16 “Ocean Fertilization” (May 2008) (calling for moratorium on OIF).

<sup>22</sup> Mason Inman, *Planning for Plan B*, 4 *Nature Climate Change* 7, 7–8 (2010); *see also* ETC Group, *LOHAFEX Update: Throwing Precaution (and Iron) to the Wind (and Waves)*, Jan. 28, 2009, [bit.ly/1SYVH4W](http://bit.ly/1SYVH4W).

<sup>23</sup> Statement von Bundesforschungsministerin Annette Schavan zum deutsch-indischen LOHAFEX-Experiment im Südatlantik, Jan. 27, 2009 (author’s translation).

<sup>24</sup> German Ministry for Environment, Press Release No. 025/09: Federal Environment Ministry regrets approval by Federal Research Ministry of iron enrichment experiment (Jan. 26, 2009), <http://bit.ly/1NtWXbE> (“takes note with regret of the decision by the Federal Research Ministry to approve the LOHAFEX experiment.”).

<sup>25</sup> Deutscher Bundestag, 16. Wahlperiode, Antwort der Bundesregierung auf die Kleine Anfrage der Abgeordneten Eva Bulling-Schröter, Lutz Heilmann, Hans-Kurt Hill und der Fraktion Die Linke, Drucksache 16/11689: Polarstern-Expedition und Algendüngung, Feb. 9, 2009, <http://bit.ly/1IdIfXF> (responding to parliamentary query about decision to authorize conduct of experiment).

to mounting evidence that OIF is not an effective means of extracting ambient CO<sub>2</sub> from the atmosphere in climatically relevant amounts and sequestering it in the deep ocean.<sup>26</sup>

## 2. Aerosol Sulfate Injection in Russia

In 2009, about 200 miles south of Moscow, a Russian team led by Yuri Izrael of the Moscow Institute of Global Change conducted a field test to evaluate how much injecting sulfate aerosols into the troposphere would reduce incoming solar radiation.<sup>27</sup> The Russian military supplied the team with the helicopter and truck from which the sulfates would be released.<sup>28</sup> Based on preliminary modeling, the research team had concluded that the test would not cause any adverse environmental impacts and, because of its benign nature and small scale, should not be subject to the restrictions codified in the international ENMOD agreement—the 1978 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (which is discussed in Chapter 3 of this book).<sup>29</sup> On this basis, the team did not announce the field test to any international organizations—or really anyone at all—before going ahead.<sup>30</sup> Two papers published by the team characterize the experiment as showing that the release of aerosol sulfates reduced insolation (i.e., the amount of solar radiation reaching the surface) to a degree consistent with what the team’s models had predicted.<sup>31</sup> Few have sought to build on those results. One non-technical reason could be that

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<sup>26</sup> Catherine Brahic, *Hungry Shrimp Eat Climate Change Experiment*, *New Scientist*, Mar. 25 2009, <http://bit.ly/1RtZVkw> (“Early results from the latest field experiment suggest the technique will fail.”); see also NRC, *Carbon Removal*, *supra* note 10, at 63 (“Given these limitations and unknowns, the committee concludes that the risks and costs [of OIF] currently outweigh the benefits.”), 109 (“there is a near consensus that at climatically relevant levels of deployment potential risks [of OIF] outweigh potential benefits.”).

<sup>27</sup> Yuri A. Izrael et al., *Field Studies of a Geo-Engineering Method of Maintaining a Modern Climate with Aerosol Particles*, 34 *Russian Meteorology & Hydrology* 635 (2009); Yuri A. Izrael et al., *Field Experiment on Studying Solar Radiation Passing Through Aerosol Layers*, 34 *Russian Meteorology & Hydrology* 265 (2009).

<sup>28</sup> Eli Kintisch, *Exclusive Excerpt: Hack the Planet*, *WIRED*, Mar. 24, 2010, <http://bit.ly/1QUFMm6>.

<sup>29</sup> Aaron Welch et al., *Climate Engineering: The Way Forward?*, 2 *Envtl. Dev.* 57, 63 (2012).

<sup>30</sup> *Id.*

<sup>31</sup> See note 27, *supra*.

Izrael is known as an advocate for SRM, and was known as such before leading the field test.<sup>32</sup> Another could be that the secrecy with which the test was carried out reduced confidence in the reported findings.

### 3. SPICE

The Stratospheric Particle Injection for Climate Engineering (SPICE) project, funded in 2010 by the British Government as one of a trio of climate engineering research initiatives,<sup>33</sup> ultimately provided more insights into research governance than into technical aspects of climate engineering. Plans for the project included study of various aerosol particles' characteristics, study of delivery vehicles and systems, and further modeling.<sup>34</sup> The planned delivery vehicle field test involved attaching a hose to a balloon, floating the balloon one kilometer off the ground, pumping water from the ground up to the nozzle of the hose, and measuring various results, including what happened to the water sprayed from the hose and how the hose and other equipment behaved throughout. Two different university ethics committees reviewed and approved the plan.<sup>35</sup> This modest test was meant to inform further plans for floating a larger balloon 20–25 kilometers up and spraying a sulfate aerosol into the air. However, the planned field test fell apart after some research team members' publication of applications for patents on pump components that would be used in the test.<sup>36</sup> There was a forceful negative reaction from several nongovernmental organizations and some members of

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<sup>32</sup> Kintisch, *supra* note 28; V.P. Meleshko et al., *Is Aerosol Scattering in the Stratosphere a Safety Technology Preventing Global Warming?*, 35 *Russian Meteorology & Hydrology* 433, 434 (2009) (citing Yuri A. Izrael, *An Efficient Way to Regulate the Global Climate Is the Main Objective of the Solution of the Climate Problem*, No. 10 *Russian Meteorology & Hydrology* (2005)).

<sup>33</sup> The other two are the Integrated Assessment of Geoengineering Proposals, <http://iagp.ac.uk/> (visited Dec. 18, 2015), and the Climate Geoengineering Governance project, Geoengineering Governance Research, *About the Project*, <http://bit.ly/1RXfyjI> (visited Dec. 18, 2015).

<sup>34</sup> SPICE Project, *Aims and Background*, <http://bit.ly/1Yw9vCs> (visited Dec. 21, 2015).

<sup>35</sup> See Jack Stilgoe, *Experiment Earth 1* (2015).

<sup>36</sup> Erin Hale, *Geoengineering Experiment Cancelled Due to Perceived Conflict of Interest*, *The Guardian*, May 16, 2012, <http://bit.ly/1OiY95e>.

the public,<sup>37</sup> apparently out of concerns that the experiment was a first step onto a slippery slope that would end in climate engineering driven by military and commercial interests.<sup>38</sup> After one of the agencies funding SPICE announced in September 2011 the decision to delay the test, the principal investigator finally cancelled it in April 2012.<sup>39</sup>

#### 4. E-PEACE

The Eastern Pacific Emitted Aerosol Cloud Experiment, or E-PEACE was conducted in July and August 2011 off the California coast with funding from the National Science Foundation and the Office of Naval Research. It sought to better understand the relationships among aerosols that marine vessels emit, marine clouds' characteristics and behavior, and those clouds' albedo.<sup>40</sup> Marine cloud "brightening" has been on the list of theoretical climate engineering options since 1990 when Jonathan Latham first began exploring how to respond to global warming by making deliberate use of the cloud-changing effects of emissions from marine vessels.<sup>41</sup> A host of research projects since then, including efforts to build wind-powered

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<sup>37</sup> Letter from ETC et al. to Chris Huhne, Secretary of State for Energy and Climate Change, Sept. 26, 2011, <http://bit.ly/1Ik9EHf>.

<sup>38</sup> *Id.*; see also Stilgoe, *supra* note 35, at 139; Nick Pidgeon et al., *Deliberating Stratospheric Aerosols for Climate Geoengineering and the SPICE Project*, 3 *Nature Climate Change* 451, 455 (2013).

<sup>39</sup> Phil Macnaghten & Richard Owen, *Good Governance for Geoengineering*, 479 *Nature* 293 (2011); see also SPICE, Work Package 2: Delivery Methods - Putting Particles up into the Stratosphere, <http://bit.ly/1Yq3BTs> (visited Dec. 18, 2015) ("The design produced by Work Package 2 will not now be tested outside . . . . The decision to call-off the test-bed was made by the project management team because external delays to the project had reduced the time available for performing adequate stakeholder engagement prior to any test-bed activities. As such it was felt inappropriate to continue with a test-bed without such stakeholder engagement.").

<sup>40</sup> Lynn M. Russell, *Offsetting Climate Change by Engineering Air Pollution to Brighten Clouds*, *The Bridge: Frontiers of Engineering*, Winter 2012, at 10 ("The E-PEACE results provide a proof of concept that cloud brightening to reduce global mean warming is possible, with existing, decades-old technology, for some cloud conditions.").

<sup>41</sup> J. Latham, *Control of Global Warming?*, 347 *Nature* 339 (1990); see also J. Latham et al., *Marine Cloud Brightening*, 370 *Phil. Transactions Royal Soc'y A* 4217 (2012); Christopher Mims, "Albedo Yachts" and *Marine Clouds: A Cure for Climate Change? A deep dive into one of the least scary geoengineering schemes to*

vessels and energy-efficient spraying apparatus,<sup>42</sup> have given shape to Latham’s initial vision. E-PEACE involved coordinated efforts to emit smoke (from a ship) and salt aerosols (from aircraft) into cloud formations, and to measure the effects on cloud size and albedo.<sup>43</sup> Notably, however, according to its principal investigator and the agencies that funded it, E-PEACE was not expressly a climate engineering experiment, but merely a scientific experiment devised to answer narrow questions about cloud perturbation.<sup>44</sup> Given the clear relevance of this sort of inquiry to climate engineering via marine cloud brightening, however, commentators quickly observed that “we’re seeing . . . research that could give geoengineering answers, but isn’t labelled as such.”<sup>45</sup> Issues relating to such “dual-purpose” research are discussed in section II.B below.

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*control global warming*, Scientific Am., Oct. 21, 2009, <http://bit.ly/1OXBKEV>; S. Twomey, *Influence of pollution on the short-wave albedo of clouds*, 34 J. Atmos. Sci. 1149 (1977).

<sup>42</sup> See Gary Cooper et al., *Preliminary results for salt aerosol production intended for marine cloud brightening, using effervescent spray atomization*, Phil. Trans. R. Soc. A 372: 20140055, at 1, 9–10 (2014), <http://dx.doi.org/10.1098/rsta.2014.0055> (“existing snow making equipment can be adapted to launch the nuclei 60–100m into the air, requiring approximately 20kW of additional power”); Robert Wood & Thomas P. Ackerman, *Defining Success and Limits of Field Experiments to Test Geoengineering by Marine Cloud Brightening*, 121 Climatic Change 459 (2013); Stephen Salter et al., *Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming*, 366 Phil. Transactions Royal Soc’y A 3989 (2008), <http://bit.ly/1OwINtX>.

<sup>43</sup> Lynn M. Russell et al., *Eastern Pacific Emitted Aerosol Cloud Experiment*, Am. Meteorological Soc’y 709, 713–14 (May 2013).

<sup>44</sup> See *id.*

<sup>45</sup> Richard Black, *Geoengineering: Risks and Benefits*, BBC News, Aug. 24, 2012, <http://bbc.in/1NOWoto>; Jack Stilgoe et al., *Public Engagement with Biotechnologies Offers Lessons for the Governance of Geoengineering Research and Beyond*, 11 PLoS Biol. e1001707, (Nov. 2013), <http://1.usa.gov/1kqUuo1> (“The E-PEACE project has clear relevance to geoengineering research but has not labelled itself as a geoengineering research project, so has avoided some of the attention attracted by SPICE.”); see also R. Wood et al., *The VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REx): Goals, Platforms, and Field Operations*, 11 Atmospheric Chem. Phys. 627 (2011), <http://bit.ly/22xfGek> (similarly omitting mention of geoengineering from characterization experiment’s motive or results).

## 5. The Haida Salmon Restoration Corporation

In the summer of 2012, about 180 miles off of Canada's west coast, the Haida Salmon Restoration Corporation, a for-profit venture led by an American entrepreneur and supported financially by a Haida Nation village reliant on the regional salmon fishery, conducted a controversial OIF field test involving 100 tons of iron-rich dust.<sup>46</sup> Whereas LOHAFEX had led to conflicts among authorities with overlapping oversight responsibilities, the company undertaking the Haida test did not seek permissions from any authority at all — notwithstanding allegedly pertinent Canadian environmental regulations and Canada's ratification of the London Convention and London Protocol.<sup>47</sup> A second feature propelled the controversy still further: the company had planned to repay its Haida Nation investors by selling carbon emissions credits for the carbon capture and sequestration it expected to accomplish via OIF.<sup>48</sup> Condemnations of the "rogue geoengineering experiment" noted that the company had dumped five times as much material as any previous OIF test, and had performed so little data collection that its carbon-related results were difficult to discern.<sup>49</sup> Canada's environmental agency investigated whether the test violated international or Canadian law, though several commentators have apparently concluded that it did not violate international law,<sup>50</sup> and others have noted that Canada may have failed to enact or enforce laws

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<sup>46</sup> Jeff Tollefson, *Ocean-Fertilization Project Off Canada Sparks Furor*, 490 *Nature* 458 (Oct. 2012).

<sup>47</sup> *Id.*; Statement of Concern Regarding the Iron Fertilization in Ocean Waters West of Canada, LC 34/15 (2012), Annex 7, paras. 1-2 ("Parties to the London Convention and London Protocol (LC/LP) express grave concern regarding the deliberate ocean fertilization activity that was recently reported to have been carried out in July of 2012 in waters off the Canadian west coast").

<sup>48</sup> Tollefson, *supra* note 46, at 458.

<sup>49</sup> *Id.* (quoting LOHAFEX principle investigator as saying: "I'm not going to condemn it offhand, but this is just not the way to do this experiment.").

<sup>50</sup> Compare Parson & Keith, *supra* note 1, at 1278 ("the project was apparently done without knowledge of Canadian authorities, yet violated no international law"), with Robert F. Service, *Legal? Perhaps. But Controversial Fertilization Experiment May Produce Little Science*, *Science*, Oct 23, 2012 ("while the London Protocol is binding, it only applies to the release of material intended to be dumped as waste, not released as part of a scientific experiment."), and Dene Moore, *Ocean fertilization experiment loses in B.C. court; charges now likely*, *The Globe & Mail*, Feb. 3, 2014, <http://bit.ly/1OhR0vX>.

called for by international agreements.<sup>51</sup> In any case, the test did seem to accomplish its stated primary purpose of promoting the phytoplankton that would support a larger salmon fishery.<sup>52</sup> Notwithstanding the controversy over the climate engineering component of the test, the company's website continues to list arguments and support for the idea that OIF can sequester CO<sub>2</sub> in the deep ocean.<sup>53</sup>

## B. Defining Climate Engineering Research

Defining climate engineering research requires the articulation of three things: first, what climate engineering is; next, what distinguishes research that counts as climate engineering research from research that does not; and last, what distinguishes research from deployment of climate engineering technologies. This subsection discusses each of these in turn.

As also discussed in Chapter 1 of this book, the Royal Society and the Intergovernmental Panel on Climate Change have defined geoengineering as the “deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change.”<sup>54</sup> By

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<sup>51</sup> Grant Wilson, *Murky Waters: Ambiguous International Law for Ocean Fertilization and Other Geoengineering*, 49 *Tex. Int'l L.J.* 507, 544 (2014) (“determining whether Canada failed at its duty to enforce the LP is difficult”).

<sup>52</sup> See Peng Xiu et al., *Satellite Bio-Optical and Altimeter Comparisons of Phytoplankton Blooms Induced by Natural and Artificial Iron Addition in the Gulf of Alaska*, 145 *Remote Sensing of Env't* 38 (2014); Sonia D. Batten & James F. R. Gower, *Did the Iron Fertilization Near Haida Gwaii in 2012 Affect the Pelagic Lower Trophic Level Ecosystem?*, 36 *J. Plankton Res.* 925 (2014).

<sup>53</sup> Haida Salmon Restoration Corporation, *References and Citations*, <http://bit.ly/2aqhv7R> (visited July 4, 2016). The company has also, however, fired and brought suit against Russ George, who spearheaded the controversial experiment. See *Geo-engineering Guru Misled Haida Group, Documents Allege*, *Epoch Times*, Feb. 26, 2014, [bit.ly/1W9a70W](http://bit.ly/1W9a70W). For further information on legal proceedings and investigations concerning this experiment, see Joshua Learn, “Geoengineering: Legal mess hampers understanding of a major CO<sub>2</sub> sequestration test,” *Climate Wire*, Nov. 13, 2014, <http://bit.ly/29nIWPh>.

<sup>54</sup> Royal Society, *supra* note 1; see also *Climate Change 2013: The Physical Science Basis*, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change 29 (Sept. 2013) (“Methods that aim to deliberately alter the climate system to counter climate change”); see also Wilfried Rickels et al., *Kiel Earth Institute, Large-Scale Intentional Interventions into the Climate System? Assessing the Climate Engineering Debate; Scoping report conducted on behalf of the German Federal Ministry of Education and Research* (2011).

this definition, geoengineering is intentional—incidental large-scale alterations of the climate do not count—and only occurs when the alterations are undertaken on a large scale, not a small one (though there are some discussions of regional-level geoengineering).<sup>55</sup> In addition, by this widely-adopted definition,<sup>56</sup> some forms of geoengineering that capture and sequester greenhouse gases so closely resemble forms of mitigation that the British House of Commons Science and Technology Committee identifies carbon capture and storage technologies as “mitigation” if they are coupled with a power generating facility but as geoengineering if they operate independently.<sup>57</sup> Other forms, such as brightening elements of the landscape to increase albedo, overlap with adaptation measures intended to reduce temperatures in urban heat islands.<sup>58</sup> A subtle but important further aspect of what geoengineering encompasses relates to

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<sup>55</sup> See Olivier Boucher et al., *Rethinking Climate Engineering Categorization in the Context of Climate Change Mitigation and Adaptation*, 5 WIREs Climate Change 23, 27 (2013) (“Planting trees on a small plot of land or whitening roofs in a small urban area do not constitute [climate engineering] as their impact on the climate system will be negligible.... [Climate engineering] can be considered to start when there is a measurable climate impact at the regional or global scale.”). Notably, the definition used by the National Academies of Science does not include a scalar criterion, and so encompasses all “intentional efforts to remove carbon dioxide from the atmosphere” and “to increase the amount of sunlight that is scattered or reflected back to space.” NRC, *Carbon Removal*, *supra* note 10, at 2 (Box S.1). By contrast, the IPCC and the Umweltbundesamt (German Federal Environment Agency) emphasize the relevance of scale to its preferred definition. See IPCC Working Group III Technical Support Unit, Meeting Report of the IPCC Expert Meeting on Geoengineering 2 (Ottar Edenhofer et al., eds. 2012), [bit.ly/1l5qICW](http://bit.ly/1l5qICW) (“scale and intent are of central importance”); Ralph Bodle, Sebastian Oberthür et al., Umweltbundesamt, Options and Proposals for the International Governance of Geoengineering 45–47 (2014) [hereinafter “UBA”], [bit.ly/1RMhew5](http://bit.ly/1RMhew5).

<sup>56</sup> See, e.g., Anna-Maria Hubert & David Reichwein, Inst. for Advanced Sustainability Studies, *An Exploration of a Code of Conduct for Responsible Scientific Research Involving Geoengineering* 18 (May 2015) [hereinafter “IASS Code of Conduct”] (proposing definition for inclusion in Code of Conduct for Responsible Scientific Research Involving Geoengineering that elaborates slightly on Royal Society’s definition).

<sup>57</sup> House of Commons (U.K.) Science and Technology Committee, *The Regulation of Geoengineering*, Fifth Report of Session 2009-10, at 20, Mar. 18, 2010, <http://bit.ly/1j7aLvE>; BPC Task Force, *supra* note 13, at 7 (same); see also Boucher et al., *supra* note 55, at 23 (noting overlap and suggesting clarification through proposed categories and subcategories).

<sup>58</sup> Boucher et al., *supra* note 55, at 26–27, 32 (noting overlaps and suggesting clarification through proposed categories and subcategories).

the particular activity that qualifies. That is, because legal decisions are likely to examine this issue closely, it is important to note that geoengineering is not a category comprised solely of technologies, nor solely of activities, but of what this chapter refers to as “approaches” or “techniques,” meaning *combinations* of technologies and purposive activities.<sup>59</sup> Thus, the capture and sequestration of carbon using biochar cannot be reduced to just the apparatus nor to just the actions involved in, say, the use of bio-energy with carbon capture and storage (BECCS).<sup>60</sup>

Chapter 2 of this volume describes the various climate engineering approaches that have been hypothesized or explored to date.<sup>61</sup>

When should research efforts get a “geoengineering” or “climate engineering” label? As with the definition of geoengineering above, the current approach relies heavily on the intent of the researcher.<sup>62</sup> The Haida Salmon Restoration Corporation’s fertilization project demonstrates both that relying on intent can invite researchers to dodge the label,<sup>63</sup> but also that intent can be inferred even if researchers do not announce that their work focuses on altering the climate.

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<sup>59</sup> See UBA, *supra* note 55, at 42–44; 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 Env'tl. Change* 465, 466 (2013) (“unlike many technoscientific issues, the distinctiveness of [SRM] does not lie in the use of novel technologies with new properties: the actual interventions themselves typically involve mundane technologies ... albeit deployed at a very large scale. Its novelty rather lies in the intention to use these technologies to establish a radically new relationship between society and nature, through a project of bringing planetary systems under human control and the ‘making’ of new climates.”).

<sup>60</sup> For a discussion of the importance of categorization and naming to the formulation of geoengineering research programs, see Rose C. Cairns, *Climate Geoengineering: Issues of Path-Dependence and Socio-Technical Lock-In*, 5 *WIREs Climate Change* 649, 656–57 (2014).

<sup>61</sup> See also David W. Keith et al., *supra* note 5 (listing field experiments and identifying their relationships to various geoengineering approaches).

<sup>62</sup> See Solar Radiation Management Governance Initiative, *Solar Radiation Management, The Governance of Research* 23 (2011) [hereinafter SRMGI], <http://bit.ly/2axM2j7> (“The difference between a climate aerosol experiment and a [solar radiation management/geoengineering] experiment might only be the intentions of the researcher.”).

<sup>63</sup> See Haida Salmon Restoration Corporation, *GeoEngineering*, <http://bit.ly/22liMC1> (visited Dec. 21, 2015) (“By reading this discussion, you are Geoengineering. We all do. Nearly every activity we humans do, affects the environment in some way.”).

Haida Salmon and the E-PEACE project also provide examples of dual-use research that, whether or not it informs future climate engineering efforts, clearly also pertains to an inquiry about non-climate issues. The list of research topics that qualify as dual use is long, and, much as climate engineering overlaps with mitigation and adaptation, the list of topics that might be labeled “geoengineering research” overlaps substantially with more general atmospheric and climate research.<sup>64</sup> Thus, the ARM Cloud Aerosol Precipitation Experiment (ACAPEX), funded by the U.S. Department of Energy, is not currently labeled as geoengineering research,<sup>65</sup> even though a future geoengineering effort would likely draw on what it discovers about atmospheric “rivers” and the effects on precipitation of aerosol particulates from various sources in marine cloud formations. Recognizing that labeling such experiments as “geoengineering research” might prove unwelcome and cumbersome, the British government stated in a 2010 report that “weather techniques such as cloud seeding should not be included within the definition of geoengineering used for the purposes of activities designed to effect a change in the global climate with the aim of minimising or reversing anthropogenic climate change.”<sup>66</sup>

What distinguishes research from deployment?<sup>67</sup> Several international agreements concerned with preventing transboundary environmental harm contemplate such a

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<sup>64</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at 10 (“Much of the required research on albedo modification overlaps considerably with basic scientific research that is needed to improve understanding of the climate system.”).

<sup>65</sup> ARM Climate Research Facility, Campaign: ARM Cloud Aerosol Precipitation Experiment (ACAPEX) 2015.01.14 to 2015.02.12, <http://1.usa.gov/1zyKhLs> (visited Jan. 5, 2016) (describing experiment which involved land-, ship-, and airplane-based monitoring of interaction of particulates with precipitation from concentrated channels of atmospheric water vapor—“atmospheric rivers”—over the Pacific and California’s coast).

<sup>66</sup> *See, e.g.*, Government Response to the House of Commons Science and Technology Committee 5th Report of Session 2009-10: The Regulation of Geoengineering 2 (Sept. 2010).

<sup>67</sup> For a discussion of this question in relation to SRM in particular, *see* Andy Parker, *Governing Solar Geoengineering Research as It Leaves the Laboratory*, 372 *Phil. Transactions of the Royal Soc’y A* 20140173 (2014).

distinction,<sup>68</sup> and the London Convention/London Protocol's Assessment Framework sets out a process for distinguishing prohibited ocean dumping from scientific research, including research into the efficacy of OIF.<sup>69</sup> Some have suggested that technical thresholds, such as the amount of solar radiation deflected by a given experiment, might provide the needed specification.<sup>70</sup> However, particularly for stratospheric or tropospheric aerosol injection, the impacts of which are poorly understood,<sup>71</sup> any specification would be difficult to agree on or implement.<sup>72</sup> Thus it would be very difficult to say when governance should transfer from institutions and authorities responsible for research oversight to those responsible for overseeing deployment.<sup>73</sup> In addition to this difficulty, there is also a deeper problem of how to

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<sup>68</sup> Secretariat of the Convention on Biological Diversity, *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters* 141–42 (Sept. 2012), [bit.ly/1meRtbd](http://bit.ly/1meRtbd) (discussing examples); *see also* Chiara Armeni & Catherine Redgwell, *International Legal and Regulatory Issues of Climate Geoengineering Governance: Rethinking the Approach*, CGG Working Paper No. 23, at 28–30 (2015), [bit.ly/1SsWqLt](http://bit.ly/1SsWqLt) (discussing distinction and approach taken by international law). This distinction also lies at the crux of the ongoing dispute over Japanese whaling, which the Japanese insist occurs for research purposes. *See Whaling in the Antarctic (Austl. v. Japan: N.Z. Intervening)*, Judgment, 2014 I.C.J. 148, para. 127 (Mar. 31), <http://bit.ly/1jqD3A0> (“... the Court’s examination of the evidence with respect to JARPA II will focus on whether the killing, taking and treating of whales in pursuance of JARPA II is for purposes of scientific research. . .”).

<sup>69</sup> *See* Resolution LC-LP.2(2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization (adopted Oct. 14, 2010), [bit.ly/1ndAQ0O](http://bit.ly/1ndAQ0O) (Framework itself is Annex 6 of the Resolution). Specifically, the Assessment Framework is “designed for Contracting Parties to evaluate proposed activities that fall within the scope of resolution LC-LP.1(2008),” which declares “ocean fertilization” to be subjected to the London Convention and states that “given the present state of knowledge, ocean fertilization activities other than legitimate scientific research should not be allowed.” Resolution LC-LP.1(2008) on the Regulation of Ocean Fertilization (adopted Oct. 31, 2008), [bit.ly/1Q0scOo](http://bit.ly/1Q0scOo).

<sup>70</sup> *See, e.g.,* Parson & Keith, *supra* note 1, at 1278; Lynn M. Russell et al., *Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan*, 41 *Ambio* 350, 363 (2012) (“... small-scale (i.e., on the order of 10 km in size) geoengineering field experiments . . .”).

<sup>71</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at 6–9.

<sup>72</sup> Alan Robock, *20 Reasons Why Geoengineering Is a Bad Idea*, *Bull. Atomic Scientists*, May/June 2008 (suggesting that for some geoengineering technologies deployment is the only real means of testing available).

<sup>73</sup> UBA, *supra* note 55, at 21.

maintain effective control over new technologies, dubbed the “Collinridge Dilemma.”<sup>74</sup> This Dilemma attends any new and potentially powerful technology because (a) that technology’s role and impacts are difficult to predict before its deployment, but (b) once it is deployed it can be difficult to alter the role it plays, notwithstanding its impacts.<sup>75</sup> Restated, even if small-scale research fails to resolve key uncertainties or control foreseeable dangers, “[r]esearch may generate its own momentum and create a constituency in favor of large-scale research and even deployment.”<sup>76</sup>

### C. Categories of Climate Engineering Research

As many commentators have observed, any effort to implement governance of climate engineering research cannot take a one-size-fits-all approach.<sup>77</sup> The range of activities that qualify as “geoengineering” or “climate engineering” is simply too wide to be usefully addressed by a uniform approach to governance. Imposing governance on different forms of climate engineering therefore requires specifying their differences and organizing them into categories useful for the purpose of governance.

Most efforts to categorize climate engineering approaches have built on the separation of carbon dioxide removal (CDR), which “address[es] the root cause of climate change by removing greenhouse gases from the atmosphere,” from solar radiation management (SRM), which “attempt[s] to offset effects of increased greenhouse gas concentrations by causing the Earth to absorb less solar radiation.”<sup>78</sup> This division aligns with what others have called

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<sup>74</sup> See David Collinridge, *The Social Control of Technology* (1980).

<sup>75</sup> Bracmort & Lattanzio, *supra* note 10, at 4 (“By the time a technology is widely deployed, it may be impossible to build desirable oversight and risk management provisions without major disruptions to established interests.”).

<sup>76</sup> SRMGI, *supra* note 62.

<sup>77</sup> See, e.g., Armeni & Redgwell, *supra* note 68, at 36; Schäfer et al., *supra* note 1, at 115–21 (discussing “[t]echnique-specific policy considerations”); Royal Society, *supra* note 1, at 47, 51–52.

<sup>78</sup> Royal Society, *supra* note 1, at ix.

“remediation” and “intervention” approaches.<sup>79</sup> Both “have the ultimate aim of reducing global temperatures, but there are major differences in their modes of action, the timescales over which they are effective, temperature effects and other consequences, so that they are generally best considered separately.”<sup>80</sup>

As explained by the U.S. National Research Council (NRC),<sup>81</sup> separate consideration of CDR/remediation and SRM/intervention makes sense for a number of reasons. First, whereas CDR is a “potentially viable option,” SRM comprises a “more speculative family of approaches.”<sup>82</sup> Second, “CDR strategies . . . are generally of lower risk [than SRM] and of almost certain benefit.”<sup>83</sup> Third, in contrast to SRM, “it is almost inevitable that some CDR will be needed in the long term” to offset emissions and then to shorten the duration of planetary recovery to preindustrial atmospheric concentrations of GHGs.<sup>84</sup> China’s planned climate engineering research program has also adopted the basic categories of CDR and SRM.<sup>85</sup>

One alternative categorization places climate engineering in the broader context of all policy responses to anthropogenic climate change,<sup>86</sup> reconfiguring climate change responses into five categories: anthropogenic emissions reductions, climate change adaptation measures, domestic removal of atmospheric GHGs, transboundary removal of atmospheric GHGs, and

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<sup>79</sup> Asilomar Scientific Organizing Committee, *The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques* 8 (Nov. 2010) [hereinafter “Asilomar Recommendations”].

<sup>80</sup> *Id.*

<sup>81</sup> See NRC, *Carbon Removal*, *supra* note 10, at 4 tbl.S.1 (“Overview of General Differences Between Carbon Dioxide Removal Proposals and Albedo Modification Methods”), 20 (“Box 1.1 Why There Are Two Separate Reports”). Somewhat confusingly, the NRC reports refer to both CDR and SRM as forms of “climate intervention.” See *id.* at 2, box S.1. This Chapter adopts the Asilomar terminology and refers only to SRM as an “intervention.”

<sup>82</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at 1.

<sup>83</sup> *Id.* at vii.

<sup>84</sup> NRC, *Carbon Removal*, *supra* note 10, at 104.

<sup>85</sup> Cao Long et al., *supra* note 7. <http://bit.ly/22wOUMr>.

<sup>86</sup> Boucher et al., *supra* note 55, at 29–30.

targeted climate modification.<sup>87</sup> This alternative formulation reframes the existing categories chiefly by distinguishing between “transboundary” GHG removals like OIF in the open ocean, which directly affects the global commons, and “domestic” removals, like afforestation within a single nation’s jurisdiction.

Whether building on the CDR/SRM categories or on the alternative configuration, analysts and commentators have employed further subcategories that take into account some or all of the following features of a given approach: scale, locus (e.g., indoors or outdoors, intra- or transboundary), temporality, utility (e.g., scientific versus commercial), and risk.<sup>88</sup> Though different categorizations employ different terms, they get at the same underlying issues. For instance, references to the “cost” and “effectiveness” of an approach<sup>89</sup> address the same point as references to its “leverage”<sup>90</sup>—i.e., its cost-effectiveness. “Reversibility” and “permanence of intended effect” are also synonyms, as are “timeliness” and “rapidity.” Some alternative terminologies overlap but are not cleanly interchangeable: “encapsulation” and “safety” are not the same as “scale of action,” “scale of intended effects,” “effect on the global commons,” or “transboundary side-effects,” but they focus on the same features and implications of climate engineering research approaches.

As described further in Section III, these categories and subcategories are critical for research governance because they help to determine questions of jurisdiction, the nature of oversight, and the intensity of oversight, among others.

## II. ISSUES AND CONCERNS

The prospect of climate engineering and its research generate a number of governance-related concerns, including “moral hazard,” “forum shopping,” a slippery slope from research to deployment, irrational “lock-in” of a particular technology, the potential for a “governance

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<sup>87</sup> *Id.* at 23.

<sup>88</sup> Bellamy, *supra* note 9, at 12–13 (summarizing categorizations discussed in 12 leading publications).

<sup>89</sup> Royal Society, *supra* note 1, at 38–39; Bracmort & Lattanzio, *supra* note 10, at 5 (same).

<sup>90</sup> Boucher et al., *supra* note 55, at 28.

trap,” and disruption to international relations and particularly to the Paris Climate Agreement. Each is discussed in turn.

### A. Moral Hazard

One of the concerns most frequently expressed about climate engineering relates to “moral hazard,” a term common to insurance and economics that describes scenarios in which one party takes a risk knowing that she is protected from the cost of that risk, which will accrue to other parties.<sup>91</sup> There are two ways in particular in which “the decision to ‘insure’ via geoengineering may influence the conduct of the ‘insured.’”<sup>92</sup> First, governments, industry and the public—misunderstanding climate engineering to be an effective substitute for reducing greenhouse gas emissions—might cease to invest in the expensive and politically difficult tasks of mitigation.<sup>93</sup> For example, the world’s largest fossil fuel companies might undertake an enormous climate engineering research and deployment effort in order to “offset” persistent GHG emissions and thereby protect their revenues from the consequences of effective mitigation efforts.<sup>94</sup> Put at ease by early results of these efforts, voters and governments’ demands for mitigation might wane.<sup>95</sup> Alternatively, governments of wealthy nations might collaborate to pursue, over the objections of poorer nations, stratospheric aerosol injection, even

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<sup>91</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at 152 (discussing “double moral hazard” that attends geoengineering).

<sup>92</sup> Albert C. Lin, *Does Geoengineering Present a Moral Hazard?*, 40 *Ecology L.Q.* 673, 689 (2013).

<sup>93</sup> *Id.* at 707 (identifying “a considerable danger that geoengineering will undermine mitigation and adaptation efforts.”);

<sup>94</sup> See Jane C.S. Long & Dane Scott, *Vested Interests and Geoengineering Research*, XXIX *Issues in Sci. & Tech.*, Spring 2013 (“The chief executive officer of Exxon Corporation, Rex Tillerson, articulated his opinion about climate change, glibly commenting: ‘. . . we’ll adapt to that. It’s an engineering problem and it has engineering solutions.’ The opinion espoused by Tillerson reflects his company’s vested interests.”).

<sup>95</sup> See Clive Hamilton, “Ethical Anxieties about Geoengineering: Moral hazard, Slippery Slope and Playing God,” paper presented at Australian Acad. Sci. Conference: Geoengineering the Climate, Canberra, Sept. 27, 2011, at 11–12, <http://bit.ly/2auDae0> (“‘Easy’ options—ones which are relatively inexpensive and do not require major economic and social upheavals—will be particularly attractive. The possible negative side-effects of geoengineering may seem less worrisome compared with the already-felt effects of global warming.”).

though doing so could foreseeably result in disruption of the monsoon relied upon by India, Bangladesh, and other nations for agricultural productivity.<sup>96</sup>

The second form of moral hazard could arise from ignorance – or at least a greater degree of uncertainty. In this scenario, a lack of research would leave the risks of deploying a technology obscure, such that an optimistic government or other entity deploys it in spite of that technology's uncertain net effects within and especially outside that country's borders. This latter version of the moral hazard concern aligns closely with more general concerns about climate engineering approaches like stratospheric aerosol injection and large-scale marine cloud brightening, which are thought to be potentially cost-effective and whose effects would certainly be felt across international boundaries. One study put it this way: “the main problem is establishing legitimate collective control over an activity that some might try to do unilaterally without prior consultation or international risk assessment.”<sup>97</sup>

## B. Forum Shopping

The entity seeking to research or deploy climate engineering technology in the foregoing scenario could be either a government or a private actor seeking to take advantage of the lax oversight imposed by a government in a given jurisdiction.<sup>98</sup> Such “forum shopping” could arise in several forms. One that already occurred was the Russian government's sponsorship of a favored scientist's sulfate aerosol injection experiment with an inappropriately nonchalant

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<sup>96</sup> See SRMGI, *supra* note 62, at 20–22; see also John D. Graham & Jonathan B. Wiener, Risk vs. Risk: Tradeoffs in Protecting Health and the Environment 230 (1997) (discussing problem of an “omitted voice,” i.e., the absence of affected parties from decision process and concomitant disproportionate influence of organized interests).

<sup>97</sup> Ken Caldeira & David W. Keith, *The Need for Climate Engineering Research*, XXVII Issues in Sci. & Tech. (Fall 2010), <http://bit.ly/1mgtF79>. See also V.P. Meleshko et al., *Is Aerosol Scattering in the Stratosphere a Safety Technology Preventing Global Warming?*, 35 Russian Meteorology & Hydrology 433 (2010) (identifying this inclination in the Russian aerosol injection experiment described in Part I).

<sup>98</sup> See Parson & Keith, *supra* note 1, at 1279 (discussing concern about forum-shopping by those seeking to conduct field tests without international sanction).

attitude to compliance with international agreements governing weather modification.<sup>99</sup>

Another that could occur is an experimenter with corporate sponsorship seeking a jurisdiction that does not require environmental review so long as no government funding is involved and no permits are required for the activity under existing law.<sup>100</sup> This might be an apt description of the Haida Corporation's 2012 OIF deployment, which may well not have violated Canadian law,<sup>101</sup> and it describes scenarios conceivable in other jurisdictions, including in international waters using ships sailing under a "flag of convenience."<sup>102</sup> This potential for forum shopping is much of the reason that some have recommended prohibiting any climate engineering research by for-profit entities without either a public partner or public oversight.<sup>103</sup>

### C. The Slippery Slope and Lock-in Effect

Concerns about a "slippery slope" and "lock-in" both amount to versions of the Collinridge Dilemma, which arises because research into a powerful but poorly understood technology may generate momentum that propels it to imprudent deployment. A characteristic version of the "slippery slope" envisions a research program funded and structured not so

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<sup>99</sup> Kintisch, *supra* note 28 (quoting "Yuri A. Izrael, . . . [s]aid to be a close confidant of Prime Minister Vladimir Putin, [] also a prominent member of the Russian Academy of Sciences," as saying: "We really will be able to control the climate.").

<sup>100</sup> See, e.g., John Vidal, *Bill Gates Backs Climate Scientists Lobbying for Large-Scale Geoengineering*, *The Guardian*, Feb. 6, 2012, [bit.ly/1bYJHKN](http://bit.ly/1bYJHKN).

<sup>101</sup> See Grant Wilson, *Murky Waters: Ambiguous International Law for Ocean Fertilization and Other Geoengineering*, 49 *Tex. Int'l L.J.* 507 (2014).

<sup>102</sup> See BBC News, *Why so many shipowners find Panama's flag convenient*, Aug. 5, 2014, [bbc.in/1oe8LUI](http://bbc.in/1oe8LUI) ("Most merchant ships flying Panama's flag belong to foreign owners wishing to avoid the stricter marine regulations imposed by their own countries."); see also Tracy Hester, *Remaking the World to Save It: Applying U.S. Environmental Laws to Climate Engineering Projects*, in *Climate Change Geoengineering: Philosophical Perspectives, Legal Issues, and Governance Frameworks* 263, 298 (Wil C. G. Burns, Andrew L. Strauss, eds. 2013) (describing how Planktos, for-profit company planning to conduct an OIF field test, decided to avoid U.S. EPA jurisdiction by switching to a non-U.S.-flagged vessel).

<sup>103</sup> Rickels et al., *supra* note 54, at 134.

much to understand a technology's potential effects as to develop that technology.<sup>104</sup> Such a program might be guided by a definition of success that assumes eventual deployment, or one that proceeds unfettered by the need to justify go/no-go decisions based on something other than operational capability.<sup>105</sup> Whatever form it takes, the key feature of a slippery slope scenario is the *absence* of external, non-technical feedback capable of steering the progress of technological development.<sup>106</sup>

Discussions of “lock-in,” or “resistan[ce] to change even if negative impacts were later discovered,” are concerned with irrational commitments to adoption after an initial experiment or small-scale deployment.<sup>107</sup> Thus the most obvious form of lock-in for SRM technologies is the “termination problem” that would result from successfully preventing further increases in the earth's average temperature only so long as deployment of a particular technology continues: cessation of that deployment would lead to a rapid and dangerous temperature rise.<sup>108</sup> This example is one of “technical” as opposed to “social” lock-in.<sup>109</sup> The latter focuses on the constituency that could be expected to coalesce around maintenance of a particular climate engineering approach, either because of gains to be had from the large-scale investments required for its research or deployment, or because that approach enables continued profitability for an emissions-intensive industry.<sup>110</sup> Such a constituency would be invested in overlooking evidence that the benefits of the approach do not exceed its costs.

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<sup>104</sup> See Robock, *supra* note 72, at 17–18; Mike Hulme, Climate Change: Climate Engineering Through Stratospheric Aerosol Injection, *Progress in Phys. Geog.*, Aug. 2012, at 1, 4.

<sup>105</sup> See Bracmort & Lattanzio, *supra* note 10, at 8 (“Innovative and entrepreneurial organizations seldom mobilize themselves to put complex technologies ‘on the shelf.’”).

<sup>106</sup> Schäfer et al., *supra* note 1, at 107.

<sup>107</sup> See Cairns, *supra* note 60, at 5 (2014).

<sup>108</sup> A. Jones et al., *The Impact of Abrupt Suspension of Solar Radiation Management (Termination Effect) in Experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP)*, 118 *J. Geophysical Res. Atmosphere* 9743 (2013).

<sup>109</sup> Cairns, *supra* note 60, at 651.

<sup>110</sup> *Id.*

As Long and Scott have observed, with somewhat forced alliteration, there are at least four potential motives for this social form of lock-in: fortune, fear, fame, and fanaticism.<sup>111</sup> “Fortune” sums up the perspective of a group or entity that stands to lose from mitigation and to gain, or continue not losing, from use of climate engineering as a mitigation substitute. “Fear” refers to the reticence of an individual or a funder to publish negative results<sup>112</sup>—a reticence that, if widespread, would bias scientific and public understanding of the climate engineering approaches at issue.<sup>113</sup> “Fame” recognizes that individuals might lose perspective and give undue priority to public recognition. “Fanaticism” acknowledges that any ideology, whether it comes to favor or oppose a particular path of climate engineering research or deployment,<sup>114</sup> would ignore facts crucial to a rational analysis of the prospects of approaches to climate engineering.

#### D. The Governance Trap

The “governance trap” occurs if existing institutions oriented to some other purpose, but with some measure of jurisdiction over climate engineering research activities, come to steer the governance of climate engineering research—and possibly do so badly. For example, the

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<sup>111</sup> Long & Scott, *supra* note 94.

<sup>112</sup> Such “publication bias” occurs where “publication of study results is based on the direction or significance of the findings.” Annie Franco et al., *Publication Bias in the Social Sciences: Unlocking the File Drawer*, 345 *Science* 6203, Sept. 19, 2014, [bit.ly/1J5HEaU](http://bit.ly/1J5HEaU).

<sup>113</sup> See, e.g., Kurt A. Spokas et al., *Biochar: A Synthesis of Its Agronomic Impact beyond Carbon Sequestration*, 41 *J. Env'tl. Quality* 973, 977 (2011), [bit.ly/1RAqk0C](http://bit.ly/1RAqk0C) (“Approximately 50% of the compiled studies observed short-term positive yield or growth impacts . . . . However, due to potential publication biases, these percentages should only be taken as reflective of the studies presented here and not as evidence of an overall biochar likelihood of producing positive impacts.”).

<sup>114</sup> See Dan M. Kahan, *The Politically Motivated Reasoning Paradigm*, in *Emerging Trends in Social & Behavioral Sciences* (forthcoming), <http://ssrn.com/abstract=2703011> (“individuals whose pro-market sensibilities predispose them toward rejection of climate change rate the strength of evidence that humans are responsible for global warming much more highly after being exposed to information on geoengineering—a technological “fix” that would obviate the need for limiting greenhouse gas emitting forms of commerce; likewise, individuals whose anti-market sensibilities predispose them to credit evidence on climate change in fact treat such evidence as *less convincing* after being told about research on geoengineering than when they are first briefed on the need to impose CO<sub>2</sub> emissions on industry.”).

Montreal Protocol could apply to the dispersion of sulfate aerosols into the stratosphere. However, the Montreal Protocol is a mechanism set up to phase out certain substances that contribute to ozone depletion; it is not designed to assess the potential impacts of field tests for new technologies.<sup>115</sup> In addition to an institutional mismatch that inappropriately shuts down research, the trap could manifest in a situation where the authority that claims jurisdiction over climate engineering research essentially fails to govern, requiring merely ministerial compliance with existing regulations in a way that does not stymie imprudent research pathways. Alternatively, the authority might apply regulatory techniques that are well suited to its core mission but not to climate engineering. Thus a governance trap is usefully understood as poor or non-governance that increases the likelihood of such scenarios as a slippery slope, a lock-in scenario, premature termination of justifiable research, use of inappropriate controls, or failure to exercise needed controls.

For climate engineering research, perhaps the most likely “trap” lies in the law governing intellectual property rights.<sup>116</sup> Since 2010, the U.S. Patent and Trademark Office has witnessed a climate engineering “patent land-grab,” with a focus on technologies related to CDR approaches.<sup>117</sup> This land-grab—and patenting more generally—could derail an optimal climate engineering research program.<sup>118</sup> The authors of the Oxford Principles of Geoengineering Research identify another problematic implication of patent law in this context:

The ability to obtain patents on geoengineering technique [sic] could create a culture of secrecy and may lead to the concealment of negative results. This has been observed in the pharmaceutical industry, where negative research results

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<sup>115</sup> Mason Inman, *Planning for Plan B*, 4 *Nature Climate Change* 7, 8 (2010).

<sup>116</sup> See Shobita Parthasarathy et al., *A Public Good? Geoengineering and Intellectual Property*, STTP Working Paper 10-1, at 4 (2010), [bit.ly/1P9bKN8](http://bit.ly/1P9bKN8) (“Intellectual property (IP) is often unrecognized as a form of governance, but it shapes the development of technology in pivotal ways.”).

<sup>117</sup> Anthony E. Chavez, *Exclusive Rights to Saving the Planet: The Patenting of Geoengineering Inventions*, 13 *Nw. J. Tech. & Intell. Prop.* 1, 10, 13 (2015).

<sup>118</sup> *Id.* at 13–17.

are deliberately concealed. This is doubly damaging—firstly, the negative consequences of a geoengineering technique could be far more wide-ranging than from a drug trial, and secondly, the concealment of negative results could lead to a public backlash against all geoengineering research and research scientists.<sup>119</sup>

Thus the normal operation of patent law, in which actors are arguably incentivized to conceal adverse findings so as not to impact the commercial potential of their products, could impair a program of climate engineering research governance that seeks to foster rapid improvements in understanding of climate engineering.<sup>120</sup>

Intellectual property may also present barriers in the international realm. If one or more national governments seek to impose special requirements on intellectual property related to climate engineering research, they will have to vie with the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs).<sup>121</sup> Members of the World Trade Organization are bound by the provisions of TRIPs, which strengthen the ability of intellectual property owners to enforce their rights across international borders.<sup>122</sup> Although TRIPs has given rise to notably few enforcement actions,<sup>123</sup> and although its provisions could be especially difficult to

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<sup>119</sup> Memorandum submitted by Tim Kruger et al. to the House of Commons following oral testimony before Science and Technology Committee ¶5 (Feb. 2010), [bit.ly/1PbVFQh](http://bit.ly/1PbVFQh).

<sup>120</sup> IASS Code of Conduct, *supra* note 56, at 89 (identifying the “non-disclosure of commercial information” as a “barrier to transparency” and noting that environmentally protective national laws and international treaties often include exceptions to disclosure requirements for proprietary information); Parthasarathy et al., *supra* note 116, at 10–12 (highlighting several pitfalls in business-as-usual patenting, including grant of overbroad patents that set the stage for future litigation, concentrated patent ownership, and ownership by “non-practicing entities”).

<sup>121</sup> Armeni & Redgwell, *supra* note 68, at 13 (noting potential conflict between environmental protections and intellectual property protections under TRIPs international agreement). Various other international agreements also contain provisions drafted to protect intellectual property rights. See Raymundo Valdés & Maegan McCann, *Intellectual Property Provisions in Regional Trade Agreements: Revision and Update*, WTO Staff Working Paper, No. ERSD-2014-14 (2014), [bit.ly/1R87luE](http://bit.ly/1R87luE).

<sup>122</sup> See generally A Handbook on the WTO TRIPs Agreement (Antony Taubman, Hannu Wager & Jayashree Watal, eds. 2012).

<sup>123</sup> See Patricia L. Judd, *Retooling TRIPs*, 55 Va. J. Int'l L. 117, 137–138 (2014); see also Peter K. Yu, *TRIPs and Its Achilles' Heel*, 18 J. Intell. Prop. L. 479 (2010–2011) (stating that, notwithstanding its enforcement

enforce in the climate engineering research context, it nonetheless presents a formal and functional hurdle that national governments cannot ignore should they create exceptions to the treatment of climate engineering-related intellectual property.<sup>124</sup>

### E. Disruption of International Relations

Because of the potential enormity of climate engineering's transboundary consequences, its research is inevitably a charged issue for international relations.<sup>125</sup> Potential disruptions incidental to disagreement over the conduct of research or its governance could take a number of diverse forms.<sup>126</sup> A full discussion of imagined paths leading from research to international strife is beyond the scope of this Chapter, but we acknowledge the potential for rifts to open

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provisions, it is unsurprising that TRIPs “fails to induce stronger global enforcement of intellectual property rights”).

<sup>124</sup> See Erica C. Smit, *Geoengineering: Issues of Accountability in International Law*, 15 Nev. L.J. 1078–81 (2015) (summarizing TRIPs and describing its potential relevance to geoengineering governance); Rafael Leal-Arcas, *Climate Change and International Trade* 447–450 (2013) (noting potential implications of international intellectual property protections for geoengineering technology development and exchange).

<sup>125</sup> See Achim Maas & Irina Comardicea, *Climate Gambit: Engineering Climate Security Risks?*, in *Backdraft: the Conflict Potential of Climate Change Adaptation and Mitigation* 37, 43 (Geoffrey D. Dabelko et al. eds. 2013) (envisioning “arms race” for geoengineering capacity); P. Michael Link et al., *Possible Implications of Climate Engineering for Peace and Security*, 94 Bull. Amer. Meteor. Soc. ES13 (Feb. 2013), [bit.ly/1niPBj3](http://bit.ly/1niPBj3); Robert J. Lempert & Don Prosnitz, RAND, *Governing Geoengineering Research: A Political and Technical Vulnerability Analysis of Potential Near-Term Options* at xi (2011), [bit.ly/1ZFdm6e](http://bit.ly/1ZFdm6e) (anticipating “significant challenges for risk management, national security, and international governance”); Clive Hamilton, *The Return of Dr Strangelove: The politics of climate engineering as a response to global warming* (June 2010), [bit.ly/1SNchUu](http://bit.ly/1SNchUu) (characterizing international relations issues arising from geoengineering as analogous to those arising from nuclear proliferation).

<sup>126</sup> Joshua B. Horton & Jesse L. Reynolds, *The International Politics of Climate Engineering: A Review and Prospectus for International Relations*, 18 Int'l Studies Rev. 1 (2016) (reviewing literature that discusses potential direct and indirect adverse effects of geoengineering research and deployment on international relations).

between states over climate engineering research and thus the importance of reducing that risk by devising internationally applicable norms, mechanisms, and institutions for governance.<sup>127</sup>

### III. GOVERNANCE: WHAT? WHEN? AND BY WHOM?

Envisioning governance of climate engineering research leads to three broad categories of possible approaches: a ban (typically on both research and deployment);<sup>128</sup> unilateral, uncoordinated, and potentially variable approaches by national governments;<sup>129</sup> or an effort on the part of actors at multiple levels—ranging from research facilities to international bodies—to monitor, coordinate, steer, and limit research in an agreed fashion.<sup>130</sup> Many have warned against pursuing the first two of these, and—although calls for a ban will certainly persist—discussion in the scientific and policymaking communities has effectively become a debate on how to govern climate engineering research—and possibly also eventual deployment—through a combination of international and national institutions.

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<sup>127</sup> *Id.* at 5–6, 10; see also Chad M. Briggs, *Is Geoengineering a National Security Risk?*, Geoengineering Our Climate? (Oct. 2013), [bit.ly/1JaP5h0](http://bit.ly/1JaP5h0) (“The security concern with SRM is therefore that related heating or cooling will result in non-linear stresses on environmental systems, where vulnerable parts of the system will be damaged or collapse, resulting in cascading impacts which may in turn destabilize vulnerable social, political, and economic systems which rely upon a steady-state environment.”).

<sup>128</sup> See, e.g., ETC Group, *Climate & Geoengineering*, [bit.ly/1PXK4I2](http://bit.ly/1PXK4I2) (visited Jan. 13, 2016) (“ETC Group opposes geoengineering and other false solutions to climate change ... and supports peasant-led agroecological responses to the climate crisis.”); Anchorage Declaration, *Indigenous Peoples’ Global Summit on Climate Change*, Apr. 24, 2009, [bit.ly/1Kdqh2K](http://bit.ly/1Kdqh2K) (“We challenge States to abandon false solutions to climate change that negatively impact Indigenous Peoples’ rights, lands, air, oceans, forests, territories and waters. These include . . . geo-engineering techniques ....”); Asia Indigenous Peoples’ Declaration on the 21st Session of the UNFCCC-Conference of Parties (COP21), Sept. 18, 2015, [bit.ly/1Orabo6](http://bit.ly/1Orabo6) (same).

<sup>129</sup> See Daniel Bodansky, *May we engineer the climate?*, 33 *Climatic Change* 309 (1996) (discussing possibility); see also Joshua B. Horton, *Geoengineering and the Myth of Unilateralism: Pressures and Prospects for International Cooperation*, 4 *Stan. J.L. Sci. & Pol’y* 56 (2011).

<sup>130</sup> UBA, *supra* note 55, at 124 (discussing these three categories); Bellamy, *supra* note 9 (anticipating third category and naming it “clumsy” governance); see also Lempert & Prosnitz, *supra* note 125, at xi (“if U.S. policymakers believe that some type of SRM technology is possible, they ought to prefer the Strong Norms policy to No Norms or Ban.”).

It is useful to frame this ongoing discussion as an effort to determine how best to apply the prevention and precautionary principles<sup>131</sup>—features of international law<sup>132</sup> and of many countries' domestic laws<sup>133</sup>—in the context of climate engineering and its research. Some have said that prevention/precaution in the context of climate engineering research is straightforward and means simply not meddling with the global climate.<sup>134</sup> Others have said that anthropogenic climate change makes the application of these principles ambivalent: given what we understand of the rapidly changing state of the climate, doesn't the greater risk lay in failing to explore, understand, and *possibly* employ climate engineering techniques?<sup>135</sup> As one commentator put it: "ignoring geoengineering today, and only considering it when all else has failed, is a recipe for

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<sup>131</sup> To oversimplify: both principles impose a duty of care on states before authorizing or undertaking a risky or potentially risky activity; whereas prevention relates to well-understood risks, precaution relates to uncertainties. "These principles require countries to take action where significant (and irreversible) environmental harm is foreseeable." International Law Association, Washington Conference: Legal Principles Relating to Climate Change 16 (2014), [bit.ly/1Zu4kTY](http://bit.ly/1Zu4kTY). For a summary description of both principles, their embodiment in international law, and an explanation of how they interact, see IASS Code of Conduct, *supra* note 56, at 41.

<sup>132</sup> See Chapter 3 of this volume; see also, e.g., United Nations Environment Programme, Declaration of the United Nations Conference on the Human Environment, UN Doc A/Conf.48/14/Rev.1, June 16, 1972, 11 ILM 1416, principles 6, 7, 15, 18 and 24 (calling for preventive action); Convention on Biological Diversity, June 5, 1992, 1760 UNTS 79, reprinted in 31 ILM 818 (1992), preambular recital 8 and art. 1 (similar); Rio Declaration on Environment and Development, June 13, 1992, A/CONF.151/5/Rev.1, reprinted in 31 ILM 874 (1992), principle 15 ("In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities."); Donald R. Rothwell & Tim Stephens, *The International Law of the Sea*, ch. 19 (2016) (discussing invocations of precautionary principle in international disputes and recognition of principle as an "approach" if not "customary international law").

<sup>133</sup> See Chapter 4 of this volume; see also, e.g., Ling Zhu & Yachao Zhao, *Polluter-pays Principle - Policy Implementation*, 45 *Env'tl. Pol'y & L.* 34 (Mar. 2015) (discussing relationship of polluter pays and prevention principles); Martha Cecilia Paz, *Precautionary Principle: Case Law in Colombia*, 3 *Civil Legal Sci.* 108 (2013); David W.-L. Wu, *Embedding Environmental Rights in Section 7 of the Canadian Charter: Resolving the Tension Between the Need for Precaution and the Need for Harm*, 33 *Nat'l J. Const. L.* 191 (2013).

<sup>134</sup> See, e.g., Robock et al., *supra* note 72, at 18.

<sup>135</sup> Jesse L. Reynolds & Floor Fleurke, *Climate Engineering Research: A Precautionary Response to Climate Change?*, 2013 *Carbon & Climate L. Rev.* 101 (2013); P. Toussaint, *Between a Rock and a Hard Place: Climate Impacts, Geoengineering and the Precautionary Principle*, 24 *Env'tl. L. & Mgmt.* 235 (2012); Lauren Hartzell-Nichols, *Precaution and Solar Radiation Management*, 15 *Ethics, Pol'y & Env't* 158 (2012).

bad, politics-led decision-making.”<sup>136</sup> This Chapter understands the basic goal of climate engineering research to be *the reconciliation of these interpretations of prevention and precaution by enabling useful and informative research to proceed—or be terminated—safely, while preventing the conduct of research that is not useful, not safe, or otherwise undesirable.*<sup>137</sup>

This section examines the prospective features of climate engineering research governance. It divides that examination into three subparts. The first provides a definition of governance and discusses the widely accepted Oxford/Asilomar principles as well as the functions that any climate engineering research governance institution would perform. The second examines the question of when and how particular climate engineering governance approaches should start to apply to research efforts. The third addresses the question of who has the authority and the capacity to administer a governance regime, identifies existing institutions, and highlights the gaps that would need to be filled.

#### **A. What: Definition, Principles, and Functions**

As Professor Daniel Bodansky has observed, “the essence of governance is to make decisions for a collective.”<sup>138</sup> The SRM Governance Initiative (SRMGI), which the Royal Society, the Environmental Defense Fund, and the World Academy of Sciences established in 2010, has proposed the following definition for research governance: “the resources, information, expertise, and methods needed for the control of an activity in order to advance the potential societal benefits provided by SRM, while managing associated risks.”<sup>139</sup> This definition, in keeping with Bodansky’s observation, encompasses all key aspects of decisionmaking about

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<sup>136</sup> J. Virgoe, *International Governance of a Possible Geoengineering Intervention to Combat Climate Change*, 95 *Climatic Change* 103, 117 (2009).

<sup>137</sup> See NRC, *Reflecting Sunlight*, *supra* note 1, at 12 (“Ultimately, the goal is to ensure that the benefits of the research are realized to inform civil society decision making, the associated challenges are well understood, and risks are kept small.”); IASS Code of Conduct, *supra* note 56, at 56; SRMGI, *supra* note 62, at 20.

<sup>138</sup> Bodansky, *supra* note 4, at 541.

<sup>139</sup> SRMGI, *supra* note 62. SRMGI’s founders explained the need for their initiative in this way: “Research into SRM...presents some special potential risks. Governance arrangements for managing these risks are mostly lacking and will need to be developed if research continues.” *Id.* at 9.

SRM, including both “hard” governance, meaning prohibitions and forms of direct governmental control over experiments, as well as “soft” governance, meaning the allocation of financing and requirements for reporting and transparency. In adopting this definition we note that it is compatible with the admonitions of the NRC that “[g]overnance’ is not a synonym for ‘regulation,’”<sup>140</sup> and of the German Environment Agency that “governance encompasses more than binding legal rules.”<sup>141</sup>

A governance system ought to be attached to a sound set of principles. Although there will likely be further statements about what should inform climate engineering research governance, the five principles articulated by participants in the 2010 Asilomar International Conference on Climate Intervention Technologies<sup>142</sup> have been especially influential on subsequent efforts, including by governments, to articulate increasingly concrete recommendations for climate engineering research governance.<sup>143</sup> In addition to codifying the consensus views of the scientific community, these principles also reflect the broadly similar Oxford Principles<sup>144</sup> which were published in 2009 and were endorsed by the British Government in 2010.<sup>145</sup> The Asilomar Principles are as follows:

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<sup>140</sup> NRC, Carbon Removal, *supra* note 10, at 12.

<sup>141</sup> See also UBA, *supra* note 55, at 121.

<sup>142</sup> Asilomar Recommendations, *supra* note 79, at 17.

<sup>143</sup> See IASS Code of Conduct, *supra* note 56, at 6, 24; see also NRC, Reflecting Sunlight, *supra* note 1; UBA, *supra* note 55, at 150 (“as a starting point for governance they demonstrate that the science community is aware of the wider implications and of the need to act responsibly within a political context”); SRMGI, *supra* note 62; BPC Task Force, *supra* note 13.

<sup>144</sup> Tim Kruger, *A Commentary on the Oxford Principles, Geoengineering Our Climate?*, May 14, 2013, [bit.ly/1REtbFQ](http://bit.ly/1REtbFQ) (“[The Oxford Principles] subsequently formed the basis of discussions [at the Asilomar Conference] and the Asilomar Principles for Responsible Conduct of Climate Engineering Research...”); see also Oxford Principles: History, [bit.ly/1Oe0jhb](http://bit.ly/1Oe0jhb) (visited Jan. 7, 2016). For a thorough commentary on the Oxford Principles by their authors, see Steve Rayner et al., *The Oxford Principles*, 121 *Climatic Change* 499 (2013).

<sup>145</sup> Government Response to the House of Commons Science and Technology Committee 5<sup>th</sup> Report of Session 2009-10: The Regulation of Geoengineering 6 (Sept. 2010), [bit.ly/1UPAhEW](http://bit.ly/1UPAhEW).

1. Climate engineering research should be aimed at promoting the collective benefit of humankind and the environment;
2. Governments must clarify responsibilities for, and, when necessary, create new mechanisms for the governance and oversight of large-scale climate engineering research activities;
3. Climate engineering research should be conducted openly and cooperatively, preferably within a framework that has broad international support;
4. Iterative, independent technical assessments of research progress will be required to inform the public and policymakers; and
5. Public participation and consultation in research planning and oversight, assessments, and development of decision-making mechanisms and processes must be provided.

While these principles leave much room for further specification, they distill several basic priorities: First, Principle 1 makes clear that the aim of research is greater understanding, not greater capacity to deploy one or more forms of climate engineering. Thus research guided by this principle could be considered successful not only if it assisted in deployment, but also if it instead supported the conclusion that deployment would be unhelpful or harmful. Second, Principle 2 recognizes that national governments are primarily responsible for climate engineering research governance but also that they will fail in that responsibility if they do not act to establish or actively support the establishment of governance mechanisms. Third, Principle 3 highlights that the mechanisms contemplated by Principle 2 should enable international transparency, and, ideally, be the result of international consultation and agreement. Fourth, Principle 4, by calling for “independent technical assessments,” effectively proposes that no research findings should be treated as sufficient to justify policy decisions unless those findings have withstood the scrutiny of review by experts working independently of the original research team. Last, Principle 5 calls for “public participation and consultation.” This marks a rare departure from the Oxford Principles, which call for notice, consultation, “and ideally . . . prior informed consent of those affected.”<sup>146</sup> Thus, taken together, Asilomar Principle 5 and Oxford Principle 2 establish both a minimum of public consultation and an ideal

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<sup>146</sup> Oxford Principles, [bit.ly/1QFGNQP](http://bit.ly/1QFGNQP).

of consent. An approach that nears the ideal is akin to the concept of “social license,” which was developed in relation extractive industry activities<sup>147</sup> and has since been discussed in relation to climate engineering as well.<sup>148</sup>

Implementation of the basic Oxford/Asilomar principles will entail performing familiar functions in potentially novel ways.<sup>149</sup> Those functions, elaborated below, include: authorizing and financing proposed and ongoing research; identifying and resolving potential conflicts of interest; establishing and enforcing requirements for disclosure and dissemination of plans, data, and analyses; conducting environmental impact assessments in advance of experiments; providing for public consultation and engagement; managing intellectual property rights; and defining, assigning, and enforcing liability for harms arising from research.

### 1. Funding and Authorizing Research

While there is nothing unusual about public or private entities funding research, there is something unusual (but not unprecedented) about restrictions, whether through ethical norms or legal strictures, on not just *how* a research agenda may be pursued but also on who may support it and whether it may be pursued at all. Thus climate engineering research governance, insofar as it seeks to apply such limits, will be in contentious territory—both ethically<sup>150</sup> and

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<sup>147</sup> See Don C. Smith & Jessica Marie Richards, *Social License to Operate: Hydraulic Fracturing-Related Challenges Facing the Oil & Gas Industry*, 1 *Oil and Gas, Natural Resources, and Energy Journal* 81, 89–95 (Apr. 2015) (“[social license] is an ongoing social contract with society that allows a project to both start and continue operating in a community”).

<sup>148</sup> Andy Parker, Oliver Morton & George Collins, Forum for Climate Engineering Assessment, *Reflecting on the “Berlin Declaration,”* July 16, 2015, [bit.ly/1OOctBcV](http://bit.ly/1OOctBcV); Draft Proposed Berlin Declaration, [bit.ly/1Uzx2S0](http://bit.ly/1Uzx2S0).

<sup>149</sup> See SRMGI, *supra* note 62, at 30.

<sup>150</sup> See Alan Robock, *Is Geoengineering Research Ethical?*, 4 *Security & Peace* 226 (2012); Mark B. Brown & David H. Guston, *Science, Democracy, and the Right to Research*, 15 *Sci. & Eng. Ethics* 351 (2009); U.S. National Bioethics Advisory Commission, *Cloning Human Beings: Report and Recommendations of the National Bioethics Advisory Commission*, vol. 2, at 6 (1997) (“Because science is both a public and social enterprise and its application can have profound impact, society recognizes that the freedom of scientific inquiry is not an absolute right and scientists are expected to conduct their research according to widely held ethical principles.”).

legally<sup>151</sup>—alongside the governance of research into technologies like nuclear power, biotechnology for medicine and agriculture, and nanotechnology.<sup>152</sup> On the other hand, funding sources shape research paths,<sup>153</sup> and several concerns noted in Part II of this Chapter would seem to justify imposing oversight on some forms of research and some sources of research funding. Thus any governance regime will need to develop and articulate answers to difficult questions, such as:

- how to distinguish “geoengineering research” from non-geoengineering research;;
- whether to impose special requirements on privately-funded geoengineering research—for instance, reporting of plans, data, and results analysis to a publicly available registry<sup>154</sup>—in order to prevent efforts to end-run restrictions, such as public records access, that would accompany the same research if funded publicly;
- how to reconcile and potentially integrate governmental oversight with self-regulation by the scientific community, such as the arrangement that grew out of the 1975 Asilomar International Conference on Recombinant DNA Molecules;<sup>155</sup>

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<sup>151</sup> See IASS Code of Conduct, *supra* note 56, at 12–16 (discussing scientific research as a subject of international law and in particular as among other protected human rights); California Constitution, art. 35, sec. 5 (“There is hereby established a right to conduct stem cell research which includes research involving adult stem cells, cord blood stem cells, pluripotent stem cells, and/or progenitor cells”), [bit.ly/1Ro7Pfs](http://bit.ly/1Ro7Pfs).

<sup>152</sup> Jack Stilgoe, *Geoengineering as Collective Experimentation*, *Sci. & Eng’g Ethics* (Apr. 2015), 5 (listing technologies characterized by “the impossibility of control in a scientific sense”).

<sup>153</sup> See Joshua S. Gans & Fiona Murray, *Funding Scientific Knowledge: Selection, Disclosure and the Public-Private Portfolio*, in *The Rate and Direction of Inventive Activity Revisited* 51, 53 (Josh Lerner & Scott Stern eds. 2012) (describing rubrics used by various private, public, and governmental entities for the selection and disclosure of funded research, and identifying implications of those rubrics’ differences).

<sup>154</sup> See Jason J. Blackstock et al., Centre for International Governance Innovation, Workshop Report: Designing Procedural Mechanisms for the Governance of Solar Radiation Management Field Experiments, Feb. 23-24, 2015, [bit.ly/1Jc1ZFX](http://bit.ly/1Jc1ZFX).

<sup>155</sup> See John E. Barkstrom, *Recombinant DNA and the Regulation of Biotechnology: Reflections on the Asilomar Conference, Ten Years After*, 19 *Akron L. Rev.* 81, 87 (1985) (“The NIH Guidelines are virtually the only form of government control for recombinant DNA research and even that control focuses primarily on contracts involving government funding for research procured through the NIH.”).

- whether to prohibit particular research efforts, either by articulating categories of research that are “off limits,” or as the result of a process that considers proposals ad hoc;
- how to justify and establish legal predicates for any of the foregoing types of restrictions.

## 2. Identifying and Resolving Potential Conflicts

Research governance in general has concerned itself in part with rooting out conflicts of interest to protect the integrity of research for at least several decades.<sup>156</sup> The standard procedural approach to this threat to research integrity entails disclosure of financial and other interests to a supervisory body and/or to the public.<sup>157</sup> When a U.S. federal agency seeks expert advice on a particular topic, the heightened requirements of the Federal Advisory Committee Act may apply.<sup>158</sup> Nonetheless, conflicts review in several academic and professional contexts continues to spark disputes over the adequacy of basic definitions and procedures<sup>159</sup> in part

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<sup>156</sup> See Michael Davis, *Conflict of Interest in the Professions* (2001); Arnold S. Relman, *Dealing with Conflicts of Interest*, 310 *New England J. Med.* 1182 (1984) (“The Journal has had no stated policy on [author conflicts of interest] until now, but my editorial associates and I think it is time we formulated one.”); James B. Conant, *Education and the National Science Foundation*, 34 *Am. Scientist* 94, 98–99 (Jan. 1946) (anticipating potential conflicts of interest in implementation of proposed scientific fellowship program).

<sup>157</sup> See, e.g., J.S. Ancker & A. Flanagan, *A Comparison of Conflict of Interest Policies at Peer-Reviewed Journals in Different Scientific Disciplines*, 13 *Sci Eng Ethics*. 147 (2007) (examining requirements of disclosures relating to financial and other relationships between authors, subjects, funders, and peer-reviewers).

<sup>158</sup> 5 U.S.C. app. 2 (2012); Federal Advisory Committee Management, 66 *Fed. Reg.* 37,728 (July 19, 2001) (final rule instructing federal agencies on implementation of FACA); see also Memorandum from Vanessa T. Vu, Director of EPA Science Advisory Board Staff Office, to Clean Air Scientific Advisory Committee (CASAC) regarding Federal Advisory Committee Act (FACA) Policies (May 3, 2005), [bit.ly/234Foaj](http://bit.ly/234Foaj) (describing how FACA requirements apply to CASAC activities).

<sup>159</sup> See, e.g., *R.J. Reynolds Tobacco Co. v. U.S. Food & Drug Admin.*, Case No. 14-5226 (D.C. Cir. Jan. 15, 2016) (overturning trial court decision holding that conflicts of interest should have led FDA, pursuant to federal ethics laws, to exclude three experts from panel that authored report finding that menthol cigarettes have adverse health impacts comparable to tobacco cigarettes); Glenn W. Suter & Susan M. Cormier, *The Problem Of Biased Data And Potential Solutions For Health And Environmental Assessments*, 21 *Human & Ecol. Risk Assessment: An International Journal* 1736 (2014) (“despite peer review, much of the scientific literature is biased. Sources of bias include publication practices, research design and implementation, funding influences, investigator expectations, statistical methods, confounding,

because factors like publication bias have persisted—even flourished—notwithstanding applications of the measures listed above.<sup>160</sup>

The pernicious potential of conflicts—actual or perceived<sup>161</sup>—in the fraught context of climate engineering argues for employing two further measures when dealing with consequential research experiments or campaigns. First, a steering committee could be formed that includes representation from ethical perspectives as well as scientific ones and that would be responsible for the review of proposed research and possibly also for decisions about funding.<sup>162</sup> And second, a general expectation could be created that all field testing will employ a “blue team/red team” model that assigns two research teams related tasks but different goals: blue to test a hypothesis or the effectiveness of a given apparatus or technique, and red to identify weaknesses, perhaps by simply critiquing the first team’s approach, or by assessing the levels of cost and environmental impact related to the test’s subject.<sup>163</sup> Actually employing either a steering committee or rival teams model, or both (they would be not only compatible,

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suppression, and fraud.”); Institute of Medicine, Nat’l Acad. Sci., *Conflict of Interest in Medical Research, Education, and Practice* (Bernard Lo & Marilyn J. Field eds. 2009) (describing sources of conflicts).

<sup>160</sup> See, e.g., Franco et al., *supra* note 112, at 6203 (“There is a strong relationship between the results of a study and whether it was published, a pattern indicative of publication bias. \* \* \* [W]hat is perhaps most striking in [our data] is not that so few null results are published, but that so many of them are never even written up (65%).”); Kerry Dwan et al., *Systematic Review of the Empirical Evidence of Study Publication Bias and Outcome Reporting Bias — An Updated Review*, 8 PLoS ONE e66844, July 5, 2013, [bit.ly/202OWA4](http://bit.ly/202OWA4) (“There is strong evidence of an association between significant results and publication; studies that report positive or significant results are more likely to be published and outcomes that are statistically significant have higher odds of being fully reported.”).

<sup>161</sup> See discussion of SPICE in Part I; Erin Hale, *Geoengineering Experiment Cancelled Due to Perceived Conflict of Interest*, *The Guardian*, May 16, 2012, [bit.ly/1OiY95e](http://bit.ly/1OiY95e).

<sup>162</sup> David E. Winickoff & Mark B. Brown, *Time for a Government Advisory Committee for Geoengineering Research*, 29 *Issues in Sci. & Tech.* 79 (Summer 2013); BPC Task Force, *supra* note 13, at 24.

<sup>163</sup> Long & Scott, *supra* note 94 (“Peer review will remain necessary—in part, to help balance the exuberance of individual scientists—but by itself will probably be inadequate. . . . In this “red team/blue team” model, one team develops the research, and the other tries to ferret out all the problems.”); Caldeira & Keith, *supra* note 97 (“a red team/blue team approach, wherein one team is tasked with showing how an approach can be made to work, and another team is tasked with showing why the approach cannot produce a system that can actually diminish environmental risk at an acceptable cost.”).

but complementary), would require specifying a long list of particulars, including the source and scope of the steering committee's authority over research and the process for determining goals and membership for the "red team" in any experiment.

### 3. Disclosure Requirements for Research Plans, Data, and Results

Existing disclosure requirements for scientists and engineers who are engaged in research and testing vary widely and depend on the researchers' affiliation, funding, field of study, and object of study. Such variability can give rise, in the field of geoengineering, to a lack of transparency, public distrust, or needless additional environmental impacts from duplicative research efforts, presenting problems for the governance of geoengineering research. One logical response would include "open access to SRM knowledge,"<sup>164</sup> or "a commitment to make public the existence of all SRM research activities" by "providing public notification of proposed field experiments and providing decisionmakers and the public with full access to the results of the research . . . (preferably through publication in refereed journals)."<sup>165</sup> Open access along these lines could help build societal trust in climate engineering.<sup>166</sup> Yet, depending on how much detail is publicized in advance of an experiment, it could also make it easy for opponents of research to attempt to disrupt it, so under some circumstances the exact time and place of experiments might not be disclosed. Scientists and policymakers can rely on research funding applications, publications, and similar media for sharing information about experiments' designs, protocols, and results.<sup>167</sup> Public disclosure of experiments also would not

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<sup>164</sup> M. Granger Morgan et al., *Needed: Research Guidelines for Solar Radiation Management*, XXIX Issues in Sci. & Tech., Spring 2013, at 37, <http://bit.ly/2aL9jBp>.

<sup>165</sup> *Id.*

<sup>166</sup> See Stefan Schäfer & Nigel Moore, Brief Summary of Workshop: Understanding Process Mechanisms for the Governance of SRM Field Experiments 7 (2014), [bit.ly/206Qeub](http://bit.ly/206Qeub); Blackstock et al., *supra* note 154, at 6–7.

<sup>167</sup> Blackstock et al., *supra* note 154, at 6–7.

substitute for the processes required to effectively engage the public in deliberations about SRM research as it relates to climate change management more generally.<sup>168</sup>

In sum, there is broad agreement that climate engineering research governance must provide for transparency, both among researchers themselves and between researchers, policy makers, and the public. Further, there is also broad agreement that this function is best performed by coordinating among multiple mechanisms—some new, some extant—rather than designating a single sluice as the channel through which all research information must flow. Whether or not compliance with the norm that all proposals, data, and analyses be made accessible is initially voluntary or immediately mandatory,<sup>169</sup> the lack of a unitary sluice for information cannot be taken as license to withhold or obscure the details of research efforts.

#### 4. Environmental Impact Assessments

As discussed in detail in Chapter 3 of this book, in the U.S., the National Environmental Policy Act requires a federal agency to assess environmental impacts before it may permit, license or fund any action significantly affecting the human environment.<sup>170</sup> Environmental impact statements (EISs) must be made public and allow for public comment in the administrative record.<sup>171</sup> The agency must consider the final version of that EIS as it makes decisions about the action.<sup>172</sup> Similar rules govern actions in the European Union and other jurisdictions,<sup>173</sup> and international law requires environmental assessment where environmental impacts could be felt across international boundaries.<sup>174</sup> Thus EISs are a readymade tool for a

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<sup>168</sup> *Id.*

<sup>169</sup> See Morgan et al., *supra* note 164, at 41–44 (weighing both options and recommending the first).

<sup>170</sup> 42 U.S.C. § 4332(2)(C).

<sup>171</sup> 43 CFR § 46.305(a) (Public involvement in the environmental assessment process).

<sup>172</sup> 40 CFR pt. 1503 (Commenting), § 1505.1 (Agency decisionmaking procedures).

<sup>173</sup> See generally Christopher Wood, *Environmental Impact Assessment: A Comparative Review* (2d ed. 2013) (discussing U.S., Canada, Britain, Australia, New Zealand, South Africa, Netherlands, and the European Union).

program of climate engineering research governance that seeks to adhere to the principle of public consultation discussed above. Reflecting that suitability, the London Convention/London Protocol's Assessment Framework for OIF experiments requires that any instance of OIF conducted for scientific research purposes be preceded by an environmental assessment process involving detailed disclosures of the experiment's goals, parameters, and expected effects to countries in the region of the proposed experiment.<sup>175</sup>

However, some aspects of EIA practice do not well fit the purpose of assessing the environmental impacts of climate engineering research. For one, the impacts of individual field tests may not rise to the level of significance necessary to trigger detailed analysis, even if some or all of those tests' impacts are considered cumulatively.<sup>176</sup> Similarly, should a class of experiment be exempted from impact assessments based on a categorical exclusion—such as the ones that the U.S. Department of Energy and National Science Foundation frequently issue for

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<sup>174</sup> *Pulp Mills on the River Uruguay (Arg. v. Uru.)*, Judgment, at 83 (Apr. 20, 2010), <http://bit.ly/1J2Ug2g> (“it may now be considered a requirement under general international law to undertake an environmental impact assessment where there is a risk that the proposed industrial activity may have a significant adverse impact in a transboundary context, in particular, on a shared resource.”); see also IASS Code of Conduct, *supra* note 56, at 71 (“As fundamentally a national instrument, EIA is entrenched in the domestic law of a large number of States.”).

<sup>175</sup> See International Maritime Organization, *Assessment Framework*, [bit.ly/239Z5gT](http://bit.ly/239Z5gT) (visited Jan. 18, 2016) (the Assessment Framework “does not contain a threshold below which experiments would be exempt from its assessment provisions. Every experiment, regardless of size or scale, should be assessed in accordance with the entire Assessment Framework.”); Resolution LC-LP.2(2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization (adopted Oct. 14, 2010), [bit.ly/1ndAQ0O](http://bit.ly/1ndAQ0O) (Framework itself is Annex 6 of the Resolution).

<sup>176</sup> IASS Code of Conduct, *supra* note 56, at 73 (“This draft Code recommends that all scientific research involving geoengineering conducted in the open environment should undergo a prior assessment.”); Nigel Moore et al., Inst. for Adv. Sustainability Studies, Workshop Report: Procedural Governance of Field Experiments in Solar Radiation Management 10 (Mar. 2015); see also Blackstock et al., *supra* note 154, at 4 (“EIAs would be particularly ineffective at the technology development and process study levels, because any environmental impacts arising from such small-scale experiments would likely be negligible and therefore fail to trigger full EIA processes; as such, there would be limited opportunities for public engagement.”).

weather-related research<sup>177</sup>—the law devised to ensure scrutiny and transparency could actually supply a means of *avoiding* impact assessment and public participation. Private funding, should it cause an experiment or research campaign to avoid the trigger of governmental involvement, could provide another potential means of avoiding the EIA process, barring a trigger based on other laws, such as pollution restrictions.<sup>178</sup>

Just as gaps in coverage by NEPA and similar laws might allow some research to go inappropriately unexamined, it is also possible that compliance with these laws could laden a particular experiment with costs and procedural burdens unwarranted by the risks and uncertainties that attend it, and so inhibit the advancement of knowledge.<sup>179</sup>

Issuance of a programmatic EIS (or the equivalent for non-U.S. jurisdictions) could ameliorate at least some of these gaps and mismatches by crafting a tiered review structure that takes into account the unusual purpose of climate engineering experiments, pays close attention to the potential accretion of cumulative impacts over the course of multiple experiments, and digests research proposals more quickly than could be expected if each experiment were reviewed as a unique action.<sup>180</sup> In addition to providing for a coherent assessment process in advance of experimentation, a programmatic EIS would make at least some interaction among scientists, regulators, political authorities, and the public mandatory in advance of field testing. This stricture might inspire discontent within the research community. It also would *not* provide a complete means of integrating scientific, political, and ethical priorities. Rather, it

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<sup>177</sup> Department of Energy, *Categorical Exclusion (CX) Determinations by CX*, [1.usa.gov/1L1eVPH](http://1.usa.gov/1L1eVPH) (visited Feb. 4, 2016) (listing seven categories of research activity to which categorical exclusions apply); 45 C.F.R. pt. 640.3 (discussing actions by or permitted or funded by NSF requiring an environmental assessment and categorical exclusions).

<sup>178</sup> Blackstock et al., *supra* note 154, at 4 (“policy makers should not assume a governmental action trigger, given both the potential for private funders to support experimentation and uncertainty regarding other regulatory triggers, such as permits for releases into air or water.”).

<sup>179</sup> See Larry Mayer, *Arctic Marine Research: The Perspective of a US Practitioner*, in *Arctic Science, International Law and Climate Change* 83, 93 (S. Wasum-Rainer, I. Winkelmann & K. Tiroch eds. 2012) (“In some cases the constraints of the environmental permitting process have delayed or prevented critical scientific studies.”).

<sup>180</sup> See Moore et al., *supra* note 176, at 13.

would likely serve as a resource on which to draw and a platform on which to base additional forms of review and public engagement.

## 5. Public Engagement

Just as “the consent of those who are affected by geoengineering research and deployment can confer legitimacy on the research and deployment or on the institutions in charge of geoengineering decision-making,”<sup>181</sup> a lack of consent—or even a perceived lack—can deprive geoengineering research of social license.<sup>182</sup> Although public consent to climate engineering research is difficult even to define,<sup>183</sup> much less to garner, some measure of consent—whether manifest through reasoned public approval by a government agency or a more direct means—is important to a viable program of climate engineering research in liberal democracies, and effective climate engineering research governance should entail public engagement.<sup>184</sup> However, as the experiences of researchers, government officials, and the public

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<sup>181</sup> Pak-Hang Wong, *Consenting to Geoengineering*, Philosophy & Tech. (published online June 7, 2015), <http://bit.ly/2aNAL2G>.

<sup>182</sup> See Jesse Reynolds, *The Regulation of Climate Engineering*, 3 L. Innovation & Tech. 113, 125 (2011) (“Given this complex political landscape, establishing legitimacy will be both crucial and difficult for any regulatory scheme.”); Adam Corner & Nick Pidgeon, *Geoengineering the Climate: the Social and Ethical Implications*, 52 *Env’t. Sci. & Pol’y for Sustainable Dev.* 24, 29 (2010) (“the prospect of [geoengineering] is something that all citizens could reasonably claim to have a legitimate stake in.”); IASS Code of Conduct, *supra* note 56, at 81 (noting calls in Aarhus Convention art. 1 and Rio Declaration principle 10 to states to guarantee information access).

<sup>183</sup> See Nick Pidgeon et al., *Deliberating stratospheric aerosols for climate geoengineering and the SPICE project*, 3 *Nature Climate Change* 451 (2013) (describing public engagement as a process of framing issues by posing basic questions, such as “What is a development for? What is the need? Who owns it? Who will be responsible if things go wrong?”); Wong, *supra* note 181 (discussing three models of public consent and two approaches to consent to geoengineering, and noting problems of resolving disagreements over issues underlying the choice of model while also seeking consent).

<sup>184</sup> See *id.*; UBA, *supra* note 55, at 131 (“A polarized debate ... would make it difficult for a state to adopt and implement any policy on geoengineering.”); Bodansky, *supra* note 4, at 547 (“Ultimately, the[] success [of nonbonding norms developed by scientists, social scientists, philosophers and lawyers] in forestalling more drastic regulation hinges on their public credibility, rather than on their legal status or source.”). For

with climate engineering experiments such as SPICE and the Haida Corporation's fertilization have demonstrated, it can be difficult to engage effectively with the public because the myriad concerns they express tend to focus not only on the risk posed by an experiment but also on its motives, the values it implies, and its implications for other priorities.<sup>185</sup> Such reactions are consistent with the characterization of climate engineering as not simply a technical capacity but "a socially constructed and contested phenomenon."<sup>186</sup> Because public reaction to the proposal or conduct of early climate engineering field experiments could, in the absence of established and tested governance mechanisms or institutions, function as a referendum on such experimentation,<sup>187</sup> the stakes of engaging the public well or badly are high.<sup>188</sup>

## 6. Managing Intellectual Property Rights

The usual tension between private and public interests in intellectual property is greatly heightened in the climate engineering context, where private research funding currently rivals

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discussion of the need for and role of public engagement in the process of commencing research into another new and contentious technology, see Jack Stilgoe et al., *Public Engagement with Biotechnologies Offers Lessons for the Governance of Geoengineering Research and Beyond*, 11 *Issues in Sci. & Tech.* 79 (2013).

<sup>185</sup> Pidgeon et al., *supra* note 183, at 452–54 (describing both general pattern and particular example of public's questions and doubts about SPICE); Jack Stilgoe et al., *Public engagement with biotechnologies offers lessons for the governance of geoengineering research and beyond*, 11 *PLoS Biology* 11 (2013) (describing how actual experiment was less concerning to public than what experiment represented); see also W. Carr et al., *Swimming upstream: Engaging the American public early on climate engineering*, 70 *Bull. of the Atomic Scientists* 38 (2014) ("such ideas are easier in theory than in practice. Meaningful public engagement can require more of scientists and regulatory agencies than many realize.").

<sup>186</sup> Bellamy, *supra* note 9, at 33; see also Macnaghten & Szerszynski, *supra* note 59, at 466 (challenging assumption "that debates around [SRM] are debates about a unified, stable, technological object ... rather than a more complex conversation in which the very nature of geoengineering is put into question.").

<sup>187</sup> Blackstock et al., *supra* note 154, at 6 ("without a politically agreed program of SRM research, any decision made on a single experiment could, in effect, turn that experiment into a political referendum on all further SRM research").

<sup>188</sup> See Carr et al., *supra* note 185, at 44 ("Upstream engagement does not necessarily guarantee better climate engineering science, technology, or regulation. The quality of the outcome depends on the effectiveness of the process itself."); Macnaghten & Szerszynski, *supra* note 59; A. Corner, *Perceptions of geoengineering: Public attitudes, stakeholder perspectives, and the challenge of 'upstream' engagement*, 3 *WIREs Climate Change* 451 (2012).

public funding in scale,<sup>189</sup> and where control of a technology's patent rights could mean partial control of the climate.<sup>190</sup> This tension led the Oxford Principles' authors to clarify how their call for regulation of climate engineering technologies as "a public good" would affect intellectual property rights:

There should [] be a presumption against exclusive control of geoengineering technology by private individuals or corporations. . . . [W]hilst [geoengineering's characterization as a public good] does not mean that there can be no intellectual property in geoengineering, it highlights that there might be a need for restrictions to ensure fair access to the benefits of geoengineering research.<sup>191</sup>

To answer the concerns informing this statement and those noted in Part II above, climate engineering research governance may need to steer around or wholly displace the normal operation of intellectual property law when it encounters climate engineering technologies and processes.

No one is publishing arguments in favor of a business-as-usual approach to intellectual property in the climate engineering context. (This is not surprising; most patent advocates instead quietly focus on building portfolios of claims before engaging in public debate.) Though proposals for intervention vary in their details, they share the basic premise that climate

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<sup>189</sup> See Fund for Innovative Climate and Energy Research, *Answers to Frequently Asked Questions*, stanford.io/1McyLso (visited Jan. 17, 2016) ("Q. What is the source and size of the fund? Who administers the fund? A. Since its inception in 2007, FICER has given out grants to 13 research projects and various scientific meetings totaling \$8.5 million. Internationally known climate scientists Dr. David Keith of Harvard University...and Dr. Ken Caldeira of the Carnegie Institution for Science select projects that receive support from the fund. While Mr. Gates provides input from time to time on the fund, Drs. Keith and Caldera make final decisions on projects."); GAO-10-903, *supra* note 6, at 18 ("We identified approximately \$100.9 million in geoengineering-related funding across USGCRP agencies in fiscal years 2009 and 2010, with about \$1.9 million of this amount related to research directly investigating a particular geoengineering approach.").

<sup>190</sup> See James Boyle & Jennifer Jenkins, *Intellectual Property: Law & The Information Society; Cases & Materials 2-3* (2014) (summarizing basic policy goals of IP law); Daniel Cressey, *Cancelled Project Spurs Debate over Geoengineering Patents*, *Nature: News*, May 23, 2012 (corrected May 24, 2012), <http://bit.ly/1JbNSjX>.

<sup>191</sup> Steve Rayner et al., *The Oxford Principles*, 121 *Climatic Change* 499, 505 (2013).

engineering research governance should limit the ability of individual private interests to exclude others from useful knowledge and know-how.<sup>192</sup> Under one such proposal, the U.S. Patent and Trademark Office would screen for climate engineering-related applications and place them in a compulsory patent pool.<sup>193</sup> Another proposal envisions crafting multiple, coordinated intellectual property mini-regimes, each specific to a particular climate engineering approach.<sup>194</sup> Yet a third proposal takes the U.S. approach to nuclear energy patents as a model for a *sui generis* climate engineering intellectual property regime,<sup>195</sup> and makes four specific recommendations with this model in mind.<sup>196</sup> A final proposal points to the suite of intellectual property policies employed by the European Organization for Nuclear Research, which successfully supports an “open science” model that does not eliminate intellectual property rights but privileges public dissemination if ever those two priorities collide.<sup>197</sup>

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<sup>192</sup> See, e.g., Arunabha Ghosh, *Environmental Institutions, International Research Programmes, and Lessons for Geoengineering Research*, *Geoengineering Our Climate?*, Working Paper, at 12–13 (Feb. 2014), [bit.ly/1mApChj](http://bit.ly/1mApChj) (“Government-funded research should [] remain in the public domain, while privately funded work should have limits on proprietary knowledge.”).

<sup>193</sup> Chavez, *supra* note 117, at 32.

<sup>194</sup> Aladdin Tingling Diakun, *Clearing the Air on ‘Geoengineering’ and Intellectual Property Rights: Towards a framework approach*, Master’s Research Paper presented to the University of Waterloo in fulfillment of the MRP requirement for the degree of Master of Arts in Global Governance 29 (2015) (“an effective analytical framework will ultimately need to evaluate the tradeoffs associated with IPRs and [geoengineering] on a case-by-case basis. In particular, the scale and distribution of potential impacts... as well as their relative intensity, will to a large degree determine how concerned we should be about IPRs.”).

<sup>195</sup> Parthasarathy et al., *supra* note 116, at 10–12 (discussing creation of Atomic Energy Commission by Atomic Energy Act of 1946 and Commission’s role in steering decisions about intellectual property protections).

<sup>196</sup> *Id.* at 12–13. Those recommendations are: (1) stop issuing broad patents; (2) create an interagency geoengineering patent task force; (3) add geoengineering to the existing sensitive application warning system within the PTO and require patent review by the Interagency Geoengineering Patent Task Force; and (4) offer non-patent based innovation incentives.

<sup>197</sup> Ghosh, *supra* note 192, at 12.

## 7. Liability

Because the effects of most approaches to climate engineering would be felt unevenly across geographies, populations, and generations, any climate engineering deployment can be expected to impose costs and deliver benefits disparately.<sup>198</sup> Having looked to other contexts in which human activity tends to yield similarly disparate outcomes, several authors have proposed regimes for defining, assigning, and enforcing liability among those who cause and those who are affected by the activity at issue.<sup>199</sup> Several factors present steep challenges to the successful operation of any such regime for climate engineering deployments, however,<sup>200</sup> chief among them the problem of determining causation.<sup>201</sup> As liability issues arising from climate engineering research activities do not differ in material ways from those arising from deployment (discussed in Chapter 5 of this volume), there is every reason to try to develop answers to all major liability questions in advance of significant research efforts.

### B. When

At what point should activities that qualify as “climate engineering research” receive heightened or particular oversight? Should it be as soon as the research gets the “climate engineering” label, such that even computer modeling activity could come within the compass of oversight? Or should it be only after the potential impacts of a given experiment are determined to be likely to exceed a particular impact threshold? Should moratoria apply until such time as key stakeholders agree to establish governance structures?

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<sup>198</sup> See, e.g., David Reichwein et al., *State Responsibility for Environmental Harm from Climate Engineering*, 5 *Climate Law* 142 (2015); Juan Moreno-Cruz et al., *A Simple Model to Account for Regional Inequalities for Solar Radiation Management*, 110 *Climate Change J.* 649 (2010).

<sup>199</sup> See, e.g., Joshua B. Horton et al., *Liability for Solar Geoengineering: Historical Precedents, Contemporary Innovations, and Governance Possibilities*, 22 *NYU Env'tl. L.J.* 225 (2015); M. Bunzl, *Geoengineering Harms and Compensation*, 4 *Stanford J.L., Sci. & Pol'y* 70 (2011).

<sup>200</sup> Toby Svoboda & Peter Irvine, *Ethical and Technical Challenges in Compensating for Harm Due to Solar Radiation Management Geoengineering*, 17 *Ethics, Pol'y & Env't* 157 (2014).

<sup>201</sup> *Id.* at 170; Pak-Hang Wong et al., *Compensation for Geoengineering Harms and No-Fault Climate Change Compensation*, Geoengineering Our Climate Working Paper No. 8 (2014), [bit.ly/1OzeoG4](http://bit.ly/1OzeoG4).

Answers to the foregoing questions vary for different approaches to climate engineering. Less is at stake in determining the phases of research for climate engineering approaches like direct air capture or afforestation whose potential adverse effects could be contained. As the National Research Council has observed, there is little doubt that one or more forms of CDR would be net beneficial and important for the purpose of restoring and maintaining the earth's carbon balance,<sup>202</sup> and as a result decisions about whether to deploy these approaches "will be largely based on cost and scalability" and less on the improved understanding of the risks presented by adverse side effects.<sup>203</sup> By contrast, approaches like stratospheric aerosol injection and marine cloud brightening have the potential to cause unknown amounts of incidental harm through complex and little understood mechanisms.<sup>204</sup> This disparity makes it important for experiments that must create the risk of harm to do so minimally, which in turn means structuring research phases with care. Accordingly, this section first discusses the phases of research particular to approaches whose potential adverse effects could not readily be contained (stratospheric aerosol injection, marine cloud brightening, OIF, and ocean alkalization) before turning to timing-related features of governance that potentially apply to all climate engineering approaches.

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<sup>202</sup> NRC, Carbon Removal, *supra* note 10, at 104.

<sup>203</sup> *Id.* at 110 ("In some contexts, it might be useful to treat various CDR proposals and albedo modification proposals jointly. This is especially true of those CDR approaches that raise novel risks and governance issues (e.g., ocean fertilization, ocean alkalization).").

<sup>204</sup> See, e.g., Douglas G. MacMartin et al., *On Solar Geoengineering and Climate Uncertainty*, 42 *Geophysical Res. Letters* 7156 (2015) (identifying uncertain parameters by examining discrepancies among model outputs); Robert Wood & Thomas P. Ackerman, *Defining Success and Limits of Field Experiments to Test Geoengineering by Marine Cloud Brightening*, 121 *Climatic Change* 459 (2013) (acknowledging multiple scientific uncertainties); see also Ben Parkes et al., *Crop Failure Rates in a Geoengineered Climate: Impact of Climate Change and Marine Cloud Brightening*, 10 *Envtl. Res. Letters* 5 (Aug. 2015), <http://bit.ly/1NOAztl> (inferring from model simulations expected effects of the increased cloud droplet formation caused by marine cloud brightening on crop failure rates in West Africa and China).

## 1. The Phases of SRM and OIF Research

The phases through which research into SRM technology would likely proceed are as follows:

- Laboratory — Useful to develop understanding of efficacies and risks well represented by laboratory experiments or computer or physical models;
- Technology development — Focused on hardware development and operations; no chemical processes;
- Process study — Micro-scale analysis of physical, chemical and, radiative processes; not going beyond the scale of natural perturbations;
- Scaling test — Conducted at the mesoscale level of 1 to 1,000 km<sup>2</sup>; intended to validate models and assess how processes may vary across scales;
- Climate response test — Designed to elicit a large-scale climate response.<sup>205</sup>

The first of these phases entails no environmental impacts; the second and third, if they entail any impacts, do not pose significant ones.<sup>206</sup> To illustrate the nature and utility of the third phase, one report offers the example of studying “the possible loss of stratospheric ozone in response to aerosol injection”:

The large-scale ozone response depends first on the small-scale physical and chemical interactions that determine how the chemistry of an air parcel evolves, and second on the large-scale atmospheric dynamics that transport constituents within the stratosphere. Most (but not all) of the uncertainty in predicting the response of ozone to injection of a novel kind of aerosol stems from uncertainty in small-scale processes so it is possible for small-scale experiments to reduce uncertainty in large-scale predictive models.<sup>207</sup>

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<sup>205</sup> David W. Keith et al., *supra* note 5, at 3 tbl.1; *see also* Blackstock et al., *supra* note 154, at 2–3 (describing similar stages of SRM research); SRMGI, *supra* note 62, at 45–54 (proposing similar “categories” of research); BPC Task Force, *supra* note 13, at 23 (“Any research should be conducted using a phased approach, starting with low-risk and low-cost exploratory research in the laboratory and only gradually considering larger-scale, higher-risk research (including field experiments) as more is understood about the technology.”).

<sup>206</sup> Jason J. Blackstock, The International Politics of Geoengineering, Memorandum submitted to House of Commons Sci. & Tech. Sub-Comm. (March 18, 2010), [bit.ly/1j7aLvE](http://bit.ly/1j7aLvE).

<sup>207</sup> Keith et al., *supra* note 5, at 4.

Thus, although impacts would vary among experiments undertaken to explore each of four climate engineering approaches considered here (i.e., those whose adverse impacts cannot readily be contained), it is generally true that only the commencement of field tests at the fourth phase promises non-negligible environmental impacts.<sup>208</sup>

## 2. The Phases of Geoengineering Research, in General

This sub-section discusses thresholds, moratoria, and the “allowed zone” for climate engineering research. These mechanisms are all potentially useful to the governance of research of any climate engineering approach.

*i. Thresholds.* Three broad categories of threshold pertain here: one relating to the scale of a given experiment, another relating to the state of the global climate, and the third relating to existence and nature of climate engineering governance institutions.

One proposal for scalar thresholds establishes numeric criteria for individual SRM experiments based on how much all SRM experiments in a given year would dim the sun (measured in watts per square meter or  $\text{Wm}^{-2}$ ), where they would do so, and for how long.<sup>209</sup> This threshold would pertain to the annual average effects of all SRM experiments, thereby limiting cumulative, worldwide “radiative forcing perturbation” in a given year.<sup>210</sup> In contrast to this ostensibly precise numeric dividing line,<sup>211</sup> the scalar threshold for OIF experiments

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<sup>208</sup> *Id.*; Blackstock, *supra* note 206.

<sup>209</sup> Parson & Keith, *supra* note 1 (proposing threshold based on “the product of area, duration, and size of radiative forcing perturbation”).

<sup>210</sup> *Id.*

<sup>211</sup> *But see* Integrated Assessment of Geoengineering Proposals, Briefing Paper No. 3: Decisionmaking for Geoengineering—Why Will It Be Challenging? 3 (2014) (“The ability to accurately detect and attribute changes in the climate should be a prerequisite for implementing geoengineering.”); NRC, Reflecting Sunlight, *supra* note 1, at 184 (“Current observing systems are insufficient to quantify the effects of any intervention at present. If albedo modification at climate-altering scales were ever to occur, it should be accompanied by an observing system that is appropriate for assessing the impacts of the deployment and informing subsequent actions.”).

exempted from the London Convention/London Protocol's prohibition on "dumping" takes the form of an environmental impact assessment without a predetermined numeric component.<sup>212</sup>

A second approach to establishing research thresholds would set limits based on the rate and degree to which the climate is changing. This approach would mark the tipping point at which the danger of failing to intervene in the global climate is felt to match or outweigh the danger of previously impermissible climate engineering experimentation or deployments. Because this threshold could take many forms, all of them uncertain, no one has yet suggested that national governments or the scientific or international communities should articulate it precisely.

The third type of threshold is less literal, and would be satisfied by the establishment and operation of governance mechanisms that satisfy particular criteria.<sup>213</sup> The draft Berlin Declaration—a statement about SRM that was presented, debated, but never finalized or agreed to by attendees at the 2014 Climate Engineering Conference<sup>214</sup>—articulates such a threshold in this way: "the establishment of an open and transparent review process.... At a minimum, such a review process should involve prior disclosure of research plans...."<sup>215</sup> The London Convention/London Protocol's imposition of the Assessment Framework satisfies this threshold for OIF.

As these types and examples reflect, thresholds could—and in the context of OIF do—describe the boundary within which climate engineering research field tests are agreed to be

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<sup>212</sup> International Maritime Organization, *Assessment Framework*, [bit.ly/239Z5gT](http://bit.ly/239Z5gT) (visited Jan. 18, 2016) (the Assessment Framework "does not contain a threshold below which experiments would be exempt from its assessment provisions. Every experiment, regardless of size or scale, should be assessed in accordance with the entire Assessment Framework."); Resolution LC-LP.2(2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization (adopted Oct. 14, 2010), [bit.ly/1ndAQ00](http://bit.ly/1ndAQ00) (Framework itself is Annex 6 of the Resolution).

<sup>213</sup> See, e.g., Jason J. Blackstock & Jane C.S. Long, *The Politics of Geoengineering*, 327 *Science* 527 (2010) ("Emerging national research programs—and even individual scientists—must forswear climatic impacts testing and carefully restrict subscale field-testing until approved by a broad, legitimate, international process.").

<sup>214</sup> Parker, Morton & Collins, *supra* note 148.

<sup>215</sup> Draft Proposed Berlin Declaration, [bit.ly/1Uzx2S0](http://bit.ly/1Uzx2S0).

safe. What the foregoing also makes clear is that thresholds can accomplish this goal only when they are combined with other governance mechanisms.

ii. *Moratoria—full or partial.* A moratorium differs from a ban in that a moratorium is temporary.<sup>216</sup> Nonetheless, it creates risks akin to those that attend outright permanent bans on climate engineering research—chiefly by inhibiting scientists who are likely to conduct research in a responsible manner,<sup>217</sup> but not necessarily those that are more likely to do so irresponsibly.<sup>218</sup> Thus most proposals for moratoria on one or more forms of climate engineering research call for *partial* moratoria,<sup>219</sup> or what the German Environment Agency calls a “general prohibition with exemptions.”<sup>220</sup> The London Convention/London Protocol governs OIF research and deployment in this way, albeit in legally nonbinding fashion, by maintaining a moratorium on all OIF unless it satisfies the LC/LP Assessment Framework. The same outcome could be accomplished for stratospheric aerosol injection and marine cloud brightening by placing a moratorium on any experiment or experiments that would have a cumulative worldwide diminishment of insolation above a threshold amount.<sup>221</sup>

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<sup>216</sup> Merriam-Webster’s Dictionary, [bit.ly/1SrKda0](http://bit.ly/1SrKda0) (visited Jan. 18, 2016) (“(1)(a) a legally authorized period of delay in the performance of a legal obligation or the payment of a debt (b) a waiting period set by an authority; (2) a suspension of activity.”).

<sup>217</sup> Attendees at the 2014 Climate Engineering Conference rejected the draft Berlin Declaration over several concerns, including that it could be read as requiring a halt to even modeling and laboratory research efforts. See Parker, Morton & Collins, *supra* note 148 .

<sup>218</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at (quoting Royal Society: “a moratorium . . . would make it almost impossible to accumulate the information necessary to make informed judgments” and “is likely to deter only those countries, firms and individuals who would be most likely to develop the technology in a responsible fashion, while failing to discourage potentially dangerous experimentation by less responsible parties.”); Daniel Bodansky, *Governing Climate Engineering: Scenarios for Analysis*, Harvard Project on Climate Agreements Discussion Paper at 22, Nov. 1, 2011, [bit.ly/1T0opTh](http://bit.ly/1T0opTh) (“A moratorium could thus have the perverse effect of leaving the field of geoengineering research to less responsible countries that ignore the moratorium and engage in riskier activities.”); BPC Task Force, *supra* note 13, at 29 (same).

<sup>219</sup> See, e.g., NRC, *Reflecting Sunlight*, *supra* note 1, at 133, 148; Draft Proposed Berlin Declaration, [bit.ly/1Uzx2S0](http://bit.ly/1Uzx2S0); Parson & Keith, *supra* note 1.

<sup>220</sup> UBA, *supra* note 55, at 21.

<sup>221</sup> Parson & Keith, *supra* note 1.

In addition to these actual and proposed moratoria which focus on the effects of climate engineering and its research, others, including NRC and the authors of the draft Berlin Declaration, have proposed moratoria on SRM field testing pending the establishment of an international research governance architecture.<sup>222</sup>

iii. An “allowed zone.” Integrating thresholds and moratoria in a way that is sensitive to concerns about needlessly impeding useful research leads to what has been called an “allowed zone.”<sup>223</sup> Much like a Categorical Exclusion under NEPA, that zone would pertain to “small experiments that operate within agreed, safe limits”<sup>224</sup> and would exempt researchers from facing more burdensome requirements that might accompany experiments which exceed those limits.<sup>225</sup> Importantly, it would not constitute an exemption from all governance measures, and indeed its existence would rely on an encompassing governance scheme that imposes at least reporting requirements on research into one or more climate engineering approaches.<sup>226</sup>

Thus an “allowed zone” need not give rise to concerns that imposing an artificial distinction between research and deployment could invite a slippery slope or lock-in scenario.

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<sup>222</sup> NRC, *Reflecting Sunlight*, *supra* note 1, at 184 (“If research and development on albedo modification were to be done at climate-altering scales, it should be carried out only as part of coordinated national or international planning, proceeding from smaller, less risky to larger, more risky projects; more risky projects should be undertaken only as information is collected to quantify the risks at each stage.”); Draft Proposed Berlin Declaration, [bit.ly/1Uzx2S0](http://bit.ly/1Uzx2S0).

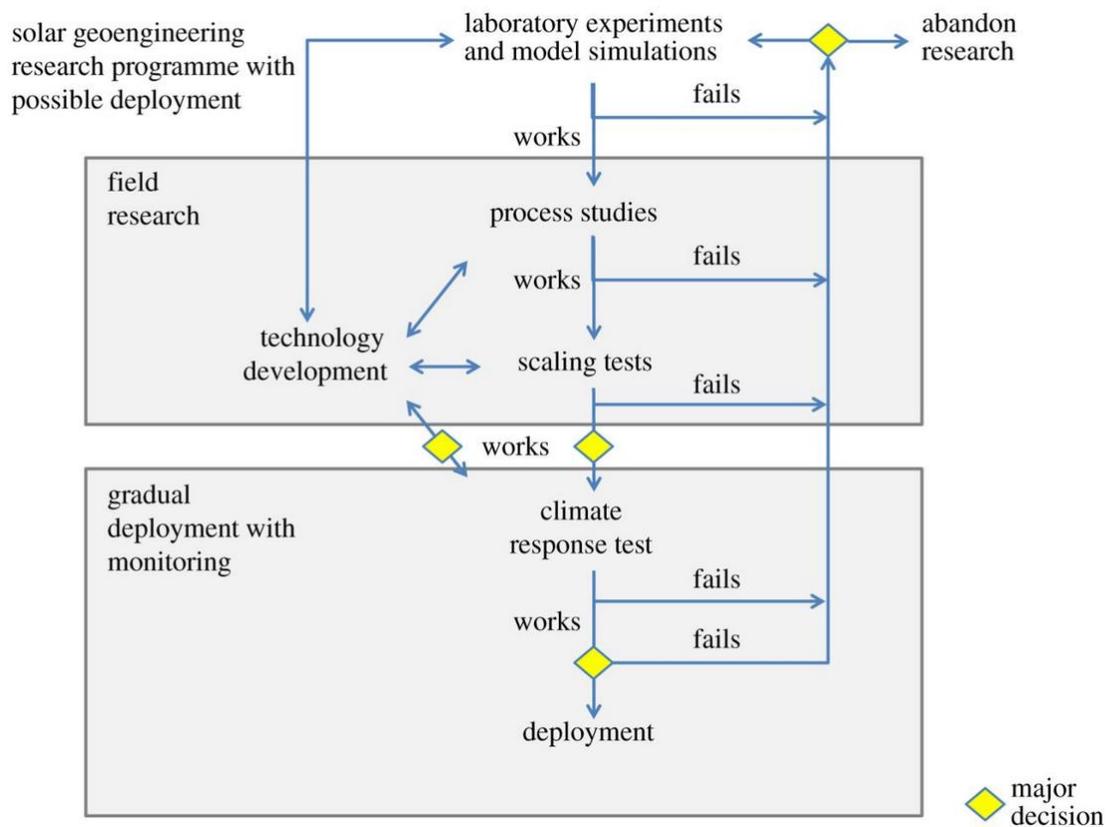
<sup>223</sup> *Geoengineering III: Domestic and International Research Governance: Hearing Before the H. Comm. on Sci. & Tech.*, 111<sup>th</sup> Cong. 273–77 (statement of Prof. M. Granger Morgan, Carnegie Mellon Univ.); *see also* SRMGI, *supra* note 62, at 55 (“take a ‘hands-off’ approach early in the research program and to gradually increase the extent of governance arrangements as research becomes increasingly risky, where risks are defined in terms of physical harms that may be caused by research and testing.”)

<sup>224</sup> SRMGI, *supra* note 62, at 49; *see also* Morgan & Ricke, *supra* note 14, at 18 (“An ‘allowed zone’ might be defined in terms of a number of different variables or factors, such as the amount of radiative forcing, the duration of the forcing, and the impact that the experiment might have on ozone destruction.”).

<sup>225</sup> Morgan & Ricke, *supra* note 14, at 18 (research in this zone should be allowed to proceed “without formal international approval, subject only to the requirements that their studies are publicly announced and all results are made public.”).

<sup>226</sup> *See* Morgan testimony, *supra* note 223, at 273 (proposing zone that would not impose any *new* checks in addition to existing environmental and other laws).

Rather, it fits nicely with a stepwise approach to climate engineering research governance that understands preliminary model-based and small-scale field testing phases to be part of, rather than distinct from, subsequent phases of larger-scale testing and potential deployment.<sup>227</sup> In a 2014 paper, Professor David Keith and his co-authors depict this sort of process schematically for SRM research (see Figure \_\_, below), and show how it would incorporate predetermined decision points and criteria for proceeding from laboratory testing to field testing, and from field testing to “gradual deployment with monitoring.”<sup>228</sup>



[FIGURE FROM KEITH ET AL. (2014)]

<sup>227</sup> Armeni & Redgwell, *supra* note 68, at 29–30; see also Caldeira & Keith, *supra* note 97 (suggesting similar).

<sup>228</sup> David W. Keith et al., *supra* note 5, at 5 (“A research programme should be sequential and iterative . . . , in the sense that one would not proceed to the next phase without a positive outcome from the prior phase. Determining that it is more difficult than expected to achieve desired outcomes, or that there are larger than expected undesired consequences would result in at least reconsideration and potentially a termination of any particular line of research”).

By incorporating perspectives informed by political as well as scientific priorities into decision points, such a process would also ensure that those decisions are legitimate as well as responsible, and that the process as a whole is designed to shut down particular lines of inquiry on either basis.

### C. By Whom

Climate engineering techniques—such as direct air capture and stratospheric aerosol injection, to name just two examples—are too unlike each other in terms of goals, containment of environment impacts, safety, scope of effect, and leverage for their research and deployment to be governed in the same way.<sup>229</sup> Accordingly, governance of climate engineering research is inevitably going to be “clumsy” because it will evolve toward oversight through an untidy compilation of overlapping authorities,<sup>230</sup> including international bodies, national governments, and the scientific community.<sup>231</sup> The Institute for Advanced Sustainability Studies’ commentary on its proposed Code of Conduct elaborates on this vision:

In terms of instrument choice, there are widespread calls for a flexible governance framework for research activities that interacts at multiple levels. There is also a need for an instrument that reaches beyond the traditional sphere of international law, in which States remain the principal actors, to involve other sectors of society, including intergovernmental and non-governmental organisations, companies, and scientific institutions, academies and individual scientists in order to respond to the transnational demands of climate governance.<sup>232</sup>

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<sup>229</sup> Armeni & Redgwell, *supra* note 68, at 36; SRMGI, *supra* note 62, at 25; *see also* Asilomar Recommendations, *supra* note 79, at 19 (“One potential simplifying mechanism would be to subdivide the approaches into categories with common potential risks (and so likely similar issues of governance).”).

<sup>230</sup> Bellamy, *supra* note 9, at 33; *see also* BPC Task Force, *supra* note 13, at 31 (calling for “an incremental but proactive approach to international engagement.”).

<sup>231</sup> *Id.*; *see also* Asilomar Recommendations, *supra* note 79, at 18 (“Recognizing the potential breadth of situations, a coordinated mix of types of oversight and governance likely has the potential to be most effective and accessible.”).

<sup>232</sup> IASS Code of Conduct, *supra* note 56, at 7.

As the IASS notes, the Food and Agriculture Organization's Code of Conduct for Responsible Fisheries may serve as a useful model for governing climate engineering research at this early stage. This is so because the FAO's code:

- Was negotiated by states, but directed at state and non-state actors, including members of the scientific community;
- Sought to provide a harmonizing instrument that would enhance governance, in part by facilitating the implementation of relevant existing agreements; and
- Recognized that it, a nonbinding guidance document, would foster subsequent iterations of governance rather than being the last word on fisheries governance.<sup>233</sup>

These points suit the present moment in climate engineering research governance, and may inform efforts to stitch together a comprehensive governance framework.

Such a framework must begin by matching up existing institutions to proposed climate engineering approaches based on those institutions' jurisdictions and competencies.<sup>234</sup> This match yields three groups of climate engineering approaches: 1) existing institutions, 2) adapted versions of existing institutions, and 3) new institutions for spaces where regulatory gaps exist.<sup>235</sup>

### 1. Governance by Existing Institutions

Research into boosting albedo using desert reflectors or other land-based forms of CDR can likely be governed adequately by existing scientific and governmental institutions.<sup>236</sup> Though these approaches vary in significant ways, on a research (as opposed to deployment) scale they all share high degrees of encapsulation and reversibility, low degrees of leverage or

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<sup>233</sup> *Id.* at 9–11.

<sup>234</sup> See Asilomar Recommendations, *supra* note 79, at 20 (“Developing an efficient and well-functioning system of review will probably require a mechanism for determining the specific institutional framework appropriate to evaluating activities of different scales and aggregate impacts.”).

<sup>235</sup> Peter Healey & Steve Rayner, Key Findings from the Climate Geoengineering Governance Project, CGG Working Paper no. 25, at 16 (Mar. 2015), <http://bit.ly/1IMVWTi>; see also NRC, Reflecting Sunlight, *supra* note 1, at 12 “[SRM] research is not specifically addressed by any federal laws or regulations.”).

<sup>236</sup> NRC, Carbon Removal, *supra* note 10, at 107–110 (recommending the US Global Change Research Program take responsibility for coordinating various CDR research efforts and concluding that “many proposed CDR approaches do not pose novel risks or governance issues (e.g., land management, bio-energy carbon capture and storage).”).

cost-effectiveness, and promise limited (if any) transboundary impacts.<sup>237</sup> As such, experimentation involving small or even mid-scale field testing will ordinarily not implicate international legal requirements related to transboundary harms.<sup>238</sup> Thus national governments and the scientific community are well positioned to monitor and coordinate such research, and to resolve disputes arising from its economic and environmental effects. This conclusion is not to say that national governments have grasped the nettle of climate engineering research governance (they have not),<sup>239</sup> but only that they are able to do so in a way that addresses the concerns and performs the functions described in Parts II and III.A above.

## 2. Governance by Adapted Institutions

The recent history of governance of research into OIF provides a helpful illustration of how adaptation by existing institutions can take place. It also provides something of a blueprint

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<sup>237</sup> Notably, some CDR methods, deployed on a large scale, could have significant environmental and transboundary impacts—for instance, large monoculture forests could threaten biodiversity; large-scale management of liquid or sequestered CO<sub>2</sub> could pollute adjacent surface or groundwaters; so too can waste products from amine-capture in industrial CDR.

<sup>238</sup> See *Pulp Mills*, *supra* note 74, at 203–219 (discussing when obligation to conduct environmental impact assessments obtains).

<sup>239</sup> The 2010 Joint Statement of the U.S. Congress and the House of Commons on geoengineering announced parallel hearings but nothing more. H.R. Comm. on Sci. & Tech., House of Commons Select Comm. on Sci. & Tech.: Collaboration and Coordination on Geoengineering, Joint Statement, Mar. 18, 2010. Since then, only a handful of U.S. government agencies have promulgated rules that can be read as contemplating geoengineering activities, and those examples do not mention geoengineering *research*. See Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO<sub>2</sub>), 75 Fed. Reg. 77229 (Dec. 10, 2010) (“This final rule applies to owners or operators of wells that will be used to inject CO<sub>2</sub> into the subsurface for the purpose of long-term storage.”). The German government, for its part, “does not intend to take an active role in supporting and funding research programmes in [geoengineering].” Chiara Armeni & Catherine Redgwell, *Geoengineering Under National Law: A Case Study of Germany*, CGG Working Paper No. 024, at 26 (Mar. 2015). The British Government has said that it is “too early to be able to establish appropriate regulatory frameworks for Geoengineering research or deployment,” because it remains unclear “what needs to be regulated and why.” UK Government Response to House of Commons Sci. & Tech. Comm. 5<sup>th</sup> Rep. of Sess. 2009-10: The Regulation of Geoengineering, at 1–2.

for possible adaptations for governing research into other climate engineering approaches, such as marine cloud brightening.<sup>240</sup>

In June 2007, Planktos, Inc., a for-profit entity seeking revenue from carbon offsets, planned to discharge 100 tons of iron dust into waters near the Galapagos.<sup>241</sup> The plan, which was never carried out, spurred the Scientific Group of the London Convention/London Protocol (LC/LP) to issue a Statement of Concern that called for the Contracting Parties to address OIF at their next meeting.<sup>242</sup> In 2008, the parties resolved that “ocean fertilization” is subject to the LC/LP and that, “given the present state of knowledge, ocean fertilization activities other than legitimate scientific research should not be allowed.”<sup>243</sup> That resolution also called for the Scientific Group to develop an assessment process for proposed projects. In October 2010 the parties issued the Assessment Framework for Scientific Research Involving Ocean Fertilization.<sup>244</sup>

In 2010, even while the LC/LP Scientific Group issued the OIF Assessment Framework and the parties to the Convention on Biological Diversity incorporated it by reference,<sup>245</sup> several members of United Nations Educational, Scientific and Cultural Organization (UNESCO)’s Intergovernmental Oceanographic Commission (IOC) resisted a proposal to give UNESCO oversight over OIF.<sup>246</sup> Those members—including the U.S., Britain, and India—prevailed in their argument that all salient aspects of OIF research governance were being overseen

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<sup>240</sup> See UBA, *supra* note 55, at 16 (“[beyond national waters], it is arguable but not clear that cloud brightening would fall under the UNCLOS provisions against marine pollution. The LP does not prohibit cloud brightening as long as sea water vapour is used and does not constitute dumping.”).

<sup>241</sup> Catherine Brahic, *Company plans ‘eco’ iron dump off Galapagos*, *New Scientist*, June 22, 2007, [bit.ly/1NhieSv](http://bit.ly/1NhieSv).

<sup>242</sup> LC-LP.1/Circ.14, Statement of concern regarding iron fertilization of the oceans to sequester CO<sub>2</sub>, July 13, 2007, [bit.ly/1V3qwD8](http://bit.ly/1V3qwD8).

<sup>243</sup> Resolution LC-LP.1(2008) on the Regulation of Ocean Fertilization (adopted Oct. 31, 2008), [bit.ly/1Q0scOo](http://bit.ly/1Q0scOo).

<sup>244</sup> Resolution LC-LP.2(2010) on the Assessment Framework for Scientific Research Involving Ocean Fertilization (adopted Oct. 14, 2010), [bit.ly/1ndAQ0O](http://bit.ly/1ndAQ0O) (Framework itself is Annex 6 of the Resolution).

<sup>245</sup> CBD COP decision IX/16 C; X/29 para 13(e) and 57-62; X/33 para 8(w)-(x).

<sup>246</sup> See UBA, *supra* note 55, at 157.

adequately pursuant to the LC/LP, and the IOC's input should be scientific only.<sup>247</sup> As subsequent experience with the Haida Corporation and Canadian government in 2012 demonstrated,<sup>248</sup> however, this consolidation of jurisdictional authority over OIF and related research still relied entirely on national governments to monitor and enforce compliance with the LC/LP—a legally nonbinding regime.<sup>249</sup>

This series of steps sorted out which international body would take responsibility for guiding decisions about OIF research, educated national governments about their role in implementing that guidance, and also informed the NGO and scientific communities about the legal aspects of OIF research governance. In sum, while the unfolding of these steps appears somewhat messy in retrospect, it is also clear that existing national and international institutions adapted themselves quickly—or at least not slowly—to fill a gap in governance.

### 3. Governance Gaps for Which New Institutions are Needed

To be effective, the governance of climate engineering research that has potentially significant transboundary impacts must restrict, encourage, and steer various activities, and must do so in a way that provides for scientific certainty, political and international legitimacy, and mechanisms for dispute resolution.<sup>250</sup> No national governments or international bodies have as yet equipped themselves to handle this composite task. As discussed at length in Chapter 4 of this volume, several U.S. laws would likely require the review and permitting of stratospheric aerosol injection activities that occur within U.S. jurisdiction. The same is true of

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<sup>247</sup> See UNESCO Doc. IOC-XXV/3 ¶142; UNESCO Intergovernmental Oceanographic Commission (IOC), Report of the Forty-third Session of the Executive Council, Paris, June 8–16, 2010; UNESCO Doc. IOC/EC-XLIII/3 ¶155 and Annex IX at 19 (2010); see also D. Wallace, *Ocean Fertilization: A Scientific Summary for Policy Makers*, IOC/BRO/2010/2 (2010), [bit.ly/1ZB2BBF](http://bit.ly/1ZB2BBF).

<sup>248</sup> Martin Lukacs, *Canadian Government 'Knew of Plans to Dump Iron into the Pacific'*, *The Guardian*, Oct. 17, 2012, [bit.ly/1nup8yT](http://bit.ly/1nup8yT).

<sup>249</sup> See Bodansky, *supra* note 218, at 17 (noting persistent need for action on the part of national governments with respect to OIF, even after 2008 adoption of resolution under London Convention).

<sup>250</sup> See Ghosh, *supra* note 192 (tabulating tasks involved in international governance of geoengineering research).

laws in Germany<sup>251</sup> and Britain,<sup>252</sup> and presumably in many other jurisdictions as well. But multiple pieces must fit together to govern climate engineering research effectively. Relying on inchoate and mismatched protections such as national laws currently provide will not address all of the concerns that surround climate engineering research.

Similarly, while several international agreements would seem to be candidates for filling the governance gap created by those activities' transboundary, atmospheric effects, multiple analyses have considered and rejected them all.<sup>253</sup> For instance, the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and its parent agreement, the Vienna Convention on the Protection of the Ozone Layer, *could* provide regulatory oversight,<sup>254</sup> but these agreements concern only the restoration and protection of the ozone layer and seek to facilitate the substitution of mature single-use technologies, and they do not address the enormous question of whether and how to intervene in the operation of the climate.<sup>255</sup> Similarly, the 1984 and 1995 Protocols to the 1979 Convention on Long-Range Transboundary Air Pollution, which impose binding limits on sulfur dioxide emissions and so already in effect govern sulfate aerosol injection in some contexts, are clearly a mismatch for climate engineering research governance: the Convention and its Protocols are oriented to protect "against air pollution," seek to "gradually reduce and prevent air pollution including long-range transboundary air pollution,"<sup>256</sup> and impose thresholds far above the levels contemplated by even mezo-scale field

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<sup>251</sup> UBA, *supra* note 55, at 19.

<sup>252</sup> Armeni & Redgwell, *supra* note 68, at 31–37.

<sup>253</sup> See, e.g., Ghosh, *supra* note 192, at 13 ("although several multilateral environmental treaties might have some relevance to geoengineering, there is a governance gap when it comes to research. Depending on the scale and scope of research, field testing and deployment, there are several aspects that could benefit from internationally coordinated efforts."); UBA, *supra* note 55, at 22–23 (examining and rejecting as candidates all existing international agreements relating to protection of the atmosphere).

<sup>254</sup> Bodansky, *supra* note 218, at 18 ("Since research to date suggests that sulfur aerosols are likely to modify the ozone layer, they fall within the ambit of the ozone regime and could potentially be regulated by the Montreal Protocol.").

<sup>255</sup> See SRMGI, *supra* note 62, Appendix at 9–10.

<sup>256</sup> Convention on Long-Range Transboundary Air Pollution art. 2, [bit.ly/1Aj8Ibr](http://bit.ly/1Aj8Ibr).

testing.<sup>257</sup> A third example, the UNFCCC, is in many respects ideally suited to perform climate engineering research governance functions: it is climate-oriented, established, capable of addressing scientific and political issues, and it has nearly universal participation among states. However, several analyses reject it because it was created chiefly to pursue climate change *mitigation*<sup>258</sup> and it carries out its mandates through a time-consuming consensus-based process.<sup>259</sup> Finally, the Outer Space Treaty of 1967 has a narrow focus and no dedicated secretariat or other institutional infrastructure.<sup>260</sup>

SRMGI, established by the Royal Society, Environmental Defense Fund, and the World Academy of Sciences in 2010 to begin a discussion about “effective governance arrangements for potentially risky research,”<sup>261</sup> has arguably done just that. However, that discussion has not yet given rise to purpose-built governance institutions at the national or international level.

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<sup>257</sup> Bodansky, *supra* note 218, at 18. The volume of sulfate aerosols required for effective SRM deployment has been estimated to be roughly 3.5 kilotons per year, depending on the particulates used. See David W. Keith & Douglas G. MacMartin, *A temporary, moderate and responsive scenario for solar geoengineering*, Nature Climate Change (Feb. 2015), doi: 10.1038/nclimate2493, <http://bit.ly/29yOeLa>. Compare that to the 2010 emissions limitations for parties to the Convention on Long-Range Transboundary Air Pollution: the United Kingdom was limited to 980 kilotons per year, Russia to 4,297. See Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions, Annex II (1994), [bit.ly/1VhvsGX](http://bit.ly/1VhvsGX).

<sup>258</sup> UBA, *supra*, note 55, at 23 (“the institutional logic of the UNFCCC is directed at combating climate change . . . . As a result, it might be intrinsically difficult . . . to pursue a precautionary approach that is *restrictive* to geoengineering. In addition, geoengineering does not fit easily with the overall approach of the UNFCCC aimed at mitigating greenhouse gas emissions and adapting to the impacts of climate change. The UNFCCC may thus best be considered a complementary forum that may be suitable for incentivising any ‘encapsulated’ geoengineering activities.”).

<sup>259</sup> SRMGI, *supra* note 62, at Appendix 6 (“The Achilles’ heel of UNFCCC governance is its slow decisionmaking process and overburdened agenda. The Conference of the Parties (COP) has adopted a consensus-based (or at least consensus minus one) decision-making approach, which means that there is considerable diplomatic leeway for a small number of states to block decisions approved by the majority, and – crucially for SRM – to cause gridlock on all novel issues.”).

<sup>260</sup> Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other Celestial Bodies 9 ILM (1967); see also Armeni & Redgwell, *supra* note 68, at 18, 26.

<sup>261</sup> *Id.* at 10.

National governments have established several possible models for gap-filling institutions, capable of providing for international coordination and oversight of the development of other new and consequential technologies, such as nuclear power development,<sup>262</sup> nuclear waste disposal,<sup>263</sup> and, most recently, of genetically modified organisms.<sup>264</sup> To date, however, and notwithstanding increasingly frequent calls to do so,<sup>265</sup> national governments and international bodies have, at best, only begun to create effective climate engineering governance norms, mechanisms, and institutions for those climate engineering approaches that are most likely to be both effective and dangerous.

## Conclusion

There is broad agreement that climate engineering research must be governed, yet this consensus has failed to spur substantial efforts by national or international actors to create and administer appropriate forms of governance. London Convention/London Protocol Resolutions on ocean iron fertilization research represent a partial exception to this point—and they would be wholly exceptional if national governments would act to implement those resolutions' key provisions. The lack of governance has variable effects: it stymies some research efforts while failing to touch others. But climate engineering proposals cannot simply be ignored. Rather, as

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<sup>262</sup> See Ghosh, *supra* note 192, at 7–8 (describing European Organization for Nuclear Research and International Thermonuclear Experimental Reactor as partial models geoengineering research governance).

<sup>263</sup> World Nuclear Association, International Nuclear Waste Disposal Concepts, [bit.ly/1ZK18cu](http://bit.ly/1ZK18cu) (updated May 2016) (discussing EU resolution to establish European Repository Development Organisation); K. Smith et al., *BIOPROTA: international collaboration in biosphere research for radioactive waste disposal*, 76 *Mineralogical Mag.* 3233 (2012), [bit.ly/1lr2Psc](http://bit.ly/1lr2Psc) (“In 2012 there are 20 funding organizations in 14 countries from East Asia, Europe and North America, with additional participation from associated technical support organizations and research institutions.”).

<sup>264</sup> John Komen, *The Emerging International Regulatory Framework for Biotechnology*, 3 *GM Crops & Food: Biotechnology in Agriculture and the Food Chain* 78 (2012) (focusing discussion on Convention on Biological Diversity and Cartagena Protocol on Biosafety).

<sup>265</sup> See, e.g., NRC, *Reflecting Sunlight*, *supra* note 1, at 154; Jane C. S. Long et al., *Start Research on Climate Engineering*, 518 *Nature* 29 (Feb. 5, 2015) (“governance and experimentation must co-evolve.”); Parson & Keith, *supra* note 2, at 1278.

the effects of climate change grow increasingly severe, and as the need to find non-conventional means to address global greenhouse gas concentrations grows pressingly urgent, it seems quite likely that climate engineering research—including field tests that verge on deployment—will also become more prevalent. The lack of an effective governance regime could leave the climate engineering research community, and the societies potentially affected by its decisions, susceptible to the various concerns noted in Section 2 above, including moral hazard, forum shopping, slippery slopes, governance traps and international tensions, or even conflicts among nations. Accordingly, there is a very real and increasingly urgent need to answer the key questions surrounding governance: what qualifies as climate engineering research subject to governance, at what point do governance requirements kick in, what substantive rules should apply, and who should do the governing. Though this chapter provides no definitive answers to these questions, it has sought to map the terrain for researchers and decision-makers and to explain the importance of moving ahead.