**Climate Engineering in Global Climate Governance:
Implications for Participation and Linkage**

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Abstract:

The prospect of climate engineering (CE)—modification of the global environment to partly offset climate change and impacts from elevated atmospheric greenhouse gases—poses major, disruptive challenges to international policy and governance. If full global cooperation to manage climate change is not initially achievable, adding CE to the agenda has major effects on the challenges and risks associated with alternative configurations of participation, e.g., variants of partial cooperation, unilateral action, and exclusion. Although risks of unilateral CE by small states or non-state actors have been over-stated, a dozen-odd powerful states may be able to pursue CE unilaterally, risking international destabilization and conflict. These risks are not limited to future CE deployment, but may also be triggered by unilateral R&D, secrecy about intentions and capabilities, or assertion of legal rights of unilateral action. They may be reduced by early cooperative steps such as international R&D collaboration and open sharing of information. CE presents novel opportunities for explicit bargaining linkages within a complete climate response. Four CE-mitigation linkage scenarios suggest how CE may enhance mitigation incentives, not weaken them as commonly assumed. Such synergy appears challenging if CE is treated only as a contingent response to a future climate crisis, but may be more achievable if CE is used earlier and at lower intensity, either to reduce peak near-term climate disruption in parallel with a program of deep emission cuts or to target regional climate processes linked to acute global risks.

Keywords: climate engineering; geoengineering; mitigation; bargaining linkage; climate scenarios; international governance;

1. INTRODUCTION AND CONTEXT

In global climate-change policy debates, the familiar dichotomy of two types of response—mitigation (reducing emissions of carbon dioxide and other greenhouse gases that are causing climate change) and adaptation (reducing harmful impacts from realized climate changes)—is being disrupted by the appearance of a third form of response, climate engineering. Climate engineering (CE), also called geoengineering, consists of intentional, engineered measures to actively change the global climate system and so

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reduce the realized climate changes that result from elevated greenhouse gases.[2] CE is not a new idea: It was first proposed as a response to anthropogenic climate change in the 1960s, and mentioned in multiple assessments over subsequent decades.[3] But CE has re-appeared in policy debates over the past several years, triggered by several sources of concern—including the growth of evident climate-change impacts, continued failure of mitigation efforts, and continuing scientific uncertainties that suggest even a shift to extreme mitigation would only reduce, not eliminate, risks of severe climate-change impacts. CE is highly controversial, and is not yet being explicitly addressed in international climate negotiations, but probably soon will be, and should be, on the international policy agenda. In its effect on climate response and policy debates, CE is a disruptive technology, presenting risks and opportunities that are large, novel, and deeply challenging to international law and governance.

Other contributions have begun to investigate the general governance challenges posed by CE.[4] In this paper, I address the previously unexamined question of how CE will affect issues related to the configuration of international cooperation on climate change. To date, the main focus of both diplomatic efforts and academic studies has been full global cooperation. While this focus makes sense given the global scale of the causes and consequences of climate change, alternative configurations of cooperation and participation must be considered if full global cooperation is not achievable, or not achievable initially—as the failure of more than two decades of diplomatic effort thus far suggests.

What specific alternatives to global cooperation must be considered? The theme of this volume, 'Climate Policy without the United States', examines one instance of a major class of alternatives, partial-cooperation approaches in which some states take coordinated action but others stand aside. Such partial-cooperation alternatives, including the specific case of cooperation without the US, have been periodically discussed since soon after the emergence of climate on policy agendas in the late 1980s.[5] They are the main alternatives to global cooperation that must be considered if climate policy is taken exclusively or predominantly to mean mitigation, but the situation changes with a broader

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2 D.W. Keith, 'Geoengineering the Climate: History and Prospect' (2000) 25(1) *Annual Review of Energy and the Environment*, pp. 245-84, at 245; J.G. Shepherd et al., *Geoengineering the climate: science, governance and uncertainty* (The Royal Society, 2009), at p. 1.

3 See, e.g., Environmental Pollution Panel, *Restoring the Quality of Our Environment* (President's Science Advisory Council, 1965); T. C. Schelling, 'Climatic Change: Implications for Welfare and Policy,' in US Nat'l Research Council, *Changing Climate* (National Academies Press, 1983), pp. 449 -82; US Nat'l Research Council, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (National Academies Press, 1992); D.W. Keith, n.2 above.

4 E.A. Parson & L.N. Ernst, 'International Governance of Climate Engineering' (2013) 14(1) *Theoretical Inquires in Law*, pp. 307-38; E. Parson et al., '"Mechanics" of SRM Research Governance'. Background Paper for the Solar Radiation Management Governance Initiative, March 2011. Available at: http://www.srmgi.org/files/2011/09/SRMGI-Mechanics-background-paper.pdf.

5 See, e.g., S. Barrett, *Environment and Statecraft* (Oxford U. Press, 2003); C. Kemfert, 'Climate coalitions and international trade' (2004) 32(1) *Energy Policy*, pp. 455-65; J. Aldy & R. Stavins, *Architectures for Agreement* (Cambridge U. Press, 2007); J. Hovi et al., 'Implementing Long-Term Climate Policy' (2009) 9(3) *Global Envt. Politics*, pp. 20-39; T. Bernauer, 'Climate Change Politics' (2013) 16(1) *Ann. Rev. of Political Science*, pp. 421-48.

policy agenda that includes CE. With this broader agenda, global cooperation still commands attention as a preferred approach. But if it is not attainable and alternatives must be considered, this broader substantive policy agenda requires considering a different set of alternative configurations of participation and non-participation. This paper makes a preliminary, admittedly speculative, examination of these issues: how does the addition of CE to the climate policy agenda change salient configurations of participation and non-participation; how might these configurations develop, and what novel risks or opportunities do they present; and what priorities for research and analysis follow from this new perspective?

Section 2 introduces the major technical approaches to CE, and outlines the three basic characteristics that shape the nature and severity of the challenges they pose to international law and governance. Section 3 examines CE's effects on questions of participation, initially treating CE as separate from other elements of climate response. Under this rather artificial assumption, the most prominent issues concern the potential for, risks of, and control of, unilateral pursuit of CE by major states. Section 4 considers CE in the context of a complete response to climate change, focusing on potential ways to build constructive bargaining linkages between CE and mitigation. It proposes four speculative linkage scenarios by which CE might enhance rather than undermine mitigation incentives. Section 5 draws tentative conclusions and identifies research priorities suggested by this preliminary investigation.

2. CLIMATE ENGINEERING TECHNOLOGIES AND THEIR POLICY-RELEVANT CHARACTERISTICS

Climate engineering (CE) means interventions that modify global-scale properties of the Earth's environment in order to counteract the heating and climate disruption caused by elevated atmospheric concentrations of greenhouse gases.[6] Many specific forms of CE intervention have been proposed, which fall into two broad classes: interventions in the global carbon cycle that reduce the atmospheric concentration of CO_2; and interventions in the Earth's radiation balance that reduce the amount of sunlight absorbed at the Earth's surface, thereby offsetting the aggregate heating caused by elevated greenhouse gases.

The approach that now seems most promising and is receiving most attention is stratospheric aerosol injection: spraying a fine mist of light-colored or reflective particles, e.g., sulfate aerosols, into the stratosphere. Viewed from Earth, this would make the sun appear a little dimmer (by about 1%), and the sky a little brighter and whiter. Although research may identify other approaches that are preferred, stratospheric aerosol injection has certain characteristics that clearly illustrate the policy and strategic challenges likely to be posed by any radiation-based CE. Its underlying scientific principles are well

6 See, e.g., Asilomar Scientific Organizing Committee, *The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques* (Climate Institute, 2010); National Research Council (US), *Advancing the Science of Climate Change: America's Climate Choices* (National Academies Press, 2010), at pp. 377-88; Shepherd et al., n. 2 above, at p. 1; Bipartisan Policy Center, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies* (Bipartisan Policy Center, 2011), at p. 3.

understood, as are the basic engineering approaches by which it would be implemented. Consequently, it could be done today, albeit crudely, with current knowledge and technology. Nature provides clear analogues for how such interventions would work, in the occasional explosive volcanic eruptions that inject large quantities of sulfur into the stratosphere—most recently the 1991 eruption of Mt. Pinatubo in the Philippines, which cooled the Earth about half a degree Celsius over the following year or two.[7]

Research is needed to study the many uncertainties about how specific CE interventions would work, their effects and risks—including, crucially, the regional and seasonal distribution of effects. Preliminary studies of these issues are underway—mostly laboratory and computer-model studies, but also a few small field experiments of atmospheric aerosols and other proposed approaches such as ocean fertilization. Early efforts to create explicit research programs are also underway in a few jurisdictions, as are various 'dual-use' studies that investigate CE capabilities and effects, but which also address other scientific questions. Since much of the field research to develop and inform CE capabilities can be done with small-scale interventions that are essentially riskless—indeed, many proposed experiments would resemble existing projects in small-scale weather modification, or the inadvertent impacts of normal commercial activities such as aviation and shipping—small-scale CE research would be hard to detect from a distance, so it is possible that other experimental interventions have already been undertaken.[8]

For purposes of understanding their role in societal response to climate change, CE technologies have three salient characteristics: they are fast, cheap, and imperfect.[9] Climate engineering is fast. A manageable scale of intervention by means already known, involving one or two hundred transport aircraft in continuous operation, could cool the Earth 1–2°C within a few years.[10] Consequently, an effective intervention could be deployed to arrest or reverse global heating even after it was known that rapid change or severe impacts were underway. Radiation-based CE is the only known response capable of such rapid effect: achieving a similar effect through even an extreme program of emission cuts, or by removing CO_2 from the atmosphere, would take decades. This capability for rapid action is the principal way, although not the only one, that CE offers a large expansion in human capability to limit risks of climate change.

Climate engineering is cheap. Estimates of the direct cost of offsetting projected twenty-first century global-average heating are of order a few billion dollars per year,[11] and are likely to decrease with further research and development of approaches. Various commentators have proposed that, for considering the strategic implications of these

[7] B.J. Soden et al., 'Global Cooling After the Eruption of Mount Pinatubo: A Test of Climate Feedback by Water Vapor' (2002) 296(5568) *Science*, pp. 727-30, at 727.

[8] E.A. Parson & D.W. Keith, 'End the Deadlock on Governance of Geoengineering Research' (2013) 339(6131) *Science*, pp.1278-9.

[9] D.W. Keith, E.A. Parson & M.G. Morgan, 'Research on Global Sun Block Needed Now' (2009) 463(28) *Nature*, pp. 426-7, at 426.

[10] J. McClellan et al., *Geoengineering Cost Analysis: Final Report* (Aurora Flight Sciences Corporation, 2011); J. R. Pierce et al., 'Efficient Formation of Stratospheric Aerosol for Climate Engineering by Emission of Condensable Vapor from Aircraft' (2010) 37(18) *Geophysical Research Letters*, pp. 1-5.

[11] McClellan et al., n. 8 above.

technologies, it is a useful approximation to consider their cost as zero.[12] While normally it is an advantage if a potentially desired option is cheap, in this case low cost is a double-edged sword, with two potentially destructive consequences. First, it has deluded some observers into a stance of naïve cheerleading for the technologies.[13] This in turn has raised concerns about excessive reliance on CE as a complete response to climate change —which it emphatically cannot be, for reasons noted below—further weakening the already inadequate support for cutting emissions. Second, CE's low cost raises problems of control by putting it within reach of more actors. Although I argue below that the prospects for unilateral CE by small states or non-state actors have been overstated, CE is still more widely available than past examples of potentially destabilizing technologies, of which the most relevant parallels are novel weapons capabilities.

Finally, CE offers only a highly imperfect corrective for the environmental effects of elevated greenhouse gases. Their correction is imperfect even if only their global-average climate effect is considered, because CE counteracts a heating that occurs aloft by a cooling at the Earth's surface, where the blocked sunlight would otherwise have been absorbed. The result is that CE controls precipitation more strongly than temperature, so a world in which CE fully offsets average greenhouse heating would have a climate drier than the starting climate.[14] These global average differences cascade to diverse, albeit uncertain, differences in regional and seasonal climate effects.[15] In addition, CE does nothing to counteract the non-climate (i.e., chemical and biological) effects of elevated CO_2, including making the oceans more acidic, and disrupting competitive relationships between different types of plants with different responses to increased CO_2.[16]

These three characteristics—fast, cheap, and imperfect—outline the basic governance and policy challenges posed by CE. Considered together, they present an acute tension: like all technological expansions of human capabilities, CE may offer the prospect of either large benefits – reducing the climate-change risks we otherwise face – or large harms, depending on how it is used and how it influences related choices. Used prudently and benevolently, it may bring large benefits of multiple forms. It can provide a contingency response to a future climate emergency, as discussed above; it can also be used earlier and less intensely, to shave the peak off projected near-term heating while a serious mitigation effort is ramped up, thereby reducing the cost of a global transition to climate-safe energy sources; or it can be targeted to reduce specific high-priority regional or seasonal risks, such as cooling Arctic summers to slow the loss of sea ice, or cooling

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12 S. Barrett, 'The Incredible Economics of Geoengineering' (2008) 39(1) *Environmental and Resource Economics*, pp. 45-54, at 49; Keith et al., n.7 above.

13 E. Teller et al., *Active Climate Stabilization: Practical Physics-based Approaches to Prevention of Climate Change* (Lawrence Livermore National Laboratory, 2002); S.D. Levitt & S.J. Dubner, *SuperFreakonomics: Global Cooling, Patriotic Prostitutes, and Why Suicide Bombers Should Buy Life Insurance* (Harper Collins, 2009), at pp. 235-300.

14 G. Bala et al., 'Impact of Geoengineering Schemes on the Global Hydrological Cycle' (2008) 105(22) *Proceedings of the National Academy of Sciences*, pp. 7664-9, at 7664.

15 A. Robock et al., 'Regional Climate Responses to Geoengineering with Tropical and Arctic SO_2 Injections' (2008) 113(D16) *Journal of Geophysical Research: Atmospheres (1984-2012)*, D16101.

16 S.C. Doney et al., 'Ocean Acidification: The Other CO_2 Problem' (2009) 1 *Marine Science*, pp. 169-92.

tropical oceans to block formation of the highest-energy hurricanes.[17] But used incompetently, negligently, or destructively, CE technologies may make matters much worse. They thus present new needs, and new challenges, for governance and control, to pursue the benefits and minimize the harms they hold.

3. UNILATERALISM AND MULTILATERALISM IN CLIMATE ENGINEERING

When CE is added to the set of potential responses to climate change, the aspiration for global cooperation still exerts powerful attraction, perhaps even more than when policy is just mitigation. Early discussions suggest that every group that takes the prospect of CE seriously asserts the importance of broad consultation and participation in decision-making.[18] But if global cooperation appears unattainable, CE requires considering a different set of alternative configurations of participation and non-participation than when climate policy is just mitigation. Partial cooperation approaches are still relevant, but various configurations of unilateral action, by the US or other states, must also be considered. So too must scenarios of involuntary non-participation, or exclusion, of some states. This section begins exploring these possibilities, initially and somewhat artificially treating governance of CE as separate from other elements of climate policy. The next section adds more realism by considering complete climate responses that include CE with linkages to other response elements, particularly to mitigation. The discussion is unavoidably speculative, but it aims to use the speculation to identify key uncertainties that require investigation, and to discipline the speculation by anchoring it to current knowledge, particularly about characteristics of CE technologies relevant to state capabilities and interests.

Considering CE governance separately from other elements of climate policy, the most prominent alternative to global cooperation that must be considered is unilateral action. This section considers unilateral action from the perspectives of international law, state capabilities, and state interests.

3.1 Current International Law and Climate Engineering

Present international law imposes virtually no control on any state's conduct of most forms of CE, whether conducted for purposes of research or operational climate modification. Multiple regimes are relevant but none meaningfully constrains CE, with

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17 M.C. MacCracken, 'On the Possible Use of Geoengineering to Moderate Specific Climate Change Impacts' (2009) 4(4) *Environmental Research Letters*, 045107.

18 See, e.g., informal consultations undertaken by SRMGI (e.g., at http://www.srmgi.org/events/african-involvement-in-solar-geoengineering/); discussions at geoengineering side events at Copenhagen climate meetings, December 2009 (presentation slides and video of discussions at http://www.cigionline.org/articles/2009/12/cop-15-side-event-international-governance-geoengineering-research); UK public dialogue on geoengineering (summary report available at http://www.nerc.ac.uk/about/consult/geoengineering-dialogue-final-report.pdf.

the result that any state may legally conduct CE, on or over its own territory, or that of other consenting states, or over the high seas.[19]

The reasons for this lack of legal control are unique to each treaty and institution, but generally lie in the narrowness and specificity of obligations imposed by environmental treaties.[20] The regimes of greatest relevance are those on stratospheric ozone depletion, climate change, and long-range air pollution. Yet the concrete obligations of the Montreal Protocol on the ozone layer are limited to controls on the production and consumption of listed chemicals, and do not include comprehensive controls on other activities that affect ozone.[21] Similarly, the Kyoto Protocol on climate change only limits national emissions of six listed greenhouse gases, and only for Parties listed in Annex B.[22] None of the sulfur-based species now considered promising candidates for stratospheric aerosol injection appear on the list of controlled substances in either of these Treaties. National emissions of sulfur dioxide are controlled under the 1999 Gothenburg Protocol to the Convention on Long-Range Transboundary Air Pollution.[23] But this Convention is a regional treaty whose membership includes only European nations plus the United States and Canada, and the way the 1999 Protocol specifies national emission limits only appears likely to seriously constrain participation in a CE program for the smaller European states.[24] Another treaty of seeming relevance, the 1977 Environmental Modification Convention (ENMOD), prohibits large-scale environmental modification,

[19] Within the exclusive economic zones (EEZ) of other nations and the airspace over it, the legal status of CE activities would depend on the interpretation of certain provisions of the UN Convention on the Law of the Sea, particularly the regime for 'marine scientific research.' See A. Hubert, 'The New Paradox in Marine Scientific Research: Regulating the Potential Environmental Impacts of Conducting Ocean Science' (2011) 42(4) *Ocean Development & International Law*, pp. 329-55.

[20] For detailed discussions of the limited applicability of existing treaty obligations to CE, , see, e.g., Parson et al., n. 3 above; A. Ghosh & J. Blackstock, 'SRMGI Background Paper: International' (Background Paper for the Solar Radiation Management Governance Initiative, March 2011), at p. 16. Available at: http://www.srmgi.org/files/2011/09/SRMGI-International-background-paper.pdf; Shepherd et al., n. 2 above, at p. 40; see also Ralph Bodle et al., *Regulatory Framework for Climate-related Geoengineering Relevant to the Convention on Biological Diversity* (Convention on Biological Diversity, 2012), UNEP/CBD/SBSTTA/16/INF/29.

[21] The Montreal Protocol on Substances that Deplete the Ozone Layer, Montreal (Canada), 16 Sep. 1987, in force 1 Jan. 1989. Available at: http://ozone.unep.org/new_site/en/Treaties/treaties_decisions-hb.php?sec_id=5.

[22] Kyoto Protocol to the United Nations Framework Convention on Climate Change, Kyoto (Japan), 10 Dec. 1997, in force 16 Feb. 2005. Available at: http://unfccc.int/kyoto_protocol/items/2830.php.

[23] 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, Gothenburg (Sweden), 30 Nov. 1999, in force 17 May 2005. Available at: http://www.unece.org/env/lrtap/multi_h1.html.

[24] Although not explicitly restricted to these, the primary focus of the Treaty is emissions from large stationary sources, so the applicability of its emissions limits to national participation in a CE program that spread sulfur dioxide in the atmosphere would require a substantial further negotiation by Parties. Moreover, even if Parties agreed that national distribution of SO_2 as part of a CE program counted toward national emissions limits, Parties with the largest budgets could accommodate CE programs within these, and there are specific reasons that these limits would not constrain CE conducted by Russia, the United States, or Canada, even if it did for other states. For these three nations alone, emissions limits apply only to part of their national territory: the European part of Russia, roughly the southeastern quarter of Canada, and the lower 48 states of the USA. Moreover, emissions limits for the USA and Canada are characterized as "indicative values" rather than binding limits. Finally, Russia and Canada are Parties to the underlying Convention, but not to this Protocol. See 1999 Protocol, ibid., Article III, and Annex II, including Tables 1 and 2.

but only if undertaken for military or other hostile purposes, and includes an explicit exemption for activities done for peaceful purposes.[25] The result is that none of these treaties impose concrete obligations that would be violated by proposed CE interventions.

Pushed by vigorous advocacy by a few NGOs, two treaties have taken explicit steps to limit or discourage CE activities: the London Convention and Protocol under the International Maritime Organization,[26] and the Convention on Biological Diversity (CBD). Even these initiatives, however, presently impose no binding legal restrictions on CE. The initiatives in the CBD, despite claims by their NGO proponents that they comprise a moratorium, impose no binding controls.[27] At most, they express a generalized disapproval for CE, in language that is remarkable for its weakness, opacity, and multiple escape clauses.[28] Action within the London Convention and Protocol has been more focused, but is limited to ocean fertilization, a CE method that appears increasingly unlikely to be effective.[29] London Parties have asserted that ocean fertilization falls within the scope of these treaties and have expressed concern about its potential adverse impacts,[30] but have constructively decided that it does not comprise 'dumping' and so falls outside the Protocol's general prohibition. Further, Parties have drawn an even stronger distinction between dumping and 'legitimate scientific research' into ocean fertilization, and have developed an 'assessment framework' to which such research should be subject—a rather generic set of procedures for environmental impact and risk assessment—and are now developing legal measures to implement this

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[25] Convention on the Prohibition of Military or Any Hostile Use of Environmental Modification Techniques, Geneva (Switzerland), 18 May 1977, in force 5 Oct. 1978. Available at: http://www.icrc.org/applic/ihl/ihl.nsf/INTRO/460.

[26] At the 30th Meeting of Contracting Parties to the London Convention and 3rd Meeting of Contracting Parties to the London Protocol, delegates adopted Resolution LC-LP.1(2008), which states that 'ocean fertilization activities other than legitimate scientific research should not be allowed,' and that such other activities are 'contrary to the aims of the Convention and Protocol and not currently qualify for any exemption from the definition of dumping in Article III.1(b) of the Convention and Article 1.4.1 of the Protocol.' See Resolution LC-LP.1(2008) On the Regulation of Ocean Fertilization, 30th Meeting of Contracting Parties to the London Convention and 3rd Meeting Contracting Parties to the London Protocol, International Maritime Organization. Available at: http://www.imo.org/blast/mainframemenu.asp?topic_id=1969.

[27] COP 10 Decision X/33. Biodiversity and Climate Change, Convention on Biological Diversity, Nagoya (Japan), 2010. Available at: www.cbd.int/decision/cop/?id=12299.

[28] The decision invites Parties and other Governments to ensure, *inter alia*, that 'no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.'

[29] P. Williamson & C. Turley, 'Ocean Acidification in a Geoengineering Context' (2012) 370(1974), *Philosophical Transactions of the Royal Society*, pp. 4317–42.

[30] Statement of Concern Regarding Iron Fertilization of the Oceans to Sequester CO_2 (2007), endorsed by the 29th Consultative Meeting and the 2nd Meeting of Contracting Parties in November 2007, International Maritime Organization. Available at: https://www.whoi.edu/cms/files/London_Convention_statement_24743_29324.pdf.

framework.[31] The upshot is that ocean fertilization is presently subject only to generalized normative statements of concern urging caution, not yet to any legally binding control, while other forms of CE, including stratospheric aerosol injection, are under even less international legal control. In the specific case of controlling US conduct, the legal situation is even weaker because the US is not a party to either the CBD or the London Protocol. Consequently, even if binding controls were adopted under one of these treaties, the US as a non-party would not be bound by them.[32]

In the absence of specific treaty provisions that would constrain national CE activities, the points of existing international law of potential relevance to CE fall into two classes: general obligations to protect and preserve the environment that appear in many treaties, such as the Vienna Convention on the Ozone Layer[33] and the UN Convention on the Law of the Sea;[34] and relevant principles of customary international law, such as the duty to avoid trans-boundary harm.[35] Although any of these could be elaborated or interpreted to apply to CE, they lack the specificity to provide operational guidance on what CE interventions, under what conditions, would be either permissible or impermissible – particularly in view of the tension between CE's potential to both reduce climate-change risks and introduce new risks. Other provisions of customary international law, such as the duty to undertake environmental impact assessment, would not limit CE itself but may create procedural obligations related to how it is conducted. [36]

3.2. Distribution of State Capabilities

[31] Resolution LC-LP.1, n. 24 above; Resolution LC-LP.2(2010) On the Assessment Framework for Scientific Research Involving Ocean Fertilization, 32nd Consultative Meeting of the Contracting Parties to the London Convention and 5th Meeting of the Contracting Parties to the London Protocol, International Maritime Organization, adopted on 14 October 2010. Available at: http://www.imo.org/blast/mainframemenu.asp?topic_id=1969.

[32] The situation under the London Protocol is slightly more complicated. The London Protocol was negotiated under the London Convention, an earlier treaty that it is intended to eventually replace. The US is not a party to the Protocol but is a party to the prior Convention. Consequently, if a decision controlling ocean fertilization were to be adopted in some form that was binding under both the Protocol and Convention, the US would be bound by it as a party to the Convention.

[33] The Vienna Convention for the Protection of the Ozone Layer, Vienna (Austria), 22 Mar. 1985, in force 22 Sep. 1988. Available at: http://ozone.unep.org/pdfs/viennaconvention2002.pdf. Article 2: 'Parties shall take appropriate measures … to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer'.

[34] UN Convention on the Law of the Sea, Montego Bay (Jamaica), 10 Dec. 1982, in force 16 Nov. 1984. Available at: http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf. Part XII, e.g., Article 192, "States have the obligation to protect and preserve the marine environment."; Article 194:1, "States shall take … all measures consistent with this Convention that are necessary to prevent, reduce, and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal and in accordance with their capabilities …"

[35] Rio Declaration on Environment and Development, 14 June 1992, Principle 2. Available at: http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=78&ArticleID=1163; see also International Court of Justice, Legality of the Threat or Use of Nuclear Weapons (General Assembly Advisory Opinion), *ICJ Reports* (1996), at p. 22.

[36] *Case Concerning Pulp Mills on the River Uruguay (Argentina v. Uruguay)*, Judgment, 20 April 2010, *ICJ Reports* (2010), at p. 14.

The present lack of any controlling international law, however, does not necessarily imply a serious threat of unilateral action to develop or deploy CE technologies. The severity of this risk will depend additionally, indeed primarily, on the distribution of relevant state capabilities and interests. Focusing on these, one common way to express the strategic novelty and challenge of CE has been to contrast its basic structure to that of cutting emissions. Cutting emissions is generally understood as a collective-action problem, in which the basic strategic challenge is to motivate and enforce costly contributions to a shared goal, while for CE the basic problem is to bring a widely distributed capability under competent and legitimate collective control. One recent discussion used the vivid 'free-rider vs. free-driver' image to illustrate this distinction: for effective global policy, the basic problem of emissions control is to overcome free-rider incentives, while the basic problem of CE is to corral multiple potential drivers, each able to act alone, into a collective decision process.[37]

Taken to an extreme, this logic would suggest that virtually anyone can do CE—as has been proposed in various colorful scenarios of CE conducted by terrorist groups, apocalyptic cults, or wealthy individuals.[38] But these scenarios overstate the distribution of capabilities and thus the risk of unilateral action, because they focus too narrowly on financial cost as the determinant of capability and neglect other, non-financial requirements and constraints. To assess these other constraints, it is crucial to note that achieving a non-trivial, sustained alteration of global climate requires continued large-scale material inputs. These in turn depend upon delivery equipment and supporting infrastructure—e.g., balloons, tethered pipes, aircraft, or ships, backed up by airports, bases, and ports—that are visible, hard to conceal, and vulnerable to military attack. This is not to claim that even powerful states would take such military action lightly, in view of the substantial associated costs and risks; yet such action will clearly be a feasible response for some states under some conditions, if they judge another state's CE actions to threaten their vital interests and have been unable to stop it through other means.

In view of the possibility of such military interdiction, unilaterally achieving a climate alteration that matters would require not just the money, technological capability, and delivery assets, but also the command of territory, global stature, and ability to deploy and project force necessary to protect a continuing operation against opposition from other states, including deterring their threats of stopping it through military action. These requirements exclude the nightmare scenarios of climate alteration by megalomaniac billionaires, terrorist groups, or apocalyptic cults, and also exclude the prospect of unilateral action by most states. Rather, the capability is likely to be limited to a few major world powers, probably numbering less than a dozen. Precisely which states could act unilaterally is indeterminate, not just because the feasibility, precise requirements, and

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37 G. Wagner & M.L. Weitzman, 'Playing God' (2012) *Foreign Policy*. Available at www.foreignpolicy.com/articles/2012/10/22/playing_god?page=0,0.

38 See, e.g., D.G. Victor, 'On the Regulation of Geoengineering' (2008) 24(2) *Oxford Review of Economic Policy*, pp. 322-6, at 324; W.D. David, 'What Does "Green" Mean? Anthropogenic Climate Change, Geoengineering, and International Environmental Law' (2009) 43 *Georgia Law Review*, pp. 901-50, at 926; M.Squillace, 'Climate Change and Institutional Competence' (2010) 41 *The University of Toledo Law Review*, pp. 889-908, at 899; Shepherd et al., n. 2 above, at p. 50.

effects of particular CE interventions are uncertain, but also because who can do it (or more precisely, who can do what) will also depend on the intensity of other states' interests in who does what. The more strongly others care—in particular, the more other powerful states are intensely opposed—the fewer states will be able to conduct unilateral CE in the face of that opposition.

But while the distribution of unilateral capability is narrower than the most apocalyptic commentaries have suggested, it is still broad enough to be significantly destabilizing. The potential for destabilization and conflict arises on the one hand from the virtual certainty that any intervention by one state strong enough to alter its own climate would also exert similarly large effects on other states; and on the other hand, from the presumption that no state would undertake a major CE program lightly. That is, in the event that any state seriously pursues a CE program, its leaders and polity must perceive the intervention as a matter of high-order national interest, due to the realized and impending harms from climate change they see and their expectation that CE can reduce these. Given the likely inability to limit the effects of a CE intervention to one state, if the state making the intervention perceives such acute interest then so also will other states.

3.3. Distribution of State Interests

Characterizing the severity of the resultant risks of international conflict requires a closer examination of states' likely interests, in particular the degree to which major states' interests over the available set of CE choices are aligned or opposed. State interests in CE will depend on what specific capabilities are available, including how controllable they are; on the specific projected regional effects of available capabilities; and on how these effects are expected to interact with ongoing greenhouse heating and natural climate variability. Although these factors are uncertain and likely to change with further research, the range of possibilities can instructively be clustered into three alternative degrees of interest alignment.

At one extreme, states' interests over available CE options might be closely aligned. This situation would be most likely to arise under three conditions. First, experienced and anticipated climate-change harms are widely distributed worldwide, so states perceive a broadly shared peril. Second, the projected effect of CE is to limit these harms in a manner that is also roughly consistent across world regions. This would require that even the imperfect joint correction of temperature and precipitation noted above is roughly consistent across regions, facilitating agreement among states on some preferred compromise between restoring prior precipitation and prior temperature. Third, and crucially, available CE capabilities remain rather crude, with little ability to control effects beyond choosing the aggregate intensity of intervention. In particular, there is no ability to tune interventions to achieve differential control of climate effects in different regions.

At the opposite extreme from this first possibility, states' interests in CE might be strongly opposed. The conditions favoring this situation would be opposite to those above. I.e., the severity of climate disruptions varies strongly among regions, so some states perceive a climate-change crisis requiring urgent response while others do not. The anticipated effects of CE in limiting harmful climate impacts also show large regional differences, in their effects or how they are valued, so states disagree whether and how to use CE even if they agree a climate crisis is occurring. Finally, scientific and technological advances have brought a strong ability to control regional effects of CE interventions. In the extreme, plausible advances in IT and nanotechnology over several decades might lead to individually controllable, optimally asymmetric stratospheric particles, allowing some degree of real-time, regional controllability of climate and weather.[39] Like CE itself, such extreme advances in regional control would present sharp double-edged possibilities. They would greatly advance the ability to reduce harms from climate change and manage climate and weather for global benefit. But precisely the same advances would enable control of CE to distribute large regional benefits and harms on command, even on a time scale of days or hours, starkly raising the stakes in how the capability is used and who controls it.[40] If states even suspected others of pursuing such capabilities, or of withholding information about capabilities and effects, opportunities for international mistrust and tension will be substantial.

Perhaps most likely is the intermediate possibility in which states' interests are mixed and variable, aligned for some choices and opposed for others. Early model studies have already cast doubt on the strongest commonality of interests from shared benefits of CE. Even if the only available dimension of CE control is the aggregate intensity of an intervention, it appears that different regions most closely approach their prior climate at different levels of intervention.[41] As interventions come to vary on more dimensions—they have more dials to turn—the possibility of tradeoffs among different regional harm-reduction objectives increases.[42] Current early study of these questions is highly tentative, of course: it has only identified the possibility of trade-offs, not characterized the intensity or degree of opposition of the resultant interests, which will depend on now-unknown future advances in capabilities. Advancing knowledge may perhaps reveal large-scale regional patterns in joint effects of climate change and CE that create foreseeable common or opposed interests, for example by latitude band (e.g., low-latitude vs. mid-latitude countries) or position relative to major mountain ranges (e.g., China vs. India over how precipitation and storms are distributed over the Himalayas). Although the details of these interests are unknown, it appears generally likely that increased CE

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39 I owe this provocative idea to discussions with David Keith.

40 Concern about the potential for conflict from control of weather and climate is as old as thermonuclear weapons. John Von Neumann, leader of the pioneering computer project that did early calculations of both thermonuclear weapons behavior and weather forecasting, suggested that control of weather and climate held even greater potential for international conflict than nuclear weapons. See J. Von Neumann, 'Can we survive technology?' (June 1955) *Fortune*, p. 151; see also the discussion in G. Dyson, *Turing's Cathedral* (Pantheon Press, 2012), at pp. 158-74.

41 M.G. Morgan & K. Ricke, *Cooling the Earth Through Solar Radiation Management: The Need for Research and Approach to its Governance* (International Risk Governance Council, 2011); K. Ricke et al., 'Regional Climate Response to Solar Radiation Management,' (2010) 3 *Nature Geoscience*, pp. 537-41.

42 D.G. MacMartin et al., 'Management of Trade-offs in Geoengineering Through Optimal Choice of Non-uniform Radiative Forcing' (2013) 3 *Nature Climate Change*, pp. 365-8.

controllability, including more dimensions for control of interventions, will increase the potential for opposed interests.[43]

Moreover, the discussion thus far may under-state the prospects for opposition, because it assumes some rational process of forming nationally aggregated interests, based on realized or projected climate effects, with each region viewing its recent climate as ideal. But any of these assumptions might not hold. State interests could be driven by smaller-scale patchiness of climate effects within countries and resultant domestic political conflict. Alternatively, climate preferences might shift, in response to realized climate changes or to recognition of the possibility of intentional climate control, such that regions' present climate is no longer judged ideal. State interests in CE might also be dominated by non-consequential or non-rational processes—e.g., religious or symbolic commitments, general technological optimism or pessimism, or generalized suspicion about other states' intentions. To the extent these other processes show strong regional variation, they could further increase the possibility of inter-state conflict over CE.

From this sketch of potential state capabilities and interests in CE, two large-scale implications can be drawn about unilateralism in CE. On the one hand, major powers such as the United States are likely to face significant temptations to unilateralism—i.e., to develop CE capabilities unilaterally, to conceal information about plans, research results and capabilities, and to act diplomatically to preserve a unilateral right of action. On the other hand, such unilateral actions are likely to be dangerous and disruptive to international stability.

Temptations to unilateralism may arise from several factors. The scientific and technical challenges of doing CE well—i.e., developing high-benefit, low-risk interventions—are sufficiently large that rich, scientifically advanced nations are likely to have substantial advantages in developing them. Scientific and government elites in such nations may be confident of these advantages, and may also be confident—perhaps over-confident—of their ability to persuade others to their view of CE. Temptations to unilateralism may be exacerbated by anticipation of economic benefits if CE research produces private intellectual property. They may also be exacerbated by the polarization of early debates on CE governance, in which widespread hostility to CE and calls for bans may lead those who favor developing CE capability to judge that doing it unilaterally may be the best way to ensure it gets done. These temptations are already evident in US policy debate, both in a few explicit calls to preserve US freedom of action and in more widespread skepticism about international consultation over early-stage research.[44]

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43 To take this speculation even further, risks of conflict might be most severe if CE exhibits intermediate degrees of regional controllability. With no regional controllability, only crude limitation of aggregate global climate risk would be possible. With moderate controllability, inter-regional tradeoffs would likely emerge—e.g., one intervention might increase risk of drought in Region A, while another shifts it to region B. But as controllability increases further, there might emerge some ability to simultaneously optimize in multiple regions, so if the control mechanism is trusted by all—a large assumption, to be sure—inter-regional tradeoffs and associated conflicts might decrease.

44 L. Lane, 'Geoengineering: Assessing the Implications of Large-scale Climate Intervention'. Statement presented at Hearing No. 111-62, US House of Representatives Committee on Science and

Yet unilateral pursuit of CE is likely to carry serious risks, which also follow from the same observations about the likely distribution of state capabilities and interests. The ability to develop CE capability, and even to deploy it, will not be limited to the US or to any single state. Other world powers can do it, possibly just as well; and even if some leading state achieves a technological breakthrough—e.g., an approach that is cheaper, safer, or more controllable—less advanced approaches can make similarly large climate perturbations, albeit more crudely. Other states can also assert the same legal arguments for a unilateral right of action. Indeed, states with programs of regional weather modification may be favored in advancing these arguments, due to the blurry line between these activities, which clearly lie within their sovereign authority, and early CE development. With both capabilities and potential justifications broadly distributed, at least among major powers, unilateral pursuit of CE by any world power, including the US, would risk others deciding to do the same; and once any major power decided to pursue this course, attempting to stop them would be difficult and risky.

Moreover, states are likely to perceive strong interests in whether and how other states pursue CE, not just at the deployment stage but also from early unilateral steps to develop capabilities that might make future deployment more likely. As discussed above, the severity of these risks will depend on how states' future interests in CE are aligned or opposed. But given current uncertainties about CE capabilities and effects, these interests might be subject to some degree of influence. In particular, states' perceived interests may form in part reactively, in response to early acts by other states that signal either anticipated rivalry or cooperation over CE. Thus, early unilateral acts by a major state—including development of capabilities, secrecy about intentions, or aggressive declaration of rights of action—may induce others to perceive CE as predominantly rivalrous and to pursue similar acts, either because they interpret these acts to indicate hostile or rivalrous intent or because they infer from these acts that it is valuable to have an independent CE capability. Conversely, early signals of cooperation and openness may have the opposite effect, steering others' perceptions and choices toward cooperation. Given the uncertain and labile nature of future CE capabilities, such cooperative early moves may even influence the direction in which future capabilities are developed, toward those that pose less risk of conflict.

In sum, following a unilateral course in climate engineering—including not just eventual deployment, but also early steps to pursue research and development alone, maintain secrecy about capabilities and results, and reserve unilateral legal rights—is a superficially tempting but dangerous course of action, for the United States and other major powers. States should anticipate and resist these temptations and instead pursue a cooperative approach to CE. Such an approach could start immediately, with informal consultations on research programs, agreement on common standards for transparency, and joint development of assessment frameworks.[45] A cooperative approach need not involve universal participation, but could start with only the dozen-odd nations likely to

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Technology, Washington, 5 November 2009. Available at: http://www.gpo.gov/fdsys/pkg/CHRG-111hhrg53007/pdf/CHRG-111hhrg53007.pdf, at pp. 39-41; see also Parson & Keith, n. 6 above.

45 Parson & Keith, n. 6 above.

be most interested in developing CE and most able to pursue it unilaterally. It also need not await a comprehensive climate regime. By building cooperation and transparency on CE while the stakes are relatively low, such early cooperation may help build norms for cooperative management of CE, which would then be available to help resolve the more challenging governance problems raised by future proposals for operational interventions.

4. CLIMATE ENGINEERING WITHIN AN INTEGRATED CLIMATE POLICY: PARTICIPATION, UNILATERALISM, AND EXCLUSION

The discussion thus far has considered CE and its implications for global climate cooperation separately from other elements of climate policy. This approach is consistent with the present literature on CE governance, which has given limited consideration to interactions with other elements of climate policy. There has yet been no examination of interactions or tradeoffs between CE and adaptation, although these may represent important future decisions over alternative ways to reduce harms from climate impacts on relatively fast time-scales. Discussions of CE-mitigation interactions have been more extensive, but thus far fall into two classes: analyses of how CE interacts with mitigation in a global dynamically optimal climate response, neglecting all politics and negotiation;[46] and discussions of the potentially destructive implicit interaction known as the "moral hazard" effect of CE, whereby its perceived availability may undermine already inadequate political support for needed mitigation.[47]

But if and when CE comes onto the policy agenda, there are likely to be large and explicit interactions with other elements of climate response, including attempts by policy-makers to link them in ways that favor their objectives. Such intentional linkages may expand the space for effective responses. In this section, I begin to consider specific possibilities for interaction and linkage, focusing in particular on how these linkages may affect incentives for, and consequences of, less than full participation. While interactions of CE with adaptation may well be important, particularly for future responses to realized or impending climate changes, in this preliminary exploration I consider only potential linkages between CE and mitigation. The discussion is based on the strategically relevant characteristics of CE discussed above, but is otherwise entirely speculative.

Key decisions on CE will be made by states—most likely through some negotiation process in which the strongest influence is exercised by the dozen-odd states with

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46 See, e.g., J. Emmerling and M. Tavoni, 'Geoengineering and abatement: a "flat" relationship under Uncertainty.' Fondazione Eni Enrico Mattei Working Paper No. 31.2013, April 16, 2013. Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2251733; J.B.Moreno-Cruz and D.W.Keith, 'Climate policy under uncertainty: a case for solar geoengineering' (2012) *Climatic Change*, available at: http://link.springer.com/article/10.1007/s10584-012-0487-4/fulltext.html.

47 Discussions of the moral hazard problem can be found in all the major reviews and assessments of CE, e.g., Shepherd, n. 2 above; Bipartisan Policy Center, n. 4 above; Asilomar Scientific Organizing Committee, n. 4 above. For more extended discussions, see, e.g., Stephen M. Gardiner, *A Perfect Moral Storm: The Ethical Tragedy of Climate Change* (Oxford University Press, 2011); B. Hale, 'The World That Would Have Been: Moral Hazard Arguments Against Geoengineering', in C.J. Preston, (ed.), *Engineering the Climate: The Ethics of Solar Radiation Management* (Lexington Books, 2012); A. Lin, 'Does Geoengineering Present a Moral Hazard?' (Forthcoming) *Ecology Law Quarterly*.

credible capacity to act unilaterally, even if the group nominally participating is larger. These states are roughly the same group of major economies that account for the bulk of global emissions, among whom it is often suggested a serious agreement on emissions cuts might also be crafted.[48] Several such forums of major states have been proposed, with membership ranging from the G8+5 at the small end, through the Major Economies Forum, to the G20 at the large end.[49] In the event that such a group of major states emerges to organize a decision-making forum for both mitigation and CE policy, this group would have the capability to explicitly link decisions on the two issues.

The most prominent near-term question concerning these linkages is how (and whether) decisions about CE can be linked with emission cuts so as to make the two approaches complementary, rather than acting as substitutes or competitors as has most often been presumed. Although this question has been previously identified, little progress has yet been achieved beyond posing it and noting its importance.[50] This section attempts to sharpen the question and advance its investigation, by proposing four alternative speculative scenarios of how mitigation and CE could be linked, with a preliminary discussion of the plausibility, likely effects, and challenges of each scenario.

4.1 Linking Climate Engineering with Mitigation: Four Possible Forms of Linkage

The first scenario, ***Plan B Linkage***, represents the simplest, most minimal, form of linkage between CE and mitigation. Effectively, it makes explicit the relationship often presumed to exist between the two responses even in the absence of intentional linkage. In this scenario, states keep trying to pursue serious emission cuts. At the same time, they conduct research to develop CE capability for future interventions and agree these will be used if and as needed to limit future severe climate changes and impacts.

For this minimal form of linkage to promote an effective climate response that includes increased near-term mitigation effort, it must present future CE deployment as a threat—an outcome so abhorrent that it motivates increased mitigation efforts to avoid it. In effect, the scenario presumes the normal 'moral hazard' concern about CE can be reversed, even with no specific measures to change incentives. This presumption seems odd if we assume rationality in future decision making, since any future decision to deploy CE would presumably be made only if CE promised to reduce climate harms

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[48] Suggestions of such alternative forums for action have been widely made. See, e.g., D.G. Victor, *The Collapse of the Kyoto Protocol and the Struggle to Slow Global Warming* (Princeton University Press, 2004); A. Dessler & E.A. Parson, *The Science and Politics of Climate Change* (Cambridge University Press, 2009); The Leaders–20 (L20) Project, 'Meeting Report: Key Elements in Breaking the Climate Change Deadlock' (Paris, 2008). Available at: http://www.l20.org/publications/38_qF_Paris-Meeting-Report-Final.pdf; R.B. Stewart et al. 'Building Blocks for Global Climate Protection' (Forthcoming) *Theoretical Inquiries in Law*.

[49] The Group of Eight + Five (G8+5) nations include the USA, Russia, Japan, Germany, UK, France, Italy, and Canada, plus China, India, Brazil, Mexico, and S. Africa. To these thirteen, the Major Economies Forum adds Australia, S. Korea, and Indonesia, plus the EU. To these seventeen, the G-20 adds Turkey, Saudi Arabia, and Argentina. See Parson et al., n. 3 above.

[50] See, e.g., Parson and Ernst, note 3 above.

otherwise anticipated—when the prospect of these worse climate harms is presently failing to provide adequate motivation for mitigation.

This scenario is not completely implausible, however, but could come about under various assumptions, related to uncertain CE effects or non-rational decision-making. For example, future CE use could be perceived as a gamble carrying risk of outcomes worse than uncontrolled climate change. If future decision-makers regard CE as likely to improve matters on average, but have not learned enough to be fully confident it will not worsen harms, they might still favor deploying it as a desperate measure in the face of severe climate change. Looking ahead to this possibility, current decision-makers might be motivated to greater mitigation efforts to avoid this awful future choice. Alternatively, the prospect of deploying CE might somehow gain more saliency or mobilize more horror about the severity of human disruption of the global environment than severe climate change alone. At first glance, these eventualities appear barely plausible—suggesting this scenario is unlikely to motivate much strengthening of near-term mitigation—but cannot be completely dismissed.

The second scenario, ***Reverse Linkage***, would reverse the contingency relationship between mitigation and future CE use from that in the plan B scenario. Under this scenario, states would jointly agree to withhold CE, no matter how severe the climate impacts occurring or anticipated, unless states had achieved some agreed level of acceptable performance on cutting emissions. This scenario admittedly requires some suspension of disbelief, yet is still instructive to explore.

The linkage in this scenario would aim to motivate states cut emissions early, to avoid the prospect of facing severe future climate change without access to CE to moderate the impacts. The most obvious difficulty with the scenario is credibility: how could a threat to refuse CE in response to some future climate emergency be credible? As preposterous as this may first appear, such refusal could be plausible in a political setting marked by intense domestic opposition to CE in the states otherwise able to deploy it. In such a setting, it would be difficult to achieve agreement to use CE under any conditions; but achieving this agreement would be easier if states have made serious contributions to reducing emissions, in part because moral hazard concerns would then be less severe.

In this regard, it is important to recall that future climate change risks come from two distinct routes—either continued failure to cut emissions, or unfavorable resolution of major uncertainties. In this scenario CE would be available to respond to a climate crisis arising from the second cause, unlucky resolution of uncertainties—because under this condition it would be easier to overcome general opposition to CE. CE would not be available, however, to respond to climate harms caused or confounded by failure to make agreed emission cuts. Given strong enough opposition to CE, the threat to withhold it under these conditions might be credible – or at least, credible enough to provide stronger motivation for near-term mitigation than the first scenario. And of course, if it does motivate stronger mitigation, the credibility of the threat to refuse future CE in case of inadequate mitigation would not be tested.[51]

The scenario poses two further difficulties, however. First, while one can construct plausible accounts in each case of how the required future threats could be made credible, both the first and second scenarios involve long time lags between the present mitigation decisions to be influenced, and the future use or non-use of CE that provide the incentive. Both thus suffer from the special credibility problems that afflict any attempt to link acts widely separated in time, as changes in conditions, actors, preferences, or capabilities can easily intervene to prevent the promised (or threatened) future actions. Second, both scenarios make future CE decisions depend on aggregate, collective mitigation performance in the interim. They thus suffer from the same free-rider, collective action problems that hinder current attempts at mitigation. Even if the inter-temporal linkage can be made credible in aggregate, each state will still have incentives to weaken its mitigation effort in hope that others do enough to trigger the desired future condition, so long as mitigation remains costly or difficult.

The third scenario, ***Real-time Linkage***, aims to address the first of these problems, the inter-temporal disconnect, by linking actions on mitigation and CE concurrently, rather than through future commitments. This scenario thus diverges from the most widely proposed way to use CE, as a response held in reserve for use in some future climate crisis. Instead, in this scenario CE would be used in one or both of the two proposed near-term modes: incremental use to shave the peak of near-term heating coupled with a phased program of steep emission cuts, with CE gradually phased out thereafter; or use targeting regional processes (such as Arctic summer sea ice loss or tropical hurricane formation) that are strongly linked to global climate risks.

In this scenario, participating states would simultaneously pursue agreed programs of steep emissions cuts and limited CE deployment in one or both of these modes. Such real-time linkage of mitigation and CE could ease several strategic and political problems, making both responses more politically feasible and effective by coupling them. Linkage would make mitigation easier by addressing the distinct inter-temporal disconnect that has obstructed efforts thus far, which may be an even more severe obstacle than mitigation's collective-action character.[52] Whereas emission cuts carry immediate costs to reduce climate risks decades in the future, introducing some small, modulated level of CE concurrently with mitigation would reduce climate risks in the near-term when they are politically salient. In addition to this clear political benefit, mitigation linked to concurrent CE could be less costly, because reductions could build gradually to match capital turnover cycles and allow orderly development and rollout of new technologies.

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[51] For the seminal discussion of the credibility of threats, see T.C. Schelling, *The Strategy of Conflict* (Harvard University Press, 1960).

[52] M. Sagoff, 'The Poverty of Economic Reasoning about Climate Change' (2010) 30 *Philosophy and Public Policy Quarterly*, pp. 8-15.

At the same time, real-time linkage could make CE less politically explosive, both because its deployment would be limited in intensity or spatial extent (albeit also done earlier, when it is arguably not "needed" to manage an imminent climate crisis); and crucially, because parallel enactment of mitigation and CE would address the strongest concern about harmful effects of CE, that it may undermine mitigation incentives. Moreover, concurrent linkage would enhance the credibility of nations' mitigation commitments, because ongoing agreement and authorization to do CE—which states would presumably want to continue because of their real-time risk-reduction benefits—would depend on continuing mitigation effort, with performance verifiable year by year. In sum, this scenario would link the two responses in a 'both or neither' political bargain, under which opponents of both mitigation and CE each tolerate the response they oppose because its scale, cost, and risks are limited by parallel pursuit of the response they favor.

Like the first two scenarios, however, this one does not specify by what process or subject to what inducements these collective decisions are made. By implicitly treating all action and consequences as collective, all three scenarios assume a return to some form of full cooperation—if not globally, then at least among the major powers participating. They thus fail to address many strategic and operational difficulties with making real deals work. Most important, they do not specify the linkage between individual states' actions and consequences that shape their incentives. Since the benefits of both mitigation and CE are likely to be distributed globally, these scenarios thus all remain vulnerable to the collective-action challenges that have hindered cooperation on mitigation thus far. In any scenario that links collective CE decisions to aggregate mitigation performance, states will still have incentives to under-perform on mitigation, so long as they expect their free-riding will not unravel the global agreement.

The fourth scenario, ***Pay to Play Linkage***, aims to address this problem. This scenario follows the third in proposing real-time coupling of a strong, agreed trajectory of mitigation with a parallel program of incremental or targeted CE. But this scenario also provides individual incentives to deter free-riding, by making each state's mitigation performance a condition for its participation in decision-making on CE. Under the dual assumptions that: 1) all participating states strongly desire a voice in CE decisions, and 2) the threat to exclude them from such participation is credible, this approach would address the problem of providing effective incentives for states to accept and meet strong mitigation commitments. To explore whether this scenario could be plausible, we must thus examine these two assumptions.

First, is the threatened consequence of non-performance—exclusion from participation in CE—painful enough that states will be motivated to pursue strong emission cuts in order to avoid it? This will turn, in part, on what it means to be excluded. A narrow interpretation of exclusion might be that non-performing states and their citizens and enterprises may not participate in implementing the agreed CE program. Such narrow exclusion would mainly target commercial interests—e.g., firms that want CE contracts—which are unlikely to be large components of overall national interest, although they could still be effective political motivators if sufficiently concentrated. More broadly, exclusion might mean non-performing governments are also barred from participating in decisions on design and implementation of the CE program—i.e., what is done, where, and how. Oddly, the extent to which such exclusion is disagreeable to states is likely to vary with the alignment of states' interests in CE, but in a manner opposite to the discussion of interest alignment above. If states' interests in CE are strongly aligned—at least over the range of choices being considered—then the cost to any state of being excluded from decision-making is likely to be low. In this case, other states are likely to implement essentially the same program as they would if the excluded state was present. As states' interests diverge—as discussed above, a function of regional variation in climate impacts, how CE limits these, CE capabilities and their controllability, and states' beliefs and suspicions about these—the cost of being excluded from decisions, and thus the motivating power of the threat of exclusion, would grow.

If we stipulate that exclusion is sufficiently disagreeable to states to be motivating, is the threat of exclusion credible? This will depend strongly on what states are in the participating group, and which state is the presumed target of the threat. Clearly the threat to exclude grows more credible if the group of states collectively binding themselves is large and strong, and the state considering free-riding is small and weak. The threat's credibility will also depend on the alignment of states' interests in CE, now once again in the direction that opposed interests pose a greater challenge. If states' interests in specific uses of CE are strongly opposed, then the threat to exclude is constructively a threat to design a CE program that takes no account of the excluded state's interests. Under some conditions, this might impose significant harm on the excluded state and thus risk serious conflict, raising the possibility that the threatened act may be too severe for the threat to be credible. But this problem might be eased by the incremental and real-time nature of the CE interventions being made in this scenario, which are less intense or less global in scale than those that would be deployed in response to some future climate emergency. Over this more limited decision space, regional disparity of interests may be attenuated, allowing a balance between the disagreeability of exclusion and the credibility of threatening it. Such intermediate degrees of interest alignment may thus be close to a politically optimal configuration of interests for CE to be able to motivate contribution to mitigation.

5. CONCLUSION

The discussion in this paper suggests that the issues associated with less than full global cooperation in climate policy, and the associated risks and opportunities, are likely to change markedly as the agenda of climate policy is broadened to include CE.

Including CE on the policy agenda raises significant risks of unilateralism, which will be particularly tempting for major powers. Even small early steps toward separate or secret research, or aggressive claims to reserve unilateral rights of action, may trigger reciprocal actions, perceptions, and expectations that hinder growth of cooperative decision-making norms that may be crucial to reducing risks of conflict under severe climate change futures. Conversely, there is high value to early cooperative steps such as informal consultation, collaboration in design and management of research programs, and risk assessment, which may build a foundation for future cooperation over higher-stakes governance questions when these arise. In this early research cooperation, it may be valuable to declare an explicit moratorium on the largest scale interventions, to assuage public concerns about a thoughtless slide from small-scale research to global operational interventions. Such a moratorium need not obstruct needed early small-scale research but may rather facilitate it, because addressing these concerns may be a necessary condition for allowing small-scale, low-risk research to proceed.[53]

Although these first steps on CE research need not consider explicit linkages to other elements of climate policy, longer-term decisions on CE—including any that begin to consider proposals or concerns about deployment—must be integrated with decisions on mitigation to contribute to an effective total climate response. This paper has examined four scenarios by which negotiated international decision-making could aim to advance effective climate response by explicitly linking CE and mitigation decisions. Although highly preliminary and speculative, this exploration of linkage scenarios identifies some possible conditions and requirements for effective linkage, and also highlights specific areas of research priority that have received little attention thus far.

First, the discussion suggests the importance of which specific states participate or exercise most influence in this linked decision-making. At a minimum, participation must include those states that could plausibly pursue CE unilaterally if they valued it highly enough. Because this is a similar group of states to those that are crucial for global mitigation negotiations, joint decisions on mitigation and CE in such a group would create the possibility for explicit linkage between the two types of response.

Second, the discussion has identified the serious inter-temporal obstacle posed to effective mitigation-CE linkage when CE is only considered a contingent response to some future climate emergency. Using CE earlier and at lower intensity, in one of its less widely considered modes, may help craft the bargaining linkages needed for effective global climate response, by making it possible to couple small, incremental deployment of CE with commitments to serious parallel emission cuts, year by year. Although such early CE deployment may raise slippery slope concerns even more acutely than the prospect of using it in some future emergency, building a sufficiently strong linkage to concurrent mitigation may address these concerns.

But while the strategic bargaining advantages of real-time linkage appear clear, this approach would pose daunting governance and management challenges. Participating states would need to make decisions similar in novelty and difficulty to those that would arise under a crisis-driven deployment of CE further in the future: e.g., what specific interventions are undertaken, how they are monitored and their risks managed, what systems for liability and compensation are applied, and how are these decisions made? Just as in a later, crisis-driven deployment, controlling these smaller, near-term CE interventions would require international decision processes able to discharge three distinct functions: competently and fairly assimilating scientific knowledge about effects and risks of proposed CE interventions; making political decisions of what specific interventions to authorize; and conducting competent real-time operational management

53 Parson & Keith, n. 6 above.

and oversight of interventions underway, to scan for unanticipated risks and modify or stop interventions as needed.[54] But in this case, these decisions would have to be addressed earlier, under even more uncertainty about effects, and absent the potentially unifying factor of a widely perceived climate crisis.

The effectiveness and risks of these linkage-based strategies will depend on several points of uncertainty, suggesting different priorities than CE research has targeted thus far. First, in view of the apparent strategic and bargaining advantages of the alternative, near-term modes of CE use, research into methods, effects, risks, and management of these would be valuable in addition to research on the longer-term, global interventions that have received most attention thus far. Second, since so much about the geopolitical risks of CE turns on uncertainty about states' interest alignment or opposition over available CE choices, research into such configurations of interests and associated conflicts and tradeoffs should be a high priority. Although study of this question has begun, the extent to which these interests depend on the actual set of CE options available remains largely unexamined, suggesting a priority for joint examination of the science and technology of specific CE capabilities, the alternative ways such capabilities might be used, and their implications for regional-scale costs and benefits. In view of the high stakes, it may be especially valuable to conduct this research in open collaborative international groups, in the hope that potential threats associated with the development of specific destabilizing capabilities may be recognized and deflected in advance, rather than having to be managed after the fact.

[54] Parson & Ernst, n. 3 above.