FORUM *for*
CLIMATE ENGINEERING
ASSESSMENT

INTERNATIONAL GOVERNANCE OF CLIMATE ENGINEERING

A Survey of Reports on Climate Engineering, 2009-2015

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FCEA Working Paper Series: 001
SSRN: 2982392
June, 2017

FORUM FOR CLIMATE ENGINEERING ASSESSMENT WORKING PAPER SERIES

SCHOOL *of* INTERNATIONAL SERVICE
AMERICAN UNIVERSITY • WASHINGTON, DC

Table of Contents

What Is Climate Engineering?

Climate engineering is the deliberate, large-scale intervention in one or more Earth systems for the purpose of counteracting the causes or symptoms of human-caused climate change. It is also called geoengineering or, less often, climate intervention. CE encompasses two very different kinds of proposed technologies: Solar geoengineering, also known as solar radiation management (SRM), would aim to cool the Earth by reflecting a small fraction of incoming sunlight back into space before it can warm the Earth. Carbon dioxide removal (CDR), sometimes called negative emissions technologies (NETs) or greenhouse gas removal technologies, would remove carbon dioxide (CO_2) or other greenhouse gases from the atmosphere and sequester them for long periods of time in biological, geological, or oceanic reservoirs. These two kinds of technologies generally raise different sets of technical, ethical, social, and legal concerns, leading to frequent calls to treat them separately. Since many of the reports being summarized here address both kinds of CE, this report will do so, too.

Introduction

Eleven years have passed since Paul Crutzen's editorial in *Climatic Change* (Crutzen 2006) broke the taboo on discussing climate engineering (CE). Since then, scholars have published hundreds of studies on the physical science, social science, ethics, law, and governance of solar geoengineering, along with hundreds more on carbon dioxide removal (CDR).[1] Between 2009 and 2015, several organizations also completed larger reports on CE, each of which contains some recommendations about or implications for the governance of CE, understood broadly to include not just formal regulation by governments or international organizations, but any system of formal or informal rules intended to control or influence research into or deployment of CE, either internationally, transnationally, or within a single country. This report surveys and synthesizes those reports' conclusions about the governance of CE.[2] Part I of this report summarizes the main points of agreement among the reports and lays out some major open questions about CE governance. Part II of this report surveys the individual reports with a view to helping readers understand each report's distinctive features and major recommendations regarding CE governance.

Discussions of CE governance stand now at a crucial juncture. As the reports surveyed here show, while the CE research community's ideas about governance have become increasingly sophisticated and specific over the last half decade, they have by and large not been translated into actual governance mechanisms, with the notable exception of the London Protocol's mechanisms for governing ocean fertilization research. This lack of governance has contributed, for better or

[1] For data on climate engineering publications, see (Belter and Seidel 2013; Oldham et al. 2014).

[2] See the bibliography (pp. 44–47) for a complete list of the reports surveyed. The reports can be downloaded as a ZIP file from www.ceassessment.org.

worse, to a bottleneck in scientific and engineering research on CE, especially in the case of solar geoengineering: Many physical scientists and engineers believe that the time has come to begin small-scale outdoor experiments,[3] but for various reasons, they have generally been unable or unwilling to conduct those experiments.[4] First, funders have balked at financing such experiments, and the lack of adequate governance mechanisms may contribute to their reluctance. Second, controversy surrounding one planned outdoor experiment in the UK led researchers to cancel the experiment (Watson 2016), leaving many researchers skittish about proposing new experiments without clearer guidelines about what kinds of experiments are permissible and under what conditions. Third, many people, including some of the researchers themselves, believe that outdoor research should not proceed without adequate governance mechanisms in place. On the other hand, existing regulations do not generally prohibit small-scale outdoor CE research *per se*, leaving open the

[3] Such proposals include spraying about one kilogram of sulfur from a balloon in the stratosphere to study the chemistry and microphysics of stratospheric aerosols over the course of a week or spraying sea salt into the lower atmosphere over the coast for two weeks to test some technology needed for marine cloud brightening (Keith, Duren, and MacMartin 2014).

[4] There have been some commercial developments connected to bioenergy with carbon capture and sequestration (BECCS) and direct air capture. Non-commercial, scientific research to date includes a series of outdoor experiments investigating a kind of CDR known as ocean iron fertilization (National Research Council 2015a, 59*ff.*), various basic science that is relevant to but not necessarily for the sake of marine cloud brightening (National Research Council 2015b, 106*ff.*), and one small outdoor experiment on aerosol physics conducted by the late Russian scientist Yuri Izrael (Izrael et al. 2009). Ocean iron fertilization experiments have all but ceased after the UN asserted regulatory authority over it under the London Convention beginning in 2008, both because of the restrictions imposed by that regulation and because of waning enthusiasm for the technology within much of the climate engineering research community. See (International Maritime Organization 2013).

possibility that funders and researchers could proceed with outdoor research without adequate input from the public or even in the face of public opposition. Until working governance mechanisms are in place, then, some important CE research remains in limbo; creating such governance mechanisms could resolve the current uncertainty by either prohibiting such research or enabling it to proceed.

With this in mind, the Forum for Climate Engineering Assessment has compiled this report to aid its Academic Working Group on International Governance of Climate Engineering (AWG) in producing policy-relevant recommendations on CE governance.

The Academic Working Group

The Forum for Climate Engineering Assessment's Academic Working Group (AWG) on International Governance of Climate Engineering is an international group of senior academics that has been assembled to formulate perspectives on the international governance of climate engineering research and potential deployment, with a focus on proposed solar radiation management/albedo modification technologies. The group has been tasked with:

1. Assessing the existing SRM governance conversation;
2. Identifying key debates and open questions;
3. Providing a fresh, authoritative analysis of governance pathways; and
4. Producing crisp, policy-relevant recommendations.

For more information about the AWG, its membership, and its work, please visit www.ceassessment.org.

Main Points of Agreement in Existing Reports

The existing reports generally agree on a number of principles for CE governance, even if they do not always agree (or specify) how to translate these into concrete policies. This section identifies six nearly universal points of agreement and four additional principles that receive significant support with little or no opposition. These principles are at a high level of abstraction because the reports tend to differ about the details more than the general principles. The individual reports usually offer more detailed recommendations, as laid out in Part II of this report.

1. **If CE is ever deployed, it should be *in addition* to traditional mitigation and adaptation.** While not strictly a principle of CE governance, the idea that CE should only be considered as a *supplement* to traditional mitigation and adaptation is critical for thinking about CE and its governance. The existing reports are nearly unanimous in stating that if CE is ever deployed, it should only be *in addition* to aggressive efforts to reduce greenhouse gas emissions and to adapt to climatic changes; none of the reports contradict this claim. This central point of agreement entails that any governance regime for CE and CE research ought to assume that CE would play only a secondary role and that governance should minimize any interference with traditional mitigation and adaptation.
2. **Existing laws and institutions provide partial governance of CE but additional governance mechanisms are needed.** Existing international rules and institutions provide partial governance mechanisms for some aspects of CE. At least within the US and EU, existing national and regional rules and institutions would also apply to some aspects of CE. At all levels, however, governance remains patchy and incomplete. (The reports included here did not address national governance structures in other countries, but because the relevant governance structures in the US and EU were not, in general, developed specifically for CE, they are likely to have

analogues in many other countries. Other countries may need to create new institutions altogether.) There is currently no single instrument or institution that can be easily extended to cover all aspects of CE, either internationally or within individual countries. Different reports issue different recommendations about how to resolve this issue. The trend in the reports is toward a regime complex that divides governance functions vertically (i.e., between international instruments or institutions and domestic ones) and horizontally (i.e., across different kinds of instruments and institutions), using a mix of new and existing governance mechanisms.

3. **A general moratorium on CE research is inadvisable at this time.** The reports surveyed here mostly recommend against a general moratorium on CE research, although their reasons for doing so differ and some of the reports do recommend a temporary ban on large-scale field tests of solar geoengineering technologies (i.e., tests that would have a detectable impact on regional or global climate) or deployment of those technologies. The two main arguments are that research ought to proceed in order to gather information about the effectiveness, risks, and costs of various proposed technologies; and that a moratorium is unlikely to succeed because some states will refuse to comply and because so much CE research overlaps with basic climate science that a ban would be either unenforceable or overly restrictive. It is worth noting, however, that one prominent critic of CE, the ETC Group, has called for a blanket moratorium on CE research (ETC Group 2010, 40), and that the Conference of Parties to the Convention on Biological Diversity has recently issued non-binding resolutions prohibiting "climate-related [CE] activities that may affect biodiversity…with the exception of small scale scientific research studies…in a controlled setting…" (Convention on Biological Diversity 2010, 8(w)).[5]

[5] For further details and discussion, see (Convention on Biological Diversity 2011; Bodle et al. 2014, 58–60).

4. **Governance structures should encourage international cooperation and coordination on CE research.** Most of the reports explicitly encourage the development of international coordination and cooperation in CE research. Some reports that are addressed primarily to national or EU policymakers encourage national policymakers to think of their own research governance structures as potential models for other countries. Suggestions for implementing this proposal range from the development of shared voluntary norms to the creation of formal international research programs.
5. **If research does proceed, transparency and openness are critical.** The reports agree that CE research, and especially research in solar geoengineering, must be transparent and open, rather than proprietary or secret. The reports do not always specify or agree about exactly what transparency requires. There is broad agreement that researchers ought to publish their results, both positive and negative, in publicly accessible venues. Other suggestions include, e.g., international registries of all CE-related research and transparency about planning and funding of research.
6. **Public engagement is desirable.** The basic principle that CE governance ought to engage, consult, or otherwise involve the public is at once widely accepted and vehemently disputed. The reports almost unanimously endorse the idea that *some* kind of public engagement is either desirable or necessary for successful governance of CE, but they offer a wide range of ideas about what form such engagement should take and what objectives it would further.

The following principles receive support in a significant number of reports and face opposition in few, if any, of them, but fall short of near-universal support:

7. **Governance should be proactive rather than reactive.** About half of the reports explicitly advocate the proactive creation of governance regimes for various CE activities, though their

proposals differ in terms of the nature of and reasons for those regimes. The shared assumption, however, is that society ought not to wait until research progresses further before establishing some kind of governance regime. A few reports are silent on the question of timing. One suggests that governance should develop "in tandem with the expansion of research" (Bipartisan Policy Center 2011, 17).

8. **Governance arrangements should be flexible and adaptive.** Even while advocating that society establish a governance regime early on, many reports emphasize that these regimes will need to evolve as circumstances change (e.g., as our knowledge of CE increases or if some actors begin planning larger-scale experiments).
9. **For now, informal, soft-law approaches to CE governance are better than formal, hard-law approaches.** In keeping with the recommendation that governance remain flexible and adaptive, many of the reports recommend informal or "soft-law" approaches for the time being. These could take the form of the creation of voluntary codes of conduct among researchers, shared norms among researchers and research funders, memoranda of understanding between various international bodies that have jurisdiction over different aspects of CE, non-binding resolutions passed by such bodies, and so on.
10. **Governance must strike the right balance between legitimacy and effectiveness.** Many of the reports identified the need to balance legitimacy with effectiveness as one of the central challenges of CE governance. On the one hand, legitimate governance of technologies with such global social and physical impacts would seem to require an inclusive, deliberative approach. On the other hand, effective governance would seem to require a nimble, flexible, and adaptive governance regime that can respond quickly to changing circumstances. Balancing these requirements may prove difficult.

Key Unresolved Questions

While the principles articulated above suggest particular characteristics that a CE governance regime should have, they leave open many of the most basic questions about what shape a CE governance regime should take. This section lists a number of key unresolved questions that will need to be answered to translate the above principles into concrete policies and institutions.

1. **What are the objectives of CE governance?** The reports generally agree that a primary objective of CE governance is to manage the physical and political risks of CE research and potential deployment, but that agreement masks an important disagreement about the specific risk-risk trade-off involved in researching CE as opposed to prohibiting or foregoing that research: Some reports put greater weight on avoiding social and environmental risks associated with doing CE research, whereas others emphasize that the failure to research CE leaves society exposed to other sorts of risks (e.g., of "irresponsible deployment" by rogue actors or of hasty deployment that would be "less successful and have more undesirable side effects" [National Research Council 2015b, 150–151]). Furthermore, the reports disagree about whether CE governance ought to discourage, tolerate, or encourage various kinds of CE research. And finally, while the reports generally agree on the importance of public engagement in CE governance, they seem to disagree on the precise objectives of that engagement and its relationship to the overall objectives of CE governance.

2. **Which institutions should take on which functions of CE governance? How should these institutions and the various governance mechanisms at their disposal relate to one another?** One pressing practical question is who should do the work of governing CE. While many reports consider the possibility of a major new international institution or regime dedicated to CE governance, the trend in the reports is toward a more decentralized approach,

in which various existing national, supranational, and international institutions take on different aspects of CE governance. One report notes that instruments or institutions can govern either the general context in which CE is or is not pursued (e.g., its relationship to other policies and social objectives or the level of international cooperation involved in that research), particular CE activities (as, e.g., the London Convention/London Protocol is currently exerting authority over ocean fertilization), or particular effects of any possible CE option (as, e.g., the Convention on Biological Diversity has attempted to exert authority over any CE activities that affect biodiversity) (Schäfer et al. 2015, 82). Another report also suggests that governance functions could be divided vertically between international and national institutions, with international institutions articulating higher-level principles and national institutions translating those into concrete policies and decisions. For instance, the international community might agree on high-level principles prohibiting certain kinds of activities and providing general criteria for exemptions, leaving individual countries to operationalize those criteria and decide which specific projects meet them (Bodle et al. 2014, 21). Exactly how this sort of vertical division of labor would work remains an important open question, as well.

3. **Should there be an "allowed zone" for research? If so, how is it to be defined?** Several reports mention the idea of an "allowed zone" for research—that is, clearly delineated criteria for research that would be allowed to proceed. Operationalizing this idea requires determining what those criteria should be (and to which technologies they should apply), what kinds of governance mechanisms would apply to research within the "allowed zone" (or to different kinds of research in different "parts" of that zone), and how research outside that zone should be treated. The London Convention/London Protocol approach, in which ocean fertilization is prohibited except for legitimate scientific research meeting certain criteria, is frequently discussed as a potential model for such an approach. One report explicitly endorses such a

model, calling for a general prohibition on CE activities (as defined by a specific blacklist) with specific exemptions as defined by a clear whitelist of allowable research activities (Bodle et al. 2014, 20ff.). Taking a somewhat different approach, several reports distinguish various stages of CE research (e.g., modeling and laboratory studies, small-scale experiments, mesoscale experiments, etc.), which could be used to delineate "allowed zones" for research into different CE technologies. Research outside the "allowed zone" could be governed more strictly or prohibited altogether. A "hands-off" approach to CE research would simply extend the "allowed zone" to all research that is not governed by existing mechanisms.

4. **How should transparency be operationalized?** While the need for transparency is among the most commonly cited principles for CE research, the reports say relatively little about how to operationalize this principle. The primary literature contains some more detailed suggestions.
5. **What form should public engagement take and how should it shape CE research and governance?** Public engagement could take many forms and exert many different kinds of influence on CE research and governance at many different levels (e.g., at the level of individual experiments or the level of high-level criteria or objectives for national or international research programs or governance mechanisms). While the reports are virtually unanimous in emphasizing the importance of some kind of public engagement, they disagree on or decline to specify exactly what forms it should take, what its objectives are, or how it should influence CE research and governance.
6. **What role should precaution play in CE governance?** The European reports, in particular, advocate a precautionary approach to CE governance. This leaves open important questions about exactly what form of the precautionary principle to apply and what it implies for CE governance, given the risk-risk trade-offs involved in CE research.

Designing a working CE governance regime would, of course, require answering many more and more detailed questions. This short list provides a starting point, with the hope that many of those more detailed questions will arise naturally in the course of answering these questions.

Key Points from Past Reports on Climate Engineering

This section offers a closer look at the ten reports examined for this report. Each subsection includes some background information on a particular report, highlights some distinctive or important features of that report, and explains that report's main recommendations on CE governance. The goal of this section is both to provide more detail on each report's governance recommendations and to help guide readers to the reports that are most helpful for addressing particular issues.

2009

The NOVIM Report

Citation: Blackstock, Jason J., D. Battisti, K. Caldeira, D. E. Eardley, J. I. Katz, D. W. Keith, S. E. Koonin, A. A. N. Patrinos, D. P. Schrag, and R. H. Socolow (2009) *Climate Engineering Responses to Climate Emergencies*. Novim.

Commissioning Organization: The NOVIM Group, an independent organization based at UC Santa Barbara. Founded in 2007 to "provide clear scientific options to the most urgent problems facing mankind," NOVIM's executive board and science advisory board comprise ten senior scientists and engineers from academia and the technology industry.

Background: The report emerged from a weeklong meeting at UC Santa Barbara in 2008, which included some of the early key players in discussions of CE, such as Ken Caldeira, David Keith, and

Rob Socolow. The working group mostly restricted themselves to technical questions aimed at fleshing out a possible decade-long research program for assessing the effectiveness of stratospheric aerosol injection in responding to "climate emergencies."

Unusual Terminology: The report uses the terms *shortwave climate engineering* (SWCE) and *longwave climate engineering* (LWCE) in place of solar geoengineering and CDR, respectively. This terminology has not caught on.

Distinctive Features: The report specifically addresses the possible use of solar geoengineering to address "climate emergencies," defined as "circumstances where severe consequences of climate change [e.g., ice sheet loss or permafrost thawing] occur too rapidly to be significantly averted by even immediate mitigation efforts" (p. 1). Many researchers once saw solar geoengineering as a potential response to such climate emergencies, but this view of the technologies has generally fallen out of favor for a number of reasons, to be replaced by more moderate proposals, such as slowing the rate of temperature change or reducing peak warming in the context of major emissions abatement. The report discusses the governance challenges and opportunities that arise at various stages in a solar geoengineering research program and after deployment (pp. 24–29).

Key Recommendations:

1. "Optimally, international coordination or governance would guide all research (including placing limits on such research) and any deployment" (p. 44).
2. Since "the development of a dynamic multivariate control-system should be central to any deployed [SRM] intervention," governance would require "rapid (<<1yr) decisions about changes in some intervention variables." Governing bodies would therefore need to be nimble (p. 45).

3. If solar geoengineering were ever deployed, governance should include "methods for evaluating [its] impacts and arbitrating potential disputes" about loss and damage, paying special attention to the technical difficulty of attributing climatic impacts to solar geoengineering (p. 45).

The Royal Society Report

Citation: Shepherd, John G., K. Caldeira, P. Cox, J. Haigh, D. W. Keith, B. Launder, G. Mace, et al. (2009) *Geoengineering the Climate: Science, Governance and Uncertainty*. London: Royal Society.

Commissioning Organization: The Royal Society, the national academy of science for the United Kingdom.

Background: The first synoptic report on CE, the report examined various proposed methods for solar geoengineering and CDR and issued recommendations related to climate policy in general, CE research, CE governance, and public engagement surrounding CE. Several people who contributed to the report have remained key players in the discussion, including Ken Caldeira, David Keith, Andy Parker, and Steve Rayner.

Distinctive Features: The report touches on many of the topics that remain central to the science and governance of CE and has informed much of the discussion since then. It includes a well-known chart summarizing early estimates of the effectiveness, affordability, safety, and speed of various CE technologies (Figure 5.1, p. 49). It is one of the more prescriptive reports issued by any major body, especially with respect to governance. It is worth reading their main recommendations in detail. See the boxed texts on pp. 57–62.

Key Recommendations:

1. CE "is not a substitute for climate change mitigation, and should only be considered as part of a wider package" of climate policies (p. 58). "Nothing now known about [CE] gives any reason to diminish [traditional mitigation and adaptation] efforts" (p. 57).
2. "Emerging but as yet untested [CDR methods] should not be formally accepted as methods for addressing climate change under the UNFCCC" (p. 57), but "CDR methods that have been demonstrated to be safe, effective, sustainable and affordable…should be deployed…as soon as they can be made available" (p. 59) and the UNFCCC should begin specifying conditions under which CDR methods would be "considered as mechanisms under the UNFCCC" (p. 61).
3. Internationally coordinated research into solar geoengineering and CDR, including both technical and social aspects, should proceed, including "carefully planned and executed experiments" (p. 57, 61–62).
4. The international scientific community should establish a voluntary code of conduct for CE research (p. 61).
5. "Prior to any large-scale experimentation or deployment," CE technologies should be evaluated with respect to their legality; effectiveness; speed of acting; environmental, social, and economic impacts; costs; funding mechanisms; public acceptability; and reversibility (p. 59).
6. Public engagement regarding CE should begin promptly (p. 60).
7. An international body should begin working toward mechanisms to govern CE "research and deployment activities" (p. 60).

The Oxford Principles

In response to the Royal Society report, a group of scholars associated with the University of Oxford proposed a set of principles for CE governance. While they are not included verbatim in any of the reports surveyed here, no summary of early work on CE governance would be complete without a list of the so-called "Oxford Principles":

1. "Principle 1: [CE] to be regulated as a public good" and "in the public interest."
2. "Principle 2: Public participation in [CE] decision-making. Wherever possible, those conducting [CE] research should be required to notify, consult, and ideally obtain the prior informed consent of those affected by the research activities."
3. "Principle 3: Disclosure of [CE] research and open publication of results."
4. "Principle 4: Independent assessment of impacts. An assessment of the impacts of [CE] research should be conducted by a body independent of those undertaking the research…"
5. "Principle 5: Governance before deployment. Any decisions with respect to deployment should only be taken with robust governance structures already in place, using existing rules and institutions wherever possible."

The Oxford Principles were first articulated in (Rayner et al. 2009) and expanded upon in (Rayner et al. 2013).

2010

The Congressional Research Service Report[6]

Citation: Bracmort, Kelsi, R. K. Lattanzio, and E. C. Barbour (2010) *Geoengineering: Governance and Technology Policy*. Washington, DC: Congressional Research Service.

Commissioning Organization: The Science and Technology Committee of the U.S. House of Representatives commissioned this report from the Congressional Research Service, which is a legislative branch agency within the Library of Congress that provides nonpartisan policy and legal analysis to the U.S. Congress.

Background: The Science and Technology Committee of the U.S. House of Representatives held hearings on CE in 2009, under the direction of Rep. Bart Gordon of Tennessee (The British House of Commons had held similar hearings earlier in 2009.). Afterward, the Congressional Research Service authored this report as "a primer [for policymakers] on the policy issues, science, and governance of [CE] technologies" (p. 3).

Distinctive Features: The most salient feature of the report is its careful consideration of the applicability of existing U.S. law to CE technologies and of the roles that various U.S. government entities could play in CE governance, as well as a discussion of international treaties and institutions (pp. 24–38). Because the report is a primer written by a nonpartisan U.S. government agency, this report generally refrains from making recommendations or drawing conclusions about governance.

Key Recommendations:

[6] The Congressional Research Service issued a very slightly updated version of this report in 2013. To preserve the chronological order of reports, the 2010 report is included in this survey. All page numbers refer to the 2010 report.

1. "Different technologies may require different methods for oversight." Some forms of CDR may be adequately governed by existing domestic mechanisms, but technologies that would be researched or deployed on the high seas, in the upper atmosphere, or otherwise beyond national jurisdictions (e.g., some kinds of CDR and most solar geoengineering) would need international governance (pp. 21–22).
2. "Regulatory frameworks must be flexible enough to cover the full cycle [of research and possible deployment]," with different methods of oversight needed for different stages of research and development (p. 22).

The Asilomar Conference and Beyond

In March 2010, the Climate Institute brought 165 experts to Asilomar, CA to try to develop principles for CE research, much as genetic engineers had laid the groundwork for regulation of research into recombinant DNA at a famous meeting in Asilomar in 1975. The Asilomar International Conference on Climate Intervention Technologies reached only a vague consensus. The conference report expresses that consensus in five carefully-worded principles that call for a transparent international research program that would be subject to independent assessment and some form of governance that includes public consultation. The discussion of those principles is worth reading as an expression of the views of the CE research community as it entered its first phase of major expansion (Asilomar Scientific Organizing Committee 2010, 17–24).

Other large conferences have often involved extensive discussion of governance, but they have not generally aimed to reach consensus about governance regimes or principles. The reports from these conferences still provide useful insight into the evolution of the CE research community's attitudes about governance. One notable exception occurred during the Climate Engineering Conference 2014 in Berlin, when another attempt to reach consensus about CE governance resulted in a deadlock. The so-called "Berlin Declaration," introduced by some conference participants, met resistance from both those who found it too permissive and those who found it too constraining. A counterproposal also failed to achieve consensus (Institute for Advanced Sustainability Studies 2014, 28–30).

2011

The Bipartisan Policy Center Report

Citation: Bipartisan Policy Center (2011) *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies.* Washington, DC.

Commissioning Organization: The Bipartisan Policy Center (BPC) is a think tank in Washington, DC that "actively promotes bipartisanship" in tackling "the key challenges facing the [United States]" in the areas of "health, energy, national and homeland security, the economy, housing, immigration, infrastructure, and governance."

Background: In March 2010, the BPC convened a "Task Force on Climate Remediation Research" to "develop recommendations for the U.S. government concerning geoengineering research and oversight policy." The Task Force included a number of key players in the discussion of CE, including Jane Long, Ken Caldeira, Steve Hamburg, David Keith, Granger Morgan, Dan Sarewitz, John Shepherd (lead author of the *Royal Society* report), David Victor, and David Winickoff.

Unusual Terminology: The report uses the term *climate remediation* to refer to all forms of CE. This terminology has not caught on and provoked some criticism even from members of the task force.

Distinctive Features: Chapter III of the report (pp. 16–21) provides detailed recommendations for establishing a CE research program under the auspices of the U.S. federal government, including an analysis of the likely contributions and limitations of different government entities in connection with such a program. It also discusses a few examples of successful, informal international research collaboration as potential models for CE research (p. 32).

Key Recommendations:

1. The U.S. government should begin a coordinated research program on solar geoengineering and CDR (p. 12), integrating the natural and social sciences throughout the research process (p. 20).

2. The government should promote international cooperation on CE research among countries that are scientifically, technologically, and financially capable to participate in that research; but for now, it should do this through informal and soft-law approaches (pp. 14, 31).
3. The White House's Office of Science and Technology Policy should take a lead role in the U.S. research program (p. 17), advised by a commission staffed with "natural scientists, engineers, social scientists, lawyers, and others with expertise relevant to developing the parameters for [CE] research," whose remit would include scientific, ethical, legal, and social issues, including "criteria…to use in deciding whether to approve field research" (p. 19).
4. Governance structures should promote transparency about CE research, including open publication of both positive and negative results, as well as facilitate ongoing communication and engagement with the public (pp. 14, 19).

The Kiel Earth Institute Report

Citation: Rickels, Wilfried, G. Klepper, J. Dovern, G. Betz, N. Brachatzek, S. Cacean, K. Güussow, et al. (2011) *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 (BMBF).* Kiel: Kiel Earth Institute.

Commissioning Organization: The German Federal Ministry of Education and Research, known by its German acronym BMBF, is a cabinet-level agency of the German government that funds a wide range of research activities and sets high-level educational policy at the federal level.

Background: The BMBF commissioned this scoping report from the Kiel Earth Institute, a "virtual institution" founded by two academic institutions in Kiel, Germany: the Helmholtz Center for Ocean Research Kiel (also known as GEOMAR) and the Kiel Institute for the World Economy.

The Kiel Earth Institute and affiliated academics have played a significant role in CE-related research, and most of its authors have continued to play important roles in international discussions of CE.

Distinctive Features: This is the second synoptic report on CE, after the Royal Society report. It is especially noteworthy for its comprehensive argument map of the CE debate (p. 23) and its discussion of the relevance of various international legal instruments to particular CE technologies (pp. 85*ff*).

Key Recommendations:

1. To manage social concerns about risk, governance processes must engage stakeholders early on (p. 72).
2. "[A]ny successful regulation of [CE] must prevent moral hazard and slippery-slope dynamic[s] from manifesting themselves while keeping open the option of terminating a CE deployment" (p. 115).

The following recommendations comprise the report's six concluding "requirements" for successful international regulation of CE:

1. "Research into, and the technical evaluation of, [CE] should be coordinated internationally so as to prevent the process from gathering its own momentum as much as possible" (p. 115).
2. "The evaluation of options, costs and dangers of [CE] should take place in two stages. The CE [research coordinating] agency…should summarize research and interpret the outcomes in a practically relevant manner. As a second step, the evaluation and classification of the research outcomes should then be undertaken by an independent supervisory committee" (p. 115).

3. "On the basis of the supervision carried out by the independent committee, the member states of the UNFCCC would make decisions about norms and rules" about which technologies to develop, which field research to allow, which technologies to deploy under which conditions, and perhaps what limits to impose on deployment intensity (p. 117).
4. "Within a regulatory framework, a definition should be provided as to how the expenditure of resources for the control of emissions on the one hand and CE deployment on the other can be compared" (p. 117).
5. "Parallel with the [implementation of the previous recommendations], additional regulations should also be created, which are capable of reducing the slippery slope problem." This could include a "time-limited moratorium" on deployment of particular technologies (p. 118).
6. "In the event of a state unilaterally abandoning a CE technology being carried out on a multilateral basis, this state should be obliged to increase its emission reduction efforts significantly" (p. 118).

The SRMGI Report

Citation: Solar Radiation Management Governance Initiative. 2010. *Solar Radiation Management: The Governance of Research.*

Commissioning Organization: The Solar Radiation Management Governance Initiative, better known by its acronym SRMGI, is a joint venture of the Environmental Defense Fund (EDF), the Royal Society, and The World Academy of Sciences (TWAS). Established to engage voices from around the world in the discussion of SRM and SRM research governance, SRMGI has conducted

workshops and outreach meetings in China, Ethiopia, India, Pakistan, Senegal, South Africa, and elsewhere.

Background: This report summarizes the results of the Initiative's first year, leaning heavily on a March 2011 conference in the UK that included 27 experts from 17 countries and input from a number of NGOs. The report, like the SRMGI, focuses exclusively on SRM. Neither the March 2011 conference nor the Initiative's various meetings around the world aspired to frame explicit recommendations, but the report highlights several "emerging conclusions" that received widespread support during the conference.

Distinctive Features: The SRMGI draws on a much more geographically diverse group of participants than the other reports. Interesting features of the report include a discussion of the various functions of CE governance (p. 30) and the different levels at which governance might occur (pp. 35–38), requirements for perceived legitimacy of a CE governance regime (pp. 41*ff.*), and some useful comparisons to governance of other contentious technologies (e.g., pp. 33–36, 46).

Key Recommendations:

1. "Nothing known currently about [solar] geoengineering provides any reason to reduce efforts to mitigate climate change by reducing greenhouse gas emissions, and to adapt to its effects" (p. 56).
2. "[G]overnance arrangements…should be developed before any such proposals [for risky forms of solar geoengineering research] are considered" (pp. 54–55).
3. "Managing the trade-off between inclusivity and effectiveness [in a governance regime] will be central to ensuring that decisions can be taken in a timely manner without being impaired by deliberative processes" (p. 56).
4. "A moratorium on all [solar geoengineering-related] research would be difficult if not impossible to enforce" (p. 9).

5. Transparency and openness of CE research is important. Conference participants exhibited "a high level of support for an international register of [solar geoengineering] research and experiments as a means of facilitating information sharing" (p. 55; *see also* p. 49).
6. Defining the boundary between "small-scale" outdoor research and mesoscale and large-scale research, which would need different kinds of governance, is a central challenge of CE governance (pp. 48–50).

The Wilson Center Report

Citation: Olson, Robert L. (2011) *Geoengineering for Decision Makers: Science And Technology*. Washington, DC: Woodrow Wilson International Center for Scholars.

Commissioning Organization: The Wilson Center is a non-partisan think tank based in Washington, DC.

Background: David Rejeski, the Wilson Center's Director of Science and Technology Innovation Program, commissioned this report from Robert Olson, a Senior Fellow at the Institute for American Futures.

Distinctive Features: The report aims to provide a comprehensive, accessible introduction to both solar geoengineering and CDR. The report is noteworthy for its accessibility, its long list of detailed recommendations for policymakers, and its detailed discussion of possible mechanisms for anticipatory, upstream governance (pp. 32–37).

Key Recommendations:

1. "Always consider [CE] issues in a broader context of *climate change management*, which includes emissions reduction as the primary strategy and adaptation as the secondary strategy, with [CE]

as a third strategy to use only if clearly needed" (p. 41), but "do not take [CE] off the table" (p. xi).

2. "Do not allow [CE] to be used as a source of carbon offsets, because this would divert efforts from emissions reduction" (p. 42).
3. For high-risk technologies (e.g., solar geoengineering), use "upstream governance approaches that begin at the earliest stage of theoretical and modeling studies…. Many strategies have been used in other areas of technological development, and some or all of them can be integrated into a framework for the upstream governance of higher risk [CE] technologies" (p. 42). [See pp. 32–37 for details.]
4. "[I]t is important for government and the scientific community to insist that all [solar geoengineering] research be in the public domain, and to stand firm in a commitment to openness, transparency and accessibility" (p. 43), and policy makers should "support the development of a coordinated, fully transparent international [research] effort in which the work of individual scientists and national programs is integrated into an international framework" (p. 44).
5. "A moratorium on large-scale or climate impact testing should be put in place until a legitimate international process for approval and oversight has been agreed upon" (p. 44).
6. "A possible model for an international mechanism for approval and oversight of large-scale testing is provided by the approach taken by the London Convention and London Protocol for regulating ocean fertilization experiments" (p. 44).
7. "Downstream governance arrangements need to be developed for authorizing both large-scale testing and actual deployment. Decisions on these matters [ought not] be made by one country or a few countries and imposed on the international system [but] it may be premature to start a

full-scale UN treaty-making effort. At this point, the important task is to organize informal but focused international dialogues about needed downstream governance arrangements" (p. 44).

2014

The Ecologic Institute Report

Citation: Bodle, Ralph, S. Oberthür, L. Donat, G. Homann, S. Sina, and E. Tedsen (2014) *Options and Proposals for the International Governance of Geoengineering.* Berlin: Ecologic Institute.

Commissioning Organization: The German Federal Environment Agency (*Umweltbundesamt*) is the German government's main environmental protection agency.

Background: The Ecologic Institute, an independent think tank in Berlin, prepared this report on CE governance for the German Federal Environment Agency, with the goal of identifying "general options and specific [implementable] recommended actions for the effective governance" of [CE].

Distinctive Features: The report is noteworthy for its exclusive focus on governance; its detailed analysis of existing legal frameworks at the German, EU, and international levels (pp. 49–120); its detailed analysis of governance options (e.g., pp. 156*ff.*), both generally and with respect to specific technologies; its detailed proposals; its careful attention to the objectives of CE governance (pp. 171*ff.*); and its annex summarizing some of the major governance proposals from the primary literature (pp. 176–185).

Key Recommendations:

The authors recommend five high-level principles for CE governance (p. 172):

1. Governance "should implement a precautionary approach in respect of the risks of [CE]."
2. Governance "should facilitate broad international participation and acceptance."

3. Governance "should avoid or at least minimize any direct or indirect undermining of climate mitigation efforts."
4. Governance "should aim at a high level of legitimacy, including through (public) participation and transparency, in particular with respect to (i) general rule-making, (ii) case-specific decision-making on any proposed concrete [CE] activity in the field, and (iii) any actual permitted [CE] activity, e.g., through monitoring and reporting;"
5. Governance "should allow for a sufficient level of flexibility in order to be able to respond to new scientific knowledge as well as the evolving public debate on [CE]."

Furthermore, they offer the following more concrete recommendations:

1. There should be "a general prohibition of [CE] activities that entail significant transboundary risks [especially ocean fertilization and solar geoengineering], combined with the possibility of exemptions. The prohibition would in principle also apply to research activities such as field experiments, but not to e.g. modelling." This could be implemented through "a positive list of the [CE] techniques covered by the prohibition," complemented by "a non-exhaustive list of the criteria used in establishing the prohibition and determining its scope in combination with a regular review of the positive list," and a "clear framing of the exemptions," based on "a transparent decision-making process applying strict and clear criteria," which would "enable legitimate research to proceed" (p. 172).
2. There should be a "vertical division of labor," with international bodies laying out general criteria and principles via informal and soft-law approaches, leaving it to individual states to create the lists of prohibitions and exemptions (p. 173).
3. "[G]overnance of [CE] research…be integrated into the general governance arrangements," rather than being addressed "separately from, and earlier than, any 'deployment' of [CE] techniques." This is because (1) "there is no clear-cut separation" of research and deployment,

and (2) "any such separate governance structures for research would be likely to provide an important precedent and blueprint for the governance of deployment" (p. 173).

4. Governance should build on existing institutions, rather than create new ones (p. 174), with the Convention on Biological Diversity being "the prime candidate for becoming the central institution recognised as a first point of contact," with the UNEP "a second-best solution" (pp. 174–175).
5. The UNFCCC is not a suitable venue for governance of CE, though it may play a role in governance of encapsulated forms of CDR (p. 174).

2015

The NAS Reports

Citation, Vol. 1: National Research Council (2015) *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration.* Washington, DC: The National Academies Press.

Citation, Vol. 2: National Research Council (2015) *Climate Intervention: Reflecting Sunlight to Cool Earth.* Washington, DC: The National Academies Press.

Commissioning Organization: The U.S. National Academy of Sciences (NAS) is an independent, non-profit organization chartered by Congress in 1863. Now part of the National Academies of Sciences, Engineering, and Medicine, NAS advises the federal government on scientific and technical matters.

Background: In 2012, the U.S. government asked the NAS to prepare a report on CE. The NAS established a committee for this purpose within the National Research Council, which is the research arm of the National Academies. The committee consisted of physical scientists, many of whom had been prominent players in discussions of CE for a decade or more. The committee

divided their report into two volumes, on CDR and solar geoengineering respectively, to stress the differences between those two kinds of CE. The report aspires to a comprehensive review of the existing scientific literature on CE.

Unusual Terminology: The report uses the term *climate intervention* instead of *climate engineering* because the latter term "implies a greater level of precision and control than might be possible" (p. viii). The term *climate intervention* has gained more traction than have earlier attempts to relabel CE, but it is still not in widespread use within the CE research community. The report also uses the less common term *albedo modification* in place of *solar geoengineering* or *solar radiation management*.

Distinctive Features: Because of the significant increase in the study of CE since the first round of comprehensive reports (e.g., the Royal Society report and the Kiel Earth Institute's Scoping Report), the NAS reports synthesize a much broader knowledge base than those earlier reports do. But because the committee includes only physical scientists and because of their explicit charge to report on technical matters (Vol. 2, p. 215), these reports says less about governance than do other recent reports. Still, the reports do make some specific recommendations about governance, especially with respect to solar geoengineering research. Furthermore, Volume 2 summarizes the history of the solar geoengineering governance debate, foregrounding certain ideas and proposals in ways that might be interpreted as implicit support for those ideas, especially when read in light of the report's suggestion that "[t]he goal of governance should be to maximize the benefits of research while minimizing risks" (Vol. 2, p. 13).

Key Recommendations:

1. While emphasizing that emissions reductions and traditional adaptation must remain the top priorities in climate policy (Vol. 2, p. 3), and advising that large-scale solar geoengineering "should not be deployed at this time" (Vol. 2, p. 9), the committee "recommends research and development investment to improve methods of carbon dioxide removal and disposal at scales

that would have a global impact on reducing greenhouse warming, in particular to minimize energy and materials consumption, identify and quantify risks, lower costs, and develop reliable sequestration and monitoring" (Vol. 2, p. 6).

2. "The committee recommends [a solar geoengineering] research program be developed and implemented that emphasizes multiple-benefit research that also furthers basic understanding of the climate system and its human dimensions" (Vol. 2, pp. 9–10).
3. "The committee recommends the initiation of a serious deliberative process to examine (a) what types of research governance, beyond those that already exist, may be needed for [solar geoengineering], and (b) the types of research that would require such governance, potentially based on the magnitude of their expected impact of radiative forcing, their potential for detrimental direct and indirect effects, and other considerations" (Vol. 2, pp. 12–13).
4. Governance "should be targeted at ensuring civil society involvement in decision making through a transparent and open process. It should focus on enabling safe and useful research on the viability and impacts of [solar geoengineering] strategies" (Vol. 2, p. 12).
5. "If a new governance structure is determined to be needed…the development of the governance structure should consider the importance of being transparent and having input from a broad set of stakeholders to ensure trust among the stakeholders and appropriate consideration of all dimensions" (Vol. 2, p. 13).
6. Governance structures "should consider setting clear and quantitative guidelines for experimentation and be responsive to domestic and international laws and treaties" (Vol. 2, p. 13), creating a clear "allowed zone" for solar geoengineering research, within which research would be subject only to domestic environmental regulation (Vol. 2, pp. 155*ff.*), and beyond which research would become subject to increasing levels of governance (Vol. 2, pp. 13).

7. While "it is premature to engage in a larger discussion of governance of deployment given the large uncertainties about [solar geoengineering]," it "is important to give careful thought to the mechanisms for governing research on [geoengineering], since they may later form part of the basis for a mechanism for governing sanctioned or unsanctioned deployment should a choice ever be made to proceed to that stage" (Vol. 2, p. 149).

The EuTRACE Report

Citation: Schäfer, S., M. Lawrence, H. Stelzer, W. Born, S. Low, et al. (2015) *The European Transdisciplinary Assessment of Climate Engineering (EuTRACE): Removing Greenhouse Gases from the Atmsophere and Reflecting Sunlight Away from Earth.*

Commissioning Organization: The European Transdisciplinary Assessment of Climate Engineering (EuTRACE) project is a joint venture of 14 European organizations from Germany, the UK, Norway, France, and Austria. The project brought together several dozen leading European CE researchers from a range of disciplines, including many of the leading European figures in the discussion of CE.

Background: This report synthesizes the various researchers' findings on the scientific, social and ethical aspects of CE during the multi-year EuTRACE project. Like the NAS reports, the EuTRACE report synthesizes a much broader knowledge base than the first round of reports. Its authors include many of the same researchers who contributed to the Kiel Earth Institute's Scoping Report in 2011 and who have made significant contributions to the discussions of CE and CE governance in the intervening years.

Distinctive Features: The report is noteworthy for its extensive discussion of governance, including: its tripartite distinction between context-focused, activity-focused, and effect-focused

governance; its detailed discussion of the state of and potential for governance by the UNFCCC, the Convention on Biological Diversity, and the London Convention/London Protocol; and its detailed discussion of EU governance options.

Key Recommendations:

The report articulates several high-level principles for CE governance:

1. "The minimisation of harm: The risk of individuals being exposed to harm from [CE], the number of people exposed to risks, and the magnitude of the potential harm should all be kept as low as possible, and serious and irreversible harm should be avoided" (p. 109).
2. "The precautionary principle is to be applied in situations of scientific uncertainty. It demands preventive measures against plausible environmental and human health threats that are serious or irreversible. Necessary and appropriate precautionary measures may be permitted or even required…when the best available scientific and technical data indicate the existence of risks. In order to decide on appropriate precautionary measures, policy makers need to define the appropriate level of protection to be applied, and the severity, persistence, and reversibility of the potential impact, were a threat to transpire" (p. 109).
3. "The principle of transparency**:** The principle of transparency calls for the open distribution of relevant information about research activities" (p. 109).
4. "The principle of international cooperation requires action to be undertaken involving the international community as far as possible, in order to build global legitimacy and peaceful resolution of possible conflicts of interest and legal disputes" (p. 109).
5. Both CDR and some kinds of SRM "may be understood as public goods, allowing for the regulation of such techniques in the public interest" (p. 110).
6. The high-level principles expressed above can be operationalized, in part, through mechanisms such as "early public engagement," "independent assessment," "disclosure mechanisms [for]

transparency," "international codes of conduct," and "responsible innovation and anticipatory governance" (pp. 110–111).

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Appendix 1. Relevant International Instruments and Institutions

This appendix lists the various international legal instruments and institutions discussed in the reports as potentially relevant to CE governance. Several of the reports also discuss relevant instruments and institutions in the U.S. (CRS, Bipartisan Policy Center [BPC], NAS), the UK (Royal Society), Germany (Keil Earth Institute [KEI], Ecologic, EuTRACE), and the EU (KEI, Ecologic, EuTRACE).

INSTRUMENT/INSTITUTION	REFERENCE(S)
International Legal Instruments	
UN Framework Convention on Climate Change (UNFCCC)	NOVIM, Royal Society, CRS, KEI, SRMGI, Ecologic, NAS, EuTRACE
UN Convention on the Law of the Sea (UNCLOS)	Royal Society, CRS, KEI, SRMGI, Ecologic, NAS
London Convention/London Protocol (LC/LP)	Royal Society, CRS, KEI, Wilson Center, Ecologic, NAS, EuTRACE
Convention on Biological Diversity (CBD)	Royal Society, CRS, KEI, SRMGI, Wilson Center, Ecologic, NAS, EuTRACE
UN Convention to Combat Desertification (UNCCD)	Royal Society, KEI, Ecologic
Long-Range Transboundary Air Pollution Convention (CLRTAP)	Royal Society, CRS, KEI, SRMGI, Ecologic, NAS
Outer Space Treaty (OST)	Royal Society, KEI, SRMGI, Ecologic, NAS, EuTRACE
Moon Treaty	Royal Society, Ecologic
Environmental Modification Treaty (ENMOD)	Royal Society, CRS, KEI, SRMGI, Ecologic, NAS, EuTRACE

Vienna Convention/Montreal Protocol	Royal Society, CRS, KEI, SRMGI, Ecologic, NAS, EuTRACE
Antarctic Treaty System	SRMGI
Chicago Convention on International Civil Aviation	Ecologic
Convention on Migratory Species (CMS)	Ecologic
International Institutions	
IPCC	NOVIM, Royal Society, KEI
World Climate Research Program (WCRP)	NOVIM, BPC
International Geosphere-Biosphere Program (IGBP)	NOVIM
UN Commission for Sustainable Development	Royal Society
World Meteorological Organization (WMO)	Royal Society
International Council for Science (ICSU)	Royal Society
Earth System Science Partnership	Royal Society
UN Environment Programme	SRMGI
International Maritime Organization (IMO)	SRMGI
International Risk Governance Council	Wilson Center