The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques

Conference Report

Prepared by the

Asilomar Scientific Organizing Committee

November 2010

Climate Institute
Washington DC

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Asilomar Scientific Organizing Committee*

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Abstract

Despite ongoing efforts to reduce emissions and adapt to the changing climate, global greenhouse gas emissions are far above what is required to reverse the increasing changes in atmospheric composition. In response to growing calls for research to explore the potential for climate engineering to provide additional options for responding, the *Asilomar International Conference on Climate Intervention Technologies* was held at the Asilomar Conference Center in California from March 22 to 26, 2010. The conference attracted a diverse group of experts from fifteen countries on six continents. Presentations and discussions covered the two major categories of climate engineering: (a) *remediation technologies*, such as afforestation, carbon removal, and ocean fertilization, that attempt to reduce the causes of climate change, and so represent an extension of mitigation, and (b) *intervention technologies*, such as solar radiation management, that attempt to moderate the results of having altered atmospheric composition, and so represent an extension of adaptation to climate change. To promote the responsible conduct of research on climate engineering, recommendations were made to adopt five principles: (1) climate engineering research should be aimed at promoting the collective benefit of humankind and the environment; (2) governments must clarify responsibilities for, and, when necessary, create new mechanisms for the governance and oversight of large-scale climate engineering research activities; (3) climate-engineering research should be conducted openly and cooperatively, preferably within a framework that has broad international support; (4) iterative, independent technical assessments of research progress will be required to inform the public and policymakers; and (5) public participation and consultation in research planning and oversight, assessments, and development of decision-making mechanisms and processes must be provided. The conferees concluded that expanding and continuing the discussion with an even broader set of participants will be an essential step in moving forward to explore the potential benefits, impacts, and implications of climate engineering.

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In Memoriam

Dr. Stephen Schneider
(1945 - 2010)

**Our colleague and friend,
who dedicated his professional career
to increasing understanding and communicating
how human activities are affecting
the climate, the environment, and society—
and how we all can make the world a better place**

THE
CLIMATE
RESPONSE
FUND

November 2010

Dear Friends and Colleagues,

The Climate Response Fund (CRF) is proud to have been able to organize the **International Conference on Climate Intervention Technologies**, held at the Asilomar Conference Center from March 22-26 2010.

We were pleased to have had Dr. Michael MacCracken, Chief Scientist of the Climate Institute in Washington DC, and the other leading scientists from around the world, serve on the Scientific Organizing Committee for the Conference. As all who attended agreed, the Conference, with its wide range of speakers and extensive time for discussions, provided a unique opportunity and format to advance international consideration of ways to ensure the safe conduct of research on climate engineering as it moves forward.

The conference recalled the important role that early agreement on guidelines by the recombinant DNA research community played in limiting the research risk and clearing a path for that research. The guidelines that emerged from that conference became key elements in ensuring the safety of that research, and the conference itself set a precedent for discussion of science for which risks are associated with research. The Asilomar Conference, held just 7 months ago, has already helped to significantly expand the scope and breadth of international discussion and has prompted greater and deeper thinking about research on climate engineering.

We are pleased to be able to make the results of the Conference available to you. The report summarizes the results of the discussions that took place at Asilomar and the recommendations that emerged from these deliberations. As calls for climate engineering research spread more widely, we hope that the open collegial dialogue among multiple constituencies that participants referred to as the 'spirit of Asilomar' will continue. Even more important, as climate impacts accelerate, we hope that building understanding about climate engineering will help the international community understand potential responses to the increasingly serious climate change issue more completely.

Finally, I want to take this opportunity to thank our strategic partner and financial contributor, the State of Victoria, Australia; and our other financial contributors: the William K Bowes, Jr. Foundation, the Franklin P. and Catherine Johnson Foundation, the Altman Family Foundation, the Qualcomm Matching Gift Program, The Swig Family Foundation, Danielle Guttman-Klein and Robert Klein, John Friedenrich, Carin and Alan Trounson, and the Ueberroth Family Foundation. Our organizational partners included the Environmental Defense Fund, the Pew Center on Global Climate Change, the Royal Society, and Guttman Initiatives. I also want to thank the staffs of the Climate Institute and Climate Response Fund. All were critical to ensure the successful conduct and outcome of the meeting.

Sincerely,

Margaret Leinen

Margaret Leinen, Ph.D.
President and Chair
Climate Response Fund

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Clockwise, from top left: Robert Socolow; Lisa Dilling and Floyd DesChamps; Scott Barrett; Tom Wigley; Graeme Pearman, Timothy Persons, James Wilsdon and Pablo Suarez; Graeme Pearman and Stephen Schneider; Catherine Redgwell

The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques: Conference Report

Prepared by the
Scientific Organizing Committee

Executive Summary

Motivated by the prospective disruption of the world's climate, the Royal Society (Royal Society, 2009), the National Academy of Sciences (NAS, 2010), and several professional societies (AMS, 2009; AGU, 2009) have recently all called for research to explore potential approaches for moderating global climate change using geoengineering. These reports and statements do not advocate the application of such approaches, instead making clear that significant research will be needed before any form of geoengineering can be considered a practical policy option. In making these recommendations, it is also understood that geoengineering will neither be able to ensure a better and benign climate nor be able to counter-balance all aspects of climate change. However, with the accelerating emergence of climate change impacts and the extended time that it will take to slow and reverse them, these prominent groups have become convinced that it is essential to initiate research to determine if geoengineering has the potential to become a viable and acceptable approach for limiting at least some impacts.

In response to the growing calls for geoengineering research, the *Asilomar International Conference on Climate Intervention Technologies* was held at the Asilomar Conference Center in California from March 22 to 26, 2010. The conference attracted over 165 experts from academic institutions, governmental and nongovernmental organizations, and the business community from fifteen countries on six continents. Their expertise covered Earth, environmental, and social sciences, risk assessment, public policy, ethics, philosophy, history, economics, international law, and more. In addition, a variety of media representing the science press, newspapers, periodicals, book authors, and documentarians also attended.

Conference Context

The results of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) and more recent research (Copenhagen Diagnosis, 2009; UNEP, 2009) provided the context and impetus for the Conference, especially the increasing indications that human-induced climate change poses a grave global risk that demands a vigorous, effective, and sustained response. Without aggressive pursuit of a multi-faceted global response strategy to limit and then reverse climate change, the environmental consequences will be severe, with concomitant social costs that are likely to lead to widespread suffering in the most affected regions.

The first component of the global strategy must be an aggressive effort to reduce emissions, generally referred to as *mitigation*. Large, near-term reductions in global emissions of greenhouse gases, which are the primary cause of the intensifying climate disruption, are essential—but are not likely to be sufficiently rapid and large to avoid serious consequences. The second essential element of the global strategy must thus be *adaptation*. Worldwide actions will be needed to build resilience to the increasing pace of change and to adapt to the intensifying changes in climate, sea level rise, and ocean acidification caused by past and continuing emissions.

Despite ongoing efforts to reduce emissions and to adapt to the changing climate, global greenhouse gas emissions are far above what is required to stop, no less reverse, the increasing changes in atmospheric composition. Even after the significant reductions in global emissions that are being called for by 2050 in the Copenhagen Accord, several decades will pass before the pace of global climate change slows and its consequences moderate. This discouraging situation and the potential to preserve important ecological services and societal benefits have led to calls for geoengineering, more appropriately referred to as *climate engineering*, to become an additional component of the global response strategy (e.g., Crutzen, 2006; Wigley, 2006).

Climate engineering can be subdivided into two major categories. The first category is *remediation technologies*, such as afforestation, carbon removal, and ocean fertilization, that attempt to reduce the causes of climate change, and so represent an extension of mitigation. The second category is *intervention technologies*, such as solar radiation management, that attempt to moderate the results of having altered atmospheric composition as a result of greenhouse gas emissions. If research demonstrates that such approaches could be effectively and responsibly deployed, they could contribute to a bridging strategy that would have the potential to moderate climate change and at least some of its impacts until sharp cuts in emissions return atmospheric composition and climate change to much lower levels.

Principles for Responsible Conduct of Climate Engineering Research

While there are indications that at least some of the climate engineering approaches have the potential to be useful complements to aggressive mitigation and adaptation, research on and understanding of the various proposals is very limited. Even as understanding improves, the complexities and interconnections of the climate system, the environment, and society require that proposals to intervene to reduce short-term, decadal-scale climate impacts be approached with humility, and consideration of proposals for long-term, century-scale climate modification be viewed with extreme hubris. While modeling studies, consideration of natural analogs, and other non-invasive experimentation can likely provide useful insights and guidance, field experiments are very likely to be required to reduce the substantial uncertainties and limitations in the results of the interventions now being suggested. Indeed, even with such information, it is likely that significant questions will still remain. Thus, in proceeding with the research effort, considerable caution is in order.

While traditional structures and norms governing scientific research can likely provide an initial level of oversight and evaluation, large-scale experiments will unavoidably carry some risk of harm to some groups. Because of this, responsibility for coordination and governance of the overall research effort and for testing plausible deployable approaches is likely to require additional mechanisms that encompass both scientific considerations and public perspectives and interests. Thoughtful involvement of the world's governments, both individually and collectively, was viewed as a helpful step and should be considered a necessary precursor and prerequisite before moving forward with large-scale, *in situ* research.

In thinking about how to address the audacity of intentional human management of the global climate system, a sense emerged that the governance system would need to address to address a range of considerations. Drawing particularly on the *Draft Principles for the Conduct of Geoengineering Research* (Rayner et al., 2010), often referred to as the Oxford Principles, five principles emerged that would likely help to add confidence to the efforts of the international scientific community by promoting the safe, responsible, and effective pursuit of what is viewed as essential research. These principles are:

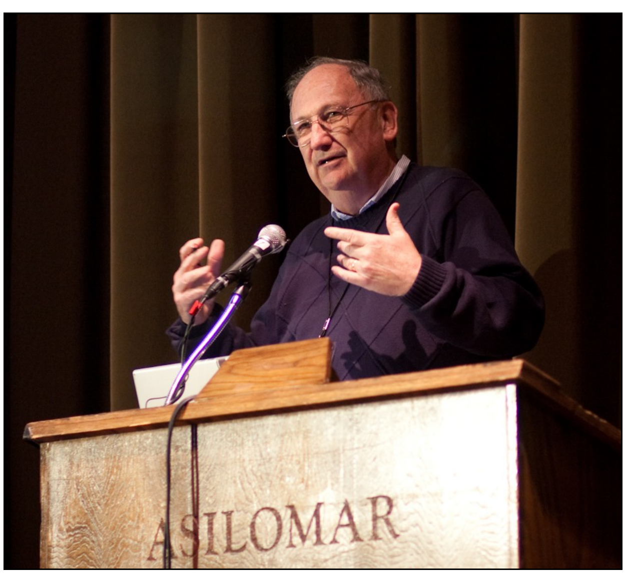
1. ***Promoting collective benefit***: Promoting the collective benefit of humankind and the environment must be the primary purpose of research conducted to develop and evaluate the potential for climate engineering technologies to moderate or reverse human-induced climate change.
2. ***Establishing responsibility and liability***: Governments must clarify responsibilities for, and, when necessary, create new mechanisms for the governance and oversight of large-scale climate engineering research activities that have the potential or intent to significantly modify the environment or affect society. These mechanisms should build upon and expand existing structures and norms for governing scientific research and, in the event of damaging outcomes, establish who would bear the cost and the degree of liability and proof that are required.
3. ***Open and cooperative research***: Climate-engineering research should be conducted openly and cooperatively, preferably within a framework that has broad international support. Research activities with the potential to affect the environment in significant ways should be subject to risk assessment, taking into account the risks and their distribution associated with both the activity itself and the ongoing limits to understanding if the experiment is not conducted.
4. ***Iterative evaluation and assessment***: Iterative, independent technical assessments of research progress on climate engineering approaches will be required. Assessing potential intended and unintended consequences, impacts, and risks will be critical to providing policymakers and the public with the information needed to evaluate the potential for climate engineering to be implemented as a complement to mitigation and adaptation.
5. ***Public involvement and consent***: Public participation and consultation in research planning and oversight, assessments, and development of decision-making mechanisms and processes must be provided to ensure consideration of the international and intergenerational implications of climate engineering.

As the conference concluded, there was agreement that the *Asilomar International Conference on Climate Intervention Technologies* had provided an invaluable opportunity to explore the conditions and precautions appropriate to consider in the undertaking of climate engineering research. Expanding and continuing the discussion with an even broader set of participants would not only be beneficial, but will also be essential so that the world community has the opportunity to participate in considering the potential benefits, impacts, and implications of climate engineering.

Introduction

Climate is a fundamental determinant of the diversity and distribution of life on Earth. It encompasses the cycle of the seasons, reliability of the monsoons, sequences of weather patterns, occurrence of extreme events, tracks of storms, and the variation of each year's conditions around the long-term average that characterize each region's environment. Within each climatic zone, plant and animal species have developed and become integral components of complex terrestrial and oceanic ecosystems that provide the bounty on which societies have come to depend over the last several thousand years. Societies, in turn, have evolved to take advantage of prevailing climate conditions and their region's ecological resources and services, seeking to ensure adequate water resources, sufficient food, and suitable conditions for their economic development. With considerable investment, societies have built in resilience to some, but not all, of the fluctuations and extremes that nature imposes. In spite of intermittent disasters, the stability of the climate over the last few millennia has provided an environment that has fostered the development of civilizations, allowing investment and infrastructure to increase wealth rather than being constant impacts, and needing to devote significant resources to repeated restoration and relocation.

Over the last few centuries, however, society's growth and activities have upset the relationship, shifting the environment and society onto a path that is altering long-prevailing climatic baselines. The changes began with deforestation and changes in land cover to accommodate the spread of agriculture. Beginning early in the twentieth century, the primary human influence became the increasing use of fossil fuels, (i.e., coal, oil, and natural gas) to provide power for transportation, commerce, and generation of electricity. The global-average atmospheric concentration of carbon dioxide (CO_2) has increased from about 280 to 390 ppmv, such that the CO_2 concentration is now nearly 40 percent above its preindustrial level. For methane (CH_4), its atmospheric concentration is now nearly 150 percent above its preindustrial value, and levels of these and several other *greenhouse gases* are continuing to rise. The increasing concentrations of these heat-trapping gases are the dominant cause of the 0.8°C warming and 15-20 cm rise in sea level observed over the last 50 years and more. Were it not for the cooling influence of the aerosols resulting from emissions of sulfur dioxide (SO_2), the warming over the 20th century would likely have been 50 percent larger.



Michael MacCracken


Margaret Leinen

Fossil fuels provide more than 80 percent of the energy services for the nearly 7 billion people on Earth. Substantial increases in emissions are likely as global population increases toward 9-10 billion, and as consumption and energy demand increase in order to help the growing number of people in the world attain a higher standard-of-living. However, without immediate global transformation of the global energy system to non-carbon-emitting technologies, model simulations project several degrees of warming during the twenty-first century, sea level rise of roughly a meter (±50%), an intensification of both storms and droughts, increased potential for rapid and abrupt shifts in climate, and the possibility of crossing irreversible thresholds. Under such conditions, impacts for both society and the environment would be very significant and would adversely affect human health and welfare, agriculture and food production, coastal communities and ecosystems, and water resources and supplies (IPCC, 2007; Copenhagen Diagnosis, 2009; UNEP, 2009).

To limit the multi-decadal extent and significance of the projected changes in climate and substantially reduce the pace of climate change over the next several decades, *mitigation* of greenhouse gas emissions is absolutely essential. Reductions in emissions of short-lived species such as methane and black carbon have the potential for reducing the near-term rate of climate change while reductions in emissions of long-lived species such as CO_2, nitrous oxides and some halocarbons are essential to limiting long-term climate change. Based on the state of international negotiations, however, the cuts in emissions needed to slow and reverse climate change over the next few decades appear to be beyond what governments and their constituents are currently willing to undertake. As a result, for decades and perhaps much longer, significant warming is likely to continue, and *adaptation* is going to become increasingly essential to moderate the harmful impacts of a wide range of intensifying changes in climate.

While adaptation can alleviate some impacts, not all of the most severe consequences of climate change can be avoided, forcing people and ecosystems in many places around the world to adjust, suffer, and relocate. For example, the ranges of plant and animal species are already shifting poleward and to higher elevations, threatening significant loss of biodiversity. In addition, ocean acidification is starting to threaten important components of the marine food chain, and the deterioration of the Greenland and Antarctic ice sheets is accelerating to a degree that the cumulative rise of sea level will threaten many low-lying coastal cities and ecosystems later this century. There are no viable large-scale options for adapting to the prospective losses of biodiversity and acidification of the oceans, and the relocations required by sea level rise could be very disruptive for an increasing number of urbanized areas. These severe consequences could become even greater if climate change pushes the Earth system past ill-defined thresholds or tipping points that, when exceeded, intensify and accelerate the impacts. Although uncertainties remain about details of the climate and impact projections, there is strong scientific agreement on overall climatic trends, on the requirement for sharp cuts in emissions to slow and reverse climate change, and on the increasing need for more effective adaptation measures.

Approaches to Climate Engineering

Several decades ago it was proposed that, in addition to mitigation and adaptation, it might also be possible to take deliberate steps to alter the climate, with the intent of limiting or counterbalancing the unintended changes to the climate resulting from human activities (e.g., see reviews by Schneider, 2001; MacCracken, 2009). Such activities have traditionally been referred to as *geoengineering*, intended to incorporate actions taken to modify the Earth system by intervening in the functioning of its atmosphere, oceans, land surface and cryosphere for the benefit of humankind. Broadly speaking, geoengineering encompasses a very wide range of human actions. For example, changes in land use and land cover have been made to provide food for roughly 30 times the population that it is estimated could be supported by the natural environment. Changes to the natural flows of rivers have been made to provide water in vast areas that previously could support only nomadic populations. While these actions have been taken with the intent of benefitting humankind, we now recognize that at least some of these actions have also unintentionally affected the climate, primarily on local and regional scales.

Over the last few centuries, however, the reach of human influences has increased to global scales, primarily as a result of combustion of fossil fuels. Indeed, while unintended, these actions are truly re-engineering the planetary climate and merit being encompassed under the term geoengineering. While actions to intentionally counter these impacts would also fall under this broad interpretation, a more appropriate moniker for these actions, and the term that will be used here to refer to activities taken to counter balance global warming and its impacts, is *climate engineering*. Distinguishing this category of actions seems also appropriate because they are intended to maintain the climate as close to its unperturbed state as possible rather than, intentionally or not, shift it to some alternative state.

Box A describes the two primary approaches to intervening in the climate system with the intent of maintaining or restoring a minimally perturbed climatic state: *remediation technologies* and *intervention technologie*s. Remediation technologies appear likely to be more expensive than mitigation, at least in the near-term, and have the potential to only slowly limit the pace and extent of climate change and ocean acidification as long as global emissions remain high. Intervention technologies, on the other hand, have the potential to be implemented quickly and at relatively low cost, but reliance on them would also require a long-term, multi-generational commitment and would likely lead to at least some detrimental side effects.

Richard Lampitt

David Keith

Box A: The Primary Approaches to Climate Engineering

Approaches and techniques for climate engineering can be broadly divided into two categories, namely remediation and intervention technologies.

Remediation technologies attempt to remove or reduce the *causes* of global environmental change. Such approaches include, most importantly, *carbon dioxide removal* (CDR), which seeks to enhance carbon uptake by the terrestrial biosphere, oceans, and marine biosphere or by directly scrubbing CO_2 from the atmosphere. By reducing the perturbation to the preindustrial atmospheric composition, remediating technologies essentially represent an extension of traditional efforts to reduce, or mitigate, greenhouse gas emissions at their source.

Uptake of carbon by the terrestrial biosphere can potentially be increased by reforestation, altering agricultural practices, burying charcoal made from biomass, and perhaps by genetically altering plant genomes. Carbon uptake by the oceans can possibly, at least in some regions, be enhanced by fertilization (e.g., by iron enrichment) and increasing vertical mixing of the oceans. The potential to directly scrub CO_2 from the atmosphere is also being investigated, with some approaches taking advantage of natural absorbents (e.g., exposure of unweathered minerals) and others using chemical processes to capture the CO_2 and then, after separation, bury it in deep geological formations or in the ocean depths or sediments.

Remediation technologies are important not only to limit the extent of climate change, but also to limit the extent of ocean acidification. Other than reducing emissions enough to halt the annual increase in the atmospheric CO_2 concentration, increasing the buffering capacity of the oceans by injection of particular chemicals seems the only viable approach. While possibly worth pursuing now at the regional scale to reduce potentially devastating impacts in special marine areas like the Great Barrier Reef, increasing carbon removal by enough to moderate ocean acidification on a global scale would require taking up the equivalent of virtually all global CO_2 emissions, which is very likely a far more ambitious effort than is feasible until global emissions are significantly reduced.

Intervention technologies attempt to moderate the *results* of having altered the atmospheric burden of greenhouse gases and aerosols. Most intervention technologies act to counter-balance the changes in the Earth's energy balance caused by the changes in atmospheric composition. Objectives of intervention technologies can range from reducing the global average temperature to, for example, sustaining aspects of the hydrologic cycle, ice sheets, snow and ice cover, etc. In seeking to reduce the extent of climate change and its environmental and social consequences, climate intervention can be seen as an extension of the concept of climate adaptation.

Of intervention technologies, the most important is *solar radiation management* (SRM), which involves actions that would reduce the absorption of the Sun's energy by the atmosphere, oceans, and/or land surface, typically by increasing their reflectivity, or albedo. Most attention has focused on reducing the absorption of solar radiation by increasing the Earth's albedo, either by increasing the sulfate loading of the stratosphere in imitation of volcanic eruptions or by increasing the reflectivity of clouds, as presently occurs as a result of diesel exhaust from ships or injection of SO_2 from coal-fired power-plants. Other possible approaches include increasing the reflectivity of the surface (e.g., of the ocean surface by injection of bubbles, or the land surface by reflective covering), increasing the sulfate loading of the troposphere by imitating the effects of SO_2 emissions from coal-fired power plants (but doing so over remote oceanic regions), and by blocking the amount of sunlight reaching the top of the atmosphere (e.g., by placing mirrors in space).

Such approaches can be global in extent or directed toward moderating the heat uptake that leads to important regional impacts. Efforts to reduce solar warming may be global or geographically distributed to achieve specific objectives (e.g., to cool the Arctic). Interventions may also be directed towards attempting to moderate specific types of impacts, for example, altering the amount of energy available to intensify hurricanes or to melt glaciers or ice sheets.

The Objectives and Organization of the Conference

In light of these calls for initiating research on possible additional approaches, the *Asilomar International Conference on Climate Intervention Technologies* sought to advance such an effort through two initiatives:

1. To initiate a broad, interdisciplinary dialogue among experts that would produce guidance for the scientific community to responsibly and safely develop, test, and evaluate the potential for intentional intervention in the climate system to counter-balance the most severe effects and impacts of climate change; and
2. To provide input for consideration of necessary and optimal mechanisms for planning, conducting, and overseeing scientific research, especially issues relating to governance of climate engineering research by governments and civil society.

To update the 165 experts from more than a dozen countries, the first two days of the conference were devoted to invited presentations on both the physical and social science aspects of the climate engineering issue (see Appendix C for the Conference program and Appendix D for a list of the participants). Sessions also explored how other fields have dealt with governance of research having strong societal connections, how governments are currently dealing with the climate intervention issue, public perceptions of climate change and climate engineering, how climate engineering might fit into the policy process currently focused on mitigation and adaptation, and the work that has already been undertaken to elaborate principles for the conduct of geoengineering research.

The remaining time was devoted to discussion among the participants in various settings, both formal and informal. These discussions focused on the characteristics of the needed research, boundaries between *de minimus* experiments and field programs that might have noticeable effects, and how to ensure the safe and responsible conduct of research that is viewed as essential to developing and evaluating options for climate engineering. These discussions did not address issues related to implementation or deployment of climate engineering, except in the context of discussing large-scale field experiments that might differ little from early implementation.

In convening the conference, the organizers and sponsors recognized there was no guarantee that there would be agreement on these issues and were pleased to find that the discussions were generally constructive rather than divisive. Despite the potential for strongly opposed views, discussions led to identification of a number of broad-based recommendations to guide research, development, and testing of potential options for climate engineering. To summarize the sense of the attendees, the SOC drafted a relatively brief Conference Statement that, after significant input from participants, was revised and approved (see Appendix B). This report draws from both the statement and the more comprehensive documentation from the conference to provide a more detailed accounting. However, although organizers sought and sponsored international participation, the limited time and perspectives offered made clear that these findings and conclusions represent only a starting point for an ongoing and wider discussion that must involve a much broader range of participants, countries, and interests if the needed international consensus is going to emerge.

Asilomar Conference Deliberations

Participants at the Asilomar Conference agreed that the risks posed by climate change require a strong commitment to mitigation of greenhouse gas emissions (especially by increasing energy efficiency and accelerating development and deployment of low and zero-carbon energy sources) and to adaptation to the changing climate. The slow pace of progress in international efforts to sharply reduce global emissions of greenhouse gases is a cause of deep concern, especially because of the potential for very large and/or abrupt changes and impacts, including as a result of both climate change and ocean acidification.

Because of the intensifying disruption, expanding research efforts to understand the potential for climate engineering was viewed for two reasons as a prudent, potentially risk-reducing response. First, climate engineering has the potential to serve as a complementary approach to mitigation and adaptation for moderating climate change and its impacts, and second, in the event of abrupt or unmanageable rates of climate change, climate engineering may be the only viable emergency response in the event of catastrophic changes and impacts. These views do not, however, make climate engineering into an alternative (or 'Plan B') for mitigation and adaptation—to the extent it might be successful, climate engineering is most appropriately viewed as a potential complement, bringing its own contributions and shortcomings to the policy table.

Despite its potential importance, understanding of how proposed climate-engineering approaches might be implemented and function is presently quite limited. Before consideration of any future implementation, research is needed on the design, effectiveness, and potential climatic benefits of the range of proposed approaches (carried out separately or in combination), on the character and importance of uncertainties and levels of confidence, on potential unintended outcomes for communities and ecosystems, and on issues of safety, governance, ethical implications and more.

To promote the consideration of the particulars of the various technological approaches and objectives, breakout groups were organized to discuss the potential for climate engineering to address a range of plausible objectives, including to:

A. Counter-balance human-induced changes in global climate, particularly the increases in surface air temperature and changes in precipitation;

B. Increase ocean uptake of CO_2 and/or moderate ocean acidification;

M. Granger Morgan

Pablo Suarez

C. Moderate specific (regional) changes in climate and/or impacts, such as in the Arctic;

D. Increase terrestrial uptake and storage of CO_2; and

E. Scrub the atmosphere and geologically sequester CO_2 and other greenhouse gases.

Recognizing the range of approaches to and objectives of climate engineering, discussions helped to clarify the need for governing principles to recognize the important distinctions between remediation technologies directed toward moderating the causes of climate change and intervention technologies designed to counterbalance climate change itself. In particular, given the scope and challenges of such research and the potential for and implications of any future implementation, it was agreed that establishing a governance system will be necessary to ensuring the responsible conduct of field research by international community. Advancing the efforts to develop a set of principles (or norms) for conduct of the research effort was seen as a useful contribution that the conference could make toward establishment of formal national and international governance mechanisms.

Conference discussions also made clear that research and its oversight must be undertaken with humility, recognizing that a complete understanding of the global climate and related social systems will never be possible. At the same time, however, ongoing emissions of greenhouse gases are pushing the world rapidly toward a level of anthropogenic interference with the climate that seems, based on the criteria included in the UN Framework Convention on Climate Change, to be manifestly 'dangerous,' greatly increasing the likelihood of unacceptably severe climatic, environmental, and societal disruption. A realistic assessment of the implications of ongoing and projected climate change with and without the invocation of climate engineering is therefore needed if those alive today are to take their responsibilities to future generations seriously.

Top row (L-R): John Shepherd; Diana Liverman, Maxwell Boykoff and Anthony Leiserowitz

Bottom row (L-R): Floyd DesChamps and Margaret Leinen; Steve Rayner

Asilomar Conference Recommendations

Drawing particularly from the issues identified in the Oxford Principles (Rayner et al., 2010), discussions led to a consensus on the general focus for a set of five important principles for organizing and governing research on climate engineering. These principles make up the conference recommendations, emphasizing the importance of ensuring that:

- The core rationale for pursuit of climate engineering research is to advance the collective well-being of society and the environment;
- Climate engineering research is internationally planned and coordinated;
- Appropriately scoped governmental oversight, public involvement, and decision-making takes place during consideration and conduct of planned activities;
- Transparency and exchange of research plans, data, and findings minimize the need for environmentally disruptive experiments and maximize the learning from experiments that are conducted; and
- Regular, independent evaluation and assessment of the extent of understanding and uncertainty is carried out to provide optimal information and confidence for the public and policymakers.

The need and rationale for each of the principles is elaborated in the following set of recommendations.

Recommendation 1: Promoting Collective Benefit

> ***Promoting the collective benefit of humankind and the environment must be the primary purpose of research conducted to develop and evaluate the potential for climate engineering technologies to moderate or reverse human-induced climate change.***

The rising prospects of dangerously disruptive climate change—or abrupt changes in climate for which adaptation might not be possible—have increased interest in exploring the potential for climate engineering as a complement to international mitigation and adaptation efforts. By reducing the ultimate social and environmental costs of climate change, pushing global climatic conditions back toward their preindustrial state—or even toward the climate of the late 20th century—would therefore seem likely to be of significant societal benefit. The appropriate justification for research on such challenging and uncertain approaches thus becomes to determine how to maximize the alleviation of climate change impacts.

For all types of such actions, however, there are likely to be unintended environmental and societal consequences. At least some of these are likely to be perceived as negative, especially by specific groups and for particular regions. Reducing uncertainties regarding these potential consequences is essential, and research must be designed to address these issues while exploring the effectiveness of the proposed climate engineering technologies.

With the potential for climate engineering, if deployed, to eventually limit adverse impacts, albeit also with possibly undesirable consequences, the collective benefit of humankind needs to be a primary consideration in evaluating the trade-offs involved in such undertakings. Examples of issues where the complexities of collective benefit will need to be explored include: (a) developing a mechanism for detecting, attributing with varying levels of confidence, and possibly compensating for unintended damages from research activities, and (b) weighing the relative intensity and acceptability of potential near-term impacts resulting from exploratory research versus the potential net, longer-term costs and benefits that might result from development and deployment of a viable climate engineering approach. Complicating such evaluations will be the need to consider such issues as rights and access to the global commons, national sovereignty, national and international security, and other interests.

Recommendation 2: Establishing Responsibility and Liability

> ***Governments must clarify responsibilities, and, when necessary, create new mechanisms, for the governance and oversight of large-scale climate engineering research activities that have the potential or intent to significantly modify the environment or affect society. These mechanisms should build upon and expand existing structures and norms for governing scientific research and, in the event of damaging outcomes, establish who would bear the cost and the degree of liability and proof that are required.***

With the international effects and implications of climate engineering research introducing considerations far beyond the purely scientific, ensuring an appropriate level and degree of governance of the research effort will be an important requirement. Effective governance will need to account for the wide range of envisioned research activities, including their scale, character, potential risks, and benefits to increasing understanding. Modeling and laboratory studies pose little to no risk of impact to the climate, environment, or society, and so new governance mechanisms are not likely to be needed. For research such as modeling and laboratory-scale experiments that poses no novel risks or challenges, adequate governance procedures, if effectively exercised, already exist within the professional scientific community, research institutions, scientific societies with their professional standards, granting agency reviews, and national and sub-national regulatory oversight.

For field experimentation, however, the issues become more complex. In general, the space and time scales of field experiments would be expected to determine their significance, reversibility, and reach, with the smallest causing only localized and temporary modifications to the environment. The set of potential activities spans a vastly differing set of scales, character, and potential for unintended consequences, thus likely posing significantly different levels of risk. In general, as time and space scales of research expand, the degree of governance required will need to be the subject of more and more extensive scientific and public considerations, especially as the scales approach those needed to characterize aspects relevant to actual deployment.

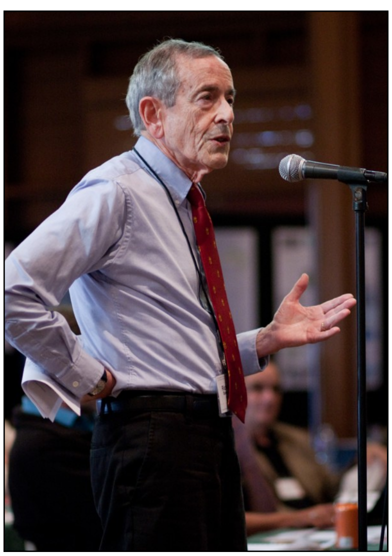
Recognizing the potential breadth of situations, a coordinated mix of types of oversight and governance likely has the potential to be most effective and accessible. With the wide variety of potential approaches likely to be studied and the similarly large range of potential benefits and possible unintended consequences that could affect those who have not given, or even been asked for, explicit consent, establishing appropriate and effective governance mechanisms will require careful consideration. Attention will also need to be given to achieving the appropriate balance between thorough evaluation and timely encouragement of the research in order to balance plausible risks and rewards. For the larger field activities needed to fully research and demonstrate capabilities, appropriate international oversight is likely to be most appropriate. Based on discussions at the conference, it seems likely that such oversight will need to be comparable to the mechanisms and capabilities put into place to govern study and investigation of the ongoing changes and impacts resulting from the rising greenhouse gas concentrations.

One potential simplifying mechanism would be to subdivide the approaches into categories with common potential risks (and so likely similar issues of governance). Indeed, this effort seems to have already begun, with the signatories to the London Convention and Protocol assuming responsibility for establishing a framework that would oversee research into climate engineering approaches involving release of materials into the marine environment. Although examples of successful governance mechanisms appear to exist in related areas, the potential governance structures for research that would involve modification of the atmospheric, terrestrial, or even extraterrestrial environments, is much less clear.

With the limited understanding of the strengths and weaknesses of proposed approaches and the accelerating pace of calls for climate engineering research, consideration of appropriate governance structures is urgently required. From the perspective of those in the climate engineering research community, a sound and responsive governance structure is needed to facilitate communication of research plans to the public and their involvement in expeditious, government-led evaluation and decision-making processes. From the perspective of government policymakers, a capable and comprehensive governance structure is needed as well to encourage effective and expeditious development and evaluation of approaches for increasing the range of options available for dealing with climate change and its impacts.

Thresholds for determining the appropriate level of oversight remain uncertain and rapid informal reviews are likely to be needed to determine whether more extensive consideration will be necessary.* With the wide range of proposed experimental approaches and environmental situations, quantitative rules or algorithms based on particular thresholds (e.g., less than X tons of material Y released over an area Z) have not yet emerged, and may not even be appropriate given the range of possible circumstances under which experiments might be conducted. Rather than focusing on specific limits for one aspect of a proposed activity, for example, it may well be most appropriate for aggregate judgments to be made based on the totality of relevant factors.

* Conference participants welcomed the announcement that the Royal Society, the Third World Academy of Sciences, and EDF have organized such a study for solar radiation management techniques, with initial results to be presented at a conference in March 2011.



Richard Benedick

John Gibbons

Jane C. S. Long

Developing an efficient and well-functioning system of review will probably require a mechanism for determining the specific institutional framework appropriate to evaluating activities of different scales and aggregate impacts. Accomplishing this will require varying degrees of collaboration among multiple organizations at various levels, including research institutions and their ethics boards, funding bodies, national regulatory authorities, and newly developed international processes.

In addition to review of the research itself, governance mechanisms will need to include provisions for developing objective procedures for evaluation of the scientific proposals, for supporting independent, expert assessment of impacts and risks, for promoting transparency and disclosure, and for ensuring public participation, consultation, and acceptance. Government establishment of a system for liability and compensation for definable and inadvertent harms caused by large-scale research activities is also likely to be needed, including how to determine the range and nature of environmentally significant changes and impacts to be expected from a persistent, but localized, experiment of climate intervention.

Recommendation 3: Open and Cooperative Research

> ***Climate-engineering research should be conducted openly and cooperatively, preferably within a framework that has broad international support. Research activities with the potential to affect the environment in significant ways should be subject to risk assessment, taking into account the risks associated with both the activity itself and from the reduced understanding if the experiment is not conducted. All such research should be interdisciplinary in design and planned, reviewed, and implemented in a transparent fashion. Data needed to assess the performance of technologies and approaches should be disclosed to allow for open review and evaluation.***

At present, the limited research efforts on climate engineering are quite varied and uncoordinated, and not all are openly described. In Europe, a number of modeling and assessment activities have begun, and a field program to investigate the potential to increase cloud brightness is being planned. Discussions of governance are also beginning under an emerging governmental framework. In North America, a few modeling, laboratory, and social sciences and humanities research projects related to climate engineering are underway, and the Congress has held several hearings relating to governance and the need for a research program. Some of the projects have public funding, whereas others have private funding from foundations or private donors and investors, for some of which concerns have been expressed about future profits being an objective that might bias interpretation of any research that is undertaken. For governments to have the information needed to evaluate whether climate-engineering techniques could provide plausible complementary options for limiting climate change and its impacts, a much more coordinated and comprehensive research effort will be needed. This will require increased funding, nationally and internationally.

For leading governments to provide the significant funding that will be needed for large-scale field programs, a co-operative international program of scientific research that would support collaborative design, planning, and implementation of early phase research projects would be an efficient way to get started. Early interest by the leaders of the World Climate Research Programme, the International Geosphere-Biosphere Programme, and the International Human Dimensions Programme in considering their roles in planning, organizing, and coordinating such an international research effort is encouraging.

To promote the most rapid progress in understanding, the international research program that is organized must be cooperative, quickly interacting, and transparent. Participation in the international program should be encouraged by scientific organizations in all nations having interests in and capabilities to investigate and undertake climate-engineering research. Initial research activities should include:

1. Numerical modeling studies of the range of approaches that could contribute to moderating climate change and its impacts;
2. Cooperative planning and conduct of field programs in order to ensure comprehensive information gathering at minimum cost and insult to the environment;
3. Coordinated programs of environmental monitoring designed to build capacity to observe and assess the effects and risk of various interventions at various distances from the experiment;
4. Observation and analysis of naturally occurring events, such as major volcanic eruptions, that may serve as analogs for climate engineering; and
5. Prompt and frequently updated release, publication, and open availability of research results (including observational data sets, model results, and analysis tools and techniques) to encourage timely analysis and identification of the strengths and weaknesses of various approaches to climate engineering.

Just as important, if climate-engineering research is going to become accepted by the public, an effective communication effort regarding the research efforts, including being transparent regarding the nature and objectives of the efforts and where they may be headed. Efforts needed to assure transparency include development of requirements for disclosure of:

6. Sources of funding for major research projects. Disclosure is of particular interest for cases when substantial funding is from other than government research and science agencies, research foundations, or philanthropic sources that do not have a tradition of public release of their research results; and
7. Research or test activities involving privately held intellectual property. Use of secret or proprietary technologies usually creates obstacles to technical assessment of performance, effectiveness, and/or risks of research activities. In addition, use of proprietary technologies can create barriers to dissemination of detailed technical information that may be needed to advance research and demonstrate and test approaches to climate engineering. Use of extant legal limits to intellectual property rights (e.g., provisions that would ensure fair licensing or application of beneficial technologies) might be one means to ensure that critical proprietary technologies are available while their value is protected.

Recommendation 4: Iterative Evaluation and Assessment

> ***Iterative, independent technical assessments of research progress on climate engineering approaches will be required. Assessing potential intended and unintended consequences, impacts, and risks will be critical to providing governments and the public with the information and confidence needed to evaluate the potential for climate engineering to be implemented as a complement to mitigation and adaptation.***

If any of the climate engineering technologies proves to be feasible and useful, governments may be forced to choose between the risks of ongoing climate change and the risks of ongoing climate change moderated or counter-balanced by climate engineering. In such cases, determining whether there is sufficient understanding to make use of climate engineering would be much more than a purely scientific decision.

Accepting that such a decision may need to be made, a critical function of national and international governance systems must be to organize and manage competent, impartial, independent, and transparent expert assessments of the benefits and risks of proposed climate-engineering approaches and the ways in which these approaches might be incorporated into other international efforts for dealing with climate change and its many impacts. To date, the potential for climate engineering has been addressed only briefly in the assessments of the Intergovernmental Panel on Climate Change (IPCC).* With the research effort expanding, future assessments will need to provide policymakers and the public with more extensive analyses of the strengths and limitations of climate engineering options.

The scope, depth, and frequency of these assessments, and the institutional framework under which they would most appropriately be conducted, merits careful consideration, especially as the proposed scale and pace of research are changing. In the initial phases, scientific assessments of climate engineering can be a component of existing evaluations and assessments conducted by research institutions, funding organizations that consider scientific merit and potential environmental risks, and the IPCC. If the scale and scope of climate-engineering research increases to a level that involves large-scale and/or long-lasting experiments, these assessments would need to consider not only the scientific aspects of the intervention, but also the changing potential environmental consequences and altered societal value over time. In addition, as the evaluations broaden to examine the costs and risks of possible future implementation, they would need to include assessments of the full range of potential impacts, including environmental, economic, legal, and socio-political consequences.

Conference participants identified a number of additional issues related to risk assessment for which policies will need to be developed as the scale of climate engineering research proceeds. These issues included determining:

- The most appropriate structure to ensure the assessment's credibility, independence, and public acceptance. This determination must be made in the context of existing structures such as the IPCC and UNFCCC. In addition, consideration must be given to the means for enhancing and sustaining the authority and legitimacy of such assessment bodies;
- The organization, funding, and management of appropriate groups of experts to conduct the required assessments. For example, might it be advisable to establish a standing International Advisory and Assessment Council to assess progress in climate engineering research, and, if so, under what auspices such an entity might be established?
- The most appropriate methods and processes for evaluating the consequences of climate engineering. The methods must be able to identify and assess the intended and unintended effects of proposed interventions on human and non-human systems and structures, on biodiversity and other environmental values, and how they compare to the effects and impacts being caused by ongoing greenhouse gas emissions.

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* IPCC Second Assessment Report (WG II, Chapter 25.4); IPCC Third Assessment Report (WG III, Chapter 4.7); IPCC Fourth Assessment Report (WG III, Chapter 11.2.2).

Recommendation 5: Public Involvement and Consent

> ***Public participation and consultation in research planning and oversight, assessments, and development of decision-making mechanisms and processes must be provided. Approaches are needed to ensure consideration of the international and intergenerational implications of climate engineering.***

The broad environmental, societal, and even cultural implications of climate engineering require public consultation and participation in decisions about major field experiments. While such experiments will presumably be designed to evaluate techniques without causing harmful outcomes, some may have (or be perceived as having) undesirable side effects. Decisions about both action and inaction necessarily fall to governments as representatives of the public. It will be essential to ensure a strong public information and education effort so that those likely to be most affected have the information needed to participate and contribute to informed governmental decision-making.

For field experiments, the need for public consultation, like the need for other elements of legitimate governance, will increase with the scale and potential risks of the proposed research experiment. As the scale increases, processes will be needed to:

- Identify and reach out to populations that may be affected, paying particular attention to outreach to the most vulnerable groups;
- Provide accessible information about the nature of the proposed field experiment, the reasons it is necessary, and the potential effects, including risks and benefits;
- Engage in consultation to improve program design and minimize unintended consequences; and
- Carry through an evaluation process that investigates and analyses public perceptions, the effectiveness of consultation, and the communication of climate engineering as the process goes on.

When the scope of potential impacts of an experiment lies within national boundaries, most nations have venues for undertaking review of research undertakings. As the scale of climate engineering research expands beyond national borders, however, the identification and responsibilities of potential decision-making institutions becomes more problematic, especially given the widening range of social and cultural perspectives deserving consideration. For governance of such research, new or modified roles for existing institutions or new governance mechanisms may be needed that could inform a widening array of policymakers and provide for adequate public participation and consultation. Careful thought will need to be given to development of capabilities for exploring, weighing, and determining the relative effects and implications of proposed climate engineering interventions and the relative interests of those who are or may be affected, whether beneficially or detrimentally.

Public and governmental concerns about climate engineering are likely to extend beyond risks of particular proposed experiments, Including the entire trajectory of developing, evaluating, and deploying climate-engineering measures. In addition, while the large-scale implications of fully undertaking climate engineering and how to weigh the potential risks and benefits of such efforts were not the focus of our conference, such concerns are legitimate and will require a serious response, even though their consideration by the appropriate governance structures may complicate decision-making regarding research activities.

Our discussions were not intended to specify the organization or authority of the needed governance systems, but focused on the capabilities that the scientific and other communities expect of decision-making authorities so that research on climate engineering can proceed. As research develops knowledge and capabilities within established practices and norms, governmental authority also needs to advance, gaining insight through experience and by having high-level access to relevant scientific and technical expertise. Governments are also going to have to provide for outreach and education to ensure that there can be an informed public debate.

Responsibility, or even liability, for unintended or damaging outcomes will need to be a critical element of government consideration. Even with research that proceeds incrementally and prudently, and with a serious commitment to risk assessment, monitoring, and regulatory control, large-scale experiments will unavoidably entail some risks. Attributing particular harms to specific research activities, however, is likely to prove difficult, just as it has required special efforts to attribute specific harms to climate change within the variability of normal weather and climate. Liability and compensation processes based on 'no-fault' principles over some range of potential impacts defined in advance of particular experiments may be needed as part of the approval process. Without such a system, it may well be that public perceptions of potential risk may become an obstacle to continued climate engineering research. Such complexities will require that public outreach and development of the governance framework proceed together.

Clockwise, from top left: Dale Jamieson; Lynn Russell; Venkatachalam Ramaswamy; James Fleming; Janot Mendler de Suarez; Daniel Rosenfeld, Paul Craig, Martin Bunzl; David Hawkins; Alan Robock; Clarisse Kehler Siebert; Breakout Session, Fei Chai at mic (center)

Summary

While the very challenging nature of better understanding the relevant functioning of both natural and societal systems suggests the need for caution, humility, and incrementalism, the imminence of significant climate change impacts is increasing the urgency of responsibly undertaking research on climate engineering. Achieving the right balance will be a significant challenge. Assuming there is overall interest in expanding the set of potentially plausible options beyond mitigation and adaptation, substantial research will be needed to determine whether proposed intervention techniques would be feasible and effective, whether the collective environmental impacts would be acceptable, and the magnitude of and potential for and intensity of undesirable consequences.

It appears that the modeling and laboratory components of the needed research can take place within the norms and standards of ongoing scientific research. Field testing and demonstrating potential deployment of climate engineering approaches will, however, need to include experimentation in the natural environment, introducing the need for more considered deliberation of expected and potential risks and benefits.

Conference discussions and overall regard for the potential impacts of research on natural environments, individuals, communities, and cultures, led us, as the Scientific Organizing Committee, to recommend adoption of a set of governance principles by the scientific research community, the social science and policy communities, and the public. These principles recognize the *unique and serious nature* of climate experimentation, urging that research on climate engineering be undertaken only for the purpose of alleviating the collective impacts being projected to result from climate change (and thus not for narrow financial or national advantage).

To ensure responsible conduct of the research, governments need to develop mechanisms to oversee the research and to encourage international coordination of these activities. We also recommend that the research be regularly assessed under an independent international framework.

In all of the planning and oversight efforts, we recognize that transparency and public involvement will be critical to ensuring that there is trust in the motivation, governance and assessment of climate engineering research. We are convinced that adherence to the recommended principles is necessary to ensure that climate engineering research will be conducted in a responsible manner meriting public and governmental support.

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Appendix A: Members of the Scientific Organizing Committee

The Scientific Organizing Committee (SOC) was assembled by the Climate Institute and was responsible for planning, conducting, and reporting on the results of the conference, including, with input from participants, preparing and approving the Conference Statement (see Appendix B) and this summary report. The members of the SOC were:

Dr. Michael MacCracken, Chief Scientist for Climate Change Programs, Climate Institute, US (Chair)

Dr. Paul Crutzen, Max Planck Institute, Germany (corresponding member)

Dr. Scott Barrett, Lenfest Professor of Natural Resource Economics, Columbia University, US

Dr. Roger Barry, Director of the World Data Center for Glaciology and Distinguished Professor of Geography, University of Colorado Boulder, US

Dr. Steven Hamburg, Chief Scientist, Environmental Defense Fund, US

Dr. Richard Lampitt, Senior Scientist, National Oceanography Center and Professor, University of Southampton, UK

Dr. Diana Liverman, Director of the Institute of the Environment and Professor of Geography and Regional Development, University of Arizona, US, and Senior Fellow in the Environmental Change Institute, Oxford University, UK.

Dr. Thomas Lovejoy, Heinz Center Biodiversity Chair at the Heinz Center for Science and the Environment, US

Dr. Gordon McBean, Professor, Departments of Geography and Political Science and Director of Policy Studies at the Institute for Catastrophic Loss Reduction, The University of Western Ontario, London, Canada

Dr. Edward Parson, Professor, School of Natural Resources and Environment and School of Law, University of Michigan, US (from March, 2010)

Mr. Stephen Seidel, Vice President for Policy Analysis and General Counsel at the Pew Center on Global Climate Change, US

Dr. John Shepherd, Professorial Research Fellow in Earth System Science, School of Ocean and Earth Science, National Oceanography Centre, University of Southampton, and Deputy Director (External Science Coordination) of the Tyndall Centre for Climate Change Research, UK

Dr. Richard Somerville, Distinguished Professor Emeritus and Research Professor at Scripps Institution of Oceanography, University of California, San Diego, US

Dr. Tom M.L. Wigley, Professor, University of Adelaide, Australia and Senior Scientist, National Center for Atmospheric Research, US

Appendix B: Asilomar Conference Statement (from 26 March 2010)

The Scientific Organizing Committee for the Asilomar International Conference on Climate Intervention Technologies drafted and approved the following statement after consideration of valuable input from Conference participants.

More than 175 experts from 15 countries with a wide diversity of backgrounds (natural science, engineering, social science, humanities, law) met for five days (March 22-26, 2010) at the Asilomar conference center in Pacific Grove, CA. The participants explored a range of issues that need to be addressed to ensure that research into the risks, impacts and efficacy of climate intervention methods is responsibly and transparently conducted and that potential consequences are thoroughly understood. The group recognized that given our limited understanding of these methods and the potential for significant impacts on people and ecosystems, further discussions must involve government and civil society. Such discussions should be undertaken with humility and recognition of the threats posed by the rapid increase in atmospheric greenhouse gas concentrations.

Participants reaffirmed that the risks posed by climate change require a strong commitment to mitigation of greenhouse gas emissions, adaptation to unavoidable climate change, and development of low-carbon energy sources independent of whether climate intervention methods ultimately prove to be safe and feasible.

The fact that humanity's efforts to reduce global emissions of greenhouse gases (mitigation) have been limited to date is a cause of deep concern. Additionally, uncertainties in the response of the climate system to increased greenhouse gases leave open the possibility of very large future changes. It is thus important to initiate further research in all relevant disciplines to better understand and communicate whether additional strategies to moderate future climate change are, or are not, viable, appropriate and ethical. Such strategies, which could be employed in addition to the primary strategy of mitigation, include climate intervention methods (solar radiation management) and climate remediation methods (carbon dioxide removal).

We do not yet have sufficient knowledge of the risks associated with using methods for climate intervention and remediation, their intended and unintended impacts, and their efficacy in reducing the rate of climatic change to assess whether they should or should not be implemented. Thus, further research is essential.

Recognizing that governments collectively have ultimate responsibility for decisions concerning climate intervention and remediation research and possible implementation, this conference represented a step in facilitating a process involving broader public participation. This process should ensure that research on this issue progresses in a timely, safe, ethical and transparent manner, addressing social, humanitarian and environmental issues.

Appendix C: Conference Program

Monday, March 22

7:30 - 8:00 PM Welcome and Introductory Remarks:

- **Michael MacCracken**, Climate Institute: *Chair of the Scientific Organizing Committee*
- **Margaret Leinen**, Climate Response Fund: *Conference Developer*

8:00 – 9:00 PM Plenary: Insights from Experiences with Guidelines and Oversight

Session Chair: **Jane Long**, Lawrence Livermore National Laboratory
Presentations:

- **David Winickoff,** University of California Berkeley: *Lessons from Experiences with Research Guidelines in Medical and Other Fields*
- **Scott Barrett**, Columbia University: *Discussant*

Tuesday, March 23

8:30 - 8:45 AM Conference Opening: **Michael MacCracken**, Climate Institute

8:45 - 12:00 PM Plenary: The Physical Science Aspects of Climate Intervention

Session Chair: **Richard Somerville**, Scripps Institution of Oceanography
Presentations:

1. **John Shepherd** FRS, University of Southampton: *Introduction and Overview of Proposed Approaches to Climate Intervention*
2. **Phil Rasch**, Pacific Northwest National Laboratory: *Model Analyses of the Potential for Aerosols in the Troposphere or Stratosphere to Limit Incoming Solar Radiation*
3. **David Keith**, University of Calgary: *Experimenting with Solar Radiance Engineering: Possibilities, Limits and their Policy Implications*
4. **Richard Lampitt**, National Oceanography Centre: *The Potential for and Challenges of Enhancing Ocean Uptake of Carbon*
5. **Jerry Melillo**, Marine Biological Laboratory: *The Potential for and Challenges of Storing More Carbon in the Terrestrial Biosphere*
6. **David Keith,** University of Calgary, and **Robert Socolow**, Princeton University: *The Potential for Scrubbing Carbon Dioxide from the Atmosphere*

1:30 - 5:30 PM Plenary: The Social Science Context of Climate Intervention

Session Chair: **Diana Liverman**, University of Arizona
Presentations:

1. **Catherine Redgwell**, University College, London: *The International Legal Framework for Climate Intervention*
2. **Oran Young**, University of California Santa Barbara: *Governing Climate Intervention: Lessons from the Study of International Institutions*
3. **David Morrow**, University of Chicago: *Ethical principles for trials of climate intervention technologies*
4. **Steve Smith**, PNNL: *The economic context for climate intervention*
5. **Scott Barrett**, Columbia University: *Geoengineering: Incentives and Institutions*
6. **David Victor**, University of California San Diego: *Regulating the Testing of Geoengineering Systems*
7. **Granger Morgan**, Carnegie-Mellon University: *Decision-making Frameworks for Geoengineering Policies*

7:30 - 9:00 PM Plenary: Plans for National and International Research Programs and Coordination

Session Chair: **Tom Lovejoy**, Heinz Center
Panel:

- **James Wilsdon**, Royal Society: *UK/EU Policy and Investment in Geoengineering Research*
- **Tim Persons**, US Government Accountability Office
- **Graeme Pearman**, Monash University
- **Pablo Suarez**, Red Cross / Red Crescent Climate Centre

Wednesday, March 24

8:30 - 9:45 AM Plenary: Thoughts on the Development of Guidelines for Research

Session Chair: **Graeme Pearman**, Monash University
Presentations:

1. **Stephen Schneider,** Stanford University: *Geoengineering: Savior, Stopgap or Non-starter*
2. **Steve Rayner**, Oxford University: *Draft Principles for the Conduct of Geoengineering Research*
3. **Michael MacCracken**, Climate Institute**:** *Introduction to the Wednesday and Thursday Morning Breakout Groups and Plenary Discussions*

10:00 - 12:00 PM Breakout Groups: **Guideline Issues Arising from Consideration of the Scientific Research Needed for the Various Approaches to Climate Intervention**

Breakout Group A: Research to Evaluate Approaches for Solar Radiation Management in the Stratosphere and Above Aimed at Moderating Global Climate Change
Breakout Session Leaders: **Tom Wigley**, National Center for Atmospheric Research, and **Ted Parson**, University of Michigan
Rapporteurs: Ben Kravitz and Kate Ricke

Breakout Group B: Research Needed to Evaluate Approaches for Solar Radiation Management in the Troposphere and at the Surface Aimed at Moderating Specific
Breakout Session Leaders: **Roger Barry**, University of Colorado Boulder, and **Michael MacCracken**, Climate Institute
Rapporteurs: Ashley Mercer and Rachel Hauser

Breakout Group C: Research Needed to Evaluate Approaches for Increasing the Uptake and Storage of Carbon in the Ocean (Ocean Carbon Capture and Storage) and Limiting Ocean Acidification
Breakout Session Leaders: **Richard Lampitt**, National Oceanography Centre, and **Chris Vivian**, Center for Environment, Fisheries and Aquaculture
Rapporteurs: Jesse Reynolds and George Collins

Breakout Group D: Research Needed to Evaluate Approaches for Increasing the Uptake and Storage of Carbon Below the Surface and in the Terrestrial Biosphere
Breakout Session Leaders: **Steven Hamburg**, Environmental Defense Fund, and **Diana Liverman**, University of Arizona
Rapporteurs: Gabrielle Wong-Parodi and Bidisha Banerjee

Breakout Group E: Research Needed to Evaluate Approaches for Direct Removal of Greenhouse Gases from the Atmosphere
Breakout Session Leaders: **Jane Long**, Lawrence Livermore National Laboratory, and **Stephen Seidel**, Pew Center on Global Climate Change
Rapporteurs: Noah Bonnheim and Amanda Reynolds

1:30 - 5:30 PM Parallel Plenary Sessions: Guidelines to Ensuring the Scientific Quality of Research on Climate Intervention Technologies (with a focus on the scientific aspects)

Group 1: Solar Radiation Management and Similar Approaches to Reduce Energy Addition

Session Co-chairs: **John Shepherd**, University of Southampton, and **Richard Somerville**, Scripps Institution of Oceanography
Rapporteurs: Rachel Hauser and Ashley Mercer

Group 2: Carbon Dioxide Reduction and Related Approaches to Reduce Climate Forcing

Session Chair: **Richard Lampitt**, National Oceanography Centre
Rapporteurs: Jesse Reynolds and Noah Bonnheim

7:15 - 8:45 PM Plenary Discussion**:** Climate change, public attitudes, the media, and insights on implications for public discourse on climate intervention/geoengineering

Session Chair: **Diana Liverman**, University of Arizona
Presenters:

1. **Max Boykoff**, University of Colorado: *Media Representations of Climate Change and Geoengineering*
2. **Tony Leiserowitz**, Yale University: *Climate Change and Geoengineering in the Public Mind*

8:45 PM Conference Reception: Hosted by Climate Response Fund

Thursday, March 25

8:30 - 10:30 AM Breakout Group Discussions (continued)

11:00 - 12:00 PM Plenary Presentations (open to participants)

Session Chair: **Floyd DesChamps**, GLOBE International
Panel discussion on the ethics of climate engineering:

1. **Shobita Parthasarathy**, University of Michigan
2. **Mark Brown**, California State University, Sacramento
3. **Jameson Wetmore**, Arizona State University
4. **Dale Jamieson**, New York University

Presentation: **James Fleming**, Colby College: *What Counts as Knowledge? The Risks of Not Reading History*

1:30 - 5:30 PM Plenary: Discussion of guideline issues related to governance and societal interests, including decision processes, public opinion and communication, economics and societal perspectives

Session chairs: **John Shepherd**, University of Southampton, and **Michael MacCracken**, Climate Institute

7:30 - 9:00 PM Plenary: The possible role of geoengineering in addressing climate change

Session Chair: **Steven Hamburg**, Environmental Defense Fund
Presentations:

1. **Tom Wigley**, University of Adelaide: *Geoengineering: Making the Difference Between Realistic and Unrealistic Mitigation Goals*
2. **Rob Socolow**, Princeton University: *Muddling through with Mitigation and Adaptation: Geoengineering's Formidable Competitor*

Friday, March 26

8:30 - 11:00 AM Plenary Session**:** Consideration of the Conference Statement

Session Chair: **John Shepherd**, University of Southampton

11:30 AM Conference closes

Appendix D: Conference Attendees (Expert Participants, Rapporteurs, and Media)

Expert Participants

Tom Ackerman, *University of Washington, US*
Roger Aines, *Lawrence Livermore National Laboratory, US*
Paola Alpresa, *LYNZOS S.L., Spain*
Jim Amonette, *Pacific Northwest National Laboratory, US*
Ana Ivelisse Aviles, *Government Accountability Office, US*
Govindasamy Bala, *Indian Institute of Science, Bangalore, India*
Scott Barrett, *Columbia University, US*
Roger Barry, *University of Colorado, US*
Richard Benedick, *Department of State, retired; National Council for Science and the Environment, US*
Gregory Benford, *University of California, Irvine, US*
Robert J. Berg, *World Federation of United Nations Association; World Academy of Art and Science, US*
Robert Bindschadler, *Emeritus scientist, NASA, US*
Jason Blackstock, *Centre for International Governance Innovation; International Institute for Applied Systems Analysis, Austria*
Daniel Bodansky, *University of Georgia, US*
Peter Boyd, *Carbon War Room, Inc., US*
Maxwell Boykoff, *University of Colorado at Boulder, US*
Stewart Brand, *Global Business Network; author, Whole Earth Discipline, US*
Peter Brewer, *Monterey Bay Aquarium Research Institute, US*
Mark Brown, *California State University, Sacramento, US*
Lopa Brunjes, *Biochar Engineering; Carbon War Room; Global Cooling, US*
Martin Bunzl, *Rutgers University, US*
Wil Burns, *International Law Association, US*
Antonio J. Busalacchi Jr., *University of Maryland, US*
Fei Chai, *University of Maine, US*
Elizabeth Chalecki, *Boston College, US*
Art Charo, *National Research Council, US*
Francisco Chavez, *Monterey Bay Aquarium Research Institute, US*
Frederick Childers, *Government Accountability Office, US*
Garry Cook, *Commonwealth Scientific and Industrial Research Organization, Australia*
Paul Craig, *Emeritus professor, University of California, Davis; Sierra Club, US*
Kim Cranston, *TransparentDemocracy.org, US*
Paul Crutzen, *Max Planck Institute, Germany*
Duane Dale, *DFD Associates, US*
David Dean, *Department of Energy, US*
Kenneth Denman, *Canadian Centre for Climate Modelling and Analysis, Canada*
Floyd DesChamps, *GLOBE International, US*
Lisa Dilling, *University of Colorado at Boulder, US*
Judy Droitcour, *Government Accountability Office, US*
Melanie Fitzpatrick, *Union of Concerned Scientists, US*
James Fleming, *Colby College, US*
James Fournier, *Biochar Engineering, US*
William Fulkerson, *University of Tennessee, US*
Alan Gadian, *Leeds University, UK*
Alfonso Ganan-Calvo, *Universidad de Sevilla, Spain*
John Gibbons, *formerly, Office of Technology Assessment, and Office of Science and Technology Policy, US*
Joseph Golden, *retired, NOAA/Cooperative Institute for Research in Environmental Sciences, US*
Danielle Guttman Klein, *Guttman Initiatives, US*
Chuck Hakkarinen, *retired, Electric Power Research Institute, US*
Steven Hamburg, *Environmental Defense Fund, US*
Daniel Harrison, *visiting professor (from Australia), University of Southern California, US*
Jennifer Haverkamp, *Environmental Defense Fund, US*
David Hawkins, *National Resources Defense Council, US*
E. Dan Hirleman, *Purdue University, US*

Martin Hoffert, *Emeritus professor, New York University, US*
Andreas Felix Hofmann, *visiting researcher (from The Netherlands), Monterey Bay Aquarium Research Institute, US*
Deborah Iglesias-Rodriguez, *National Oceanography Centre, UK*
Robert Jackson, *Duke University, US*
Dale Jamieson, *New York University, US*
David Keith, *University of Calgary, Canada*
Robert N. Klein II, *Klein Financial Corporation; Independent Citizens Oversight Committee, California Institute of Regenerative Medicine, US*
Gernot Klepper, *Kiel Institute for World Economics, Germany*
Tim Kruger, *Cquestrate; Oxford Geoengineering, UK*
Kelly Kryc, *Gordon and Betty Moore Foundation, US*
Richard Lampitt, *National Oceanography Center, UK*
Lee Lane, *American Enterprise for Public Policy Research, US*
John Latham, *National Center for Atmospheric Research, US; Emeritus professor, University of Manchester, UK*
Margaret Leinen, *Climate Response Fund, US*
Anthony Leiserowitz, *Yale University, US*
Chris Lennard, *University of Cape Town, South Africa*
Andrew Lenton, *Commonwealth Scientific and Industrial Research Organization, Australia*
Eli Lewine, *Government Accountability Office,* US
Albert Lin, *University of California, Davis, US*
Diana Liverman, *University of Arizona, US; Oxford University, UK*
Andrew Lockley, *Moderator, climateintervention.org, UK*
Jane C. S. Long, *Lawrence Livermore National Laboratory, US*
Thomas Lovejoy, *Heinz Center for Science and the Environment, US*
Michael MacCracken, *Climate Institute, US*
Douglas MacMynowski, *California Institute of Technology, US*
Bryan Martel, *Environmental Capital Group, US*
Andrew S. Mathews, *University of California Santa Cruz, US*
Luiz Gylvan Meira Filho, *University of S‹o Paulo, Brazil*
Jerry Melillo, *Woods Hole Ecology Research Center, US*
Janot Mendler de Suarez, *Global Forum on Oceans, Coasts and Islands, US*
Juan Moreno-Cruz, *University of Calgary, Canada*
M. Granger Morgan, *Carnegie Mellon University, US*
David Morrow, *University of Chicago, US*
Armand Neukermans, *Silver Lining, US*
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Graeme Pearman, *Graeme Pearman Consulting Pty Ltd; retired Commonwealth Scientific and Industrial Research Organization, Australia*
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Arthur Petersen, *Netherlands Environmental Assessment Agency, The Netherlands; London School of Economics and Political Science, UK; Massachusetts Institute of Technology, US*
Christiano Pires de Campos, *Petrobras, Brazil*
Venkatachalam Ramaswamy, *NOAA/Geophysical Fluid Dynamics Laboratory; Princeton University, US*
Phil Rasch, *Pacific Northwest National Laboratory, US*
Greg Rau, *Lawrence Livermore National Laboratory, US*
Steve Rayner, *University of Oxford, UK*
Catherine Redgwell, *University College London, UK*
Kevin Rennert, *staff, Senate Energy Committee, US*
Jennie Rice, *Pacific Northwest National Laboratory, US*
James Rhodes, *Scripps Institution of Oceanography, University of California San Diego, US*
Allison Robertshaw, *Zennstršm Philanthropies, UK*
Alan Robock, *Rutgers University, US*

Daniel Rosenfeld, *The Hebrew University of Jerusalem, Israel*
Lew Rothstein, *University of Rhode Island, US*
Lynn Russell, *Scripps Institution of Oceanography, University of California San Diego, US*
Stephen Salter, *Emeritus professor, University of Edinburgh; Artemis Intelligent Power, UK*
Stephen Schneider, *Stanford University, US*
Jerry Schubel, *Aquarium of the Pacific, US*
Stephen Seidel, *Pew Center on Global Climate Change, US*
Russell Seitz, *Fellow of the Department of Physics, Harvard University, US*
Sybil Seitzinger, *International Geosphere-Biosphere Programme, Sweden*
Elton Sherwin, *Ridgewood Capital, US*
John Shepherd, *National Oceanography Centre; Tyndall Centre for Climate Change Research, UK*
Clarisse Kehler Siebert, *Stockholm Environment Institute, Sweden*
Steven Smith, *University of Maryland, US*
Robert Socolow, *Princeton University, US*
Richard Somerville, *Scripps Institution of Oceanography, University of California, San Diego, US*
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Pablo Suarez, *Red Cross/Red Crescent Climate Centre, US; International Institute for Applied Systems Analysis, Austria; Boston University, US*
Masahiro Sugiyama, *Central Research Institute of Electric Power Industry Japan*
Judith Swift, *University of Rhode Island, US*
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Claire Tomkins, *Carbon War Room, US*
William Travis, *University of Colorado at Boulder, US*
Lisa Van Arsdale, *Government Accountability Office, US*
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David Victor, *University of California Los Angeles, US*
Chris Vivian, *Lowestoft Laboratory, UK*
Gernot Wagner, *Environmental Defense Fund, US*
James Wang, *Environmental Defense Fund, US*
Kelly Wanser, *eCert, Inc., US*
Andrew Watson, *University of East Anglia, UK*
Naomi Webber, *Research Council UK Office in the United States, US*
A. Joshua West, *University of Southern California, US; Oxford University, UK*
Jameson Wetmore, *Arizona State University, US*
Daniel Whaley, *Climos, US*
Kevin Whilden, *Conserve Markets, US*
Leslie Wickman, *Aerospace Corporation, US*
Tom Wigley, *University of Adelaide, Australia*
James Wilsdon, *Royal Society Science Policy Centre, UK*
Oliver Wingenter, *New Mexico Institute of Mining and Technology, US*
David Winickoff, *University of California, Berkeley, US*
Oran Young, *University of California, Santa Barbara*
Frank Zeman, *New York Institute of Technology, US*
Charlie Zender, *University of California, Irvine, US*

Rapporteurs

Bidisha Banerjee, *M.E.M. candidate, School of Forestry & Environmental Studies, Yale University, US*
Noah Bonnheim, *B.A. candidate, Colby College; B.E. candidate, Dartmouth College, US*
George Collins, *J.D. candidate, Yale Law School; M.E.M. candidate, School of Forestry & Environmental Studies, Yale University, US*
Rachel Hauser, *Science writer; M.Sc. candidate in environmental sciences, University of Colorado, US*
Benjamin Kravitz, *Graduate assistant, Rutgers University, US*
Ashley Mercer, *Graduate student, University of California, Berkeley, US*
Amanda Reynolds, *B.A. candidate, Colby College, US*
Jesse Reynolds, *Graduate student, University of Tilburg Institute for Law, Technology, and Society, The Netherlands*
Kate Ricke, *Ph.D. candidate, Carnegie Mellon University, US*
Gabrielle Wong-Parodi, *Ph.D. candidate in the Energy and Resources Group, University of California, Berkeley, US*

Media

Chris Aikenhead, Canadian Broadcasting Corporation, Canada
Lee Buric, Independent filmmaker, US
Christopher Cokinos, *The American Scholar*, US
Gwyneth Cravens, Writer, US
Gwynne Dyer, Freelance journalist, UK
Erika Engelhaupt, *Science News*, US
Jim Giles, *New Scientist*, US
Jeff Goodell, Book author, US
Cheryl Hogue, *Chemical & Engineering News*, US
Ben Kalina, Independent film producer, US
Eli Kintisch, *Science*, US
Oliver Morton, *The Economist*, UK
Sascha Pohflepp, Freelance journalist, US/UK
Jim Rendon, *Mother Jones* magazine, US
Shannon Service, University of California, Berkeley, US
Bette Thompson, Canadian Broadcasting Corporation, Canada
Jerry Thompson, Canadian Broadcasting Corporation, Canada
Jeff Tollefson, *Nature*, UK

Top row (L-R): Jane C. S. Long and Danielle Guttman-Klein; Shobita Parthasarathy; Roger Barry; David Victor
Bottom row (L-R): Edward Parson; Alan Gadian; Bidisha Banerjee; Deborah Iglesias-Rodriguez

Acknowledgments

The Scientific Organizing Committee (SOC) is grateful for the many efforts that supported its activities. Dr. Margaret Leinen, founder and CEO of the Climate Response Fund (CRF), provided support for the Climate Institute to establish the SOC, graciously praising and gently probing to ensure progress was being made, but separating herself from the organization of the program, the selection of attendees, and the range of discussions at the conference. Through the CRF, Dr. Leinen was able to bring together a number of organizational partners for the meeting, especially the State of Victoria, Australia, Environmental Defense Fund, the Pew Center on Global Climate Change, the Royal Society, and Guttman Initiatives. All were helpful and strongly interested in the successful conduct and outcome of the meeting, while similarly respectful of the SOC's responsibilities.

For the actual conduct of the meeting, the SOC, and especially its chair, Michael MacCracken, is especially grateful to Corinne Kisner and John-Michael Cross of the Climate Institute. Corinne expertly handled many of the organizational aspects for the Conference and the participants as well as overall administrative support for the entire undertaking. John-Michael enthusiastically joined in on these efforts as the Conference grew and led in the publication of this report. In addition, Danielle Guttman-Klein of Guttman Initiatives, and Bill Bennett, Cathy Cook and Edward Sullivan of the Climate Response Fund team were very instrumental in the successful outcome of the Conference. We also appreciate the many helpful efforts of Michelle Egen at Boulder Travel and the staff of the Asilomar Conference Center in ensuring that the participants were able to travel to and participate in the Conference.

In preparation of this report, the SOC is particularly grateful to the many participants who provided review comments that helped to greatly improve the summarization of the findings from the conference. Conference group photo courtesy of Robert Klein III; all other photos courtesy of Duane Dale, DFDphotography.com.

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THE CLIMATE RESPONSE FUND

The Climate Response Fund, a non-profit foundation based in Alexandria, VA, was established in 2009 in response to the growing concern about climate change and the complex political, economic and social issues surrounding international scientific studies and methodologies for climate response. We foster discussion of climate engineering research (sometimes called geoengineering) to decrease the risk that these techniques might be called on or deployed before they are adequately understood and governed.