

THE BIPARTISAN POLICY CENTER'S

TASK FORCE ON CLIMATE REMEDiation RESEARCH



BIPARTISAN POLICY CENTER

Geoengineering: A national strategic plan for research on the potential effectiveness, feasibility, and consequences of climate remediation technologies

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** These members support the recommendations of this report, but they do not support the introduction of the new term "climate remediation."



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**TASK FORCE ON CLIMATE
REMEDiation RESEARCH**

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DISCLAIMER

This report is the product of a rigorous, reasoned process undertaken by the Bipartisan Policy Center's (BPC's) Task Force on Climate Remediation Research. It should not be construed that every member of the project's leadership is entirely satisfied with all of the policies contained in the report or that they agree with any recommendations made independently. As a whole, the task force believes this report is a balanced and comprehensive approach to addressing climate remediation research.

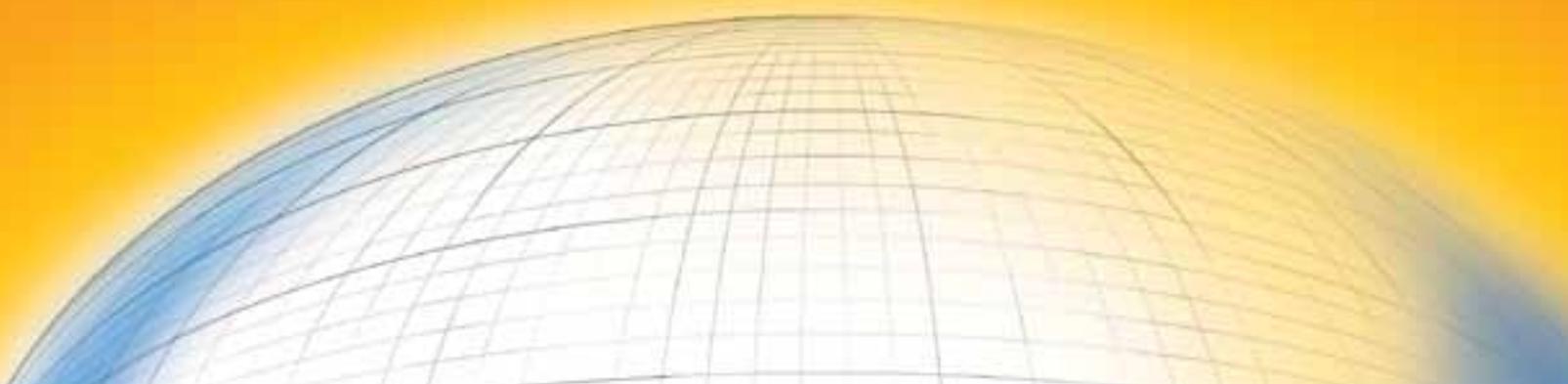
The findings and recommendations expressed herein do not necessarily represent the views or opinions of BPC, its founders, or its board of directors.

ACKNOWLEDGMENTS

The Bipartisan Policy Center would like to thank its funders for their strong support. Additionally, BPC's Task Force on Climate Remediation Research wishes to express gratitude for the substantial guidance and support provided by Timothy J. Mealey, Samuel Thernstrom, and Josh Trapani.

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I. Introduction

This report presents the conclusions of the Task Force on Climate Remediation Research, which was convened by the nonprofit Bipartisan Policy Center in March 2010 to develop recommendations for the U.S. government concerning geoengineering research and oversight policy. Participants included leaders from the scientific, science policy, foreign policy, national security, legal, and environmental communities who together brought a wide range of perspectives and expertise to the task force.

Geoengineering is controversial—indeed, the term itself is controversial because it is both broad and imprecise. The task force avoids using the term “geoengineering” in the body of this report.¹ We prefer the term “climate remediation,” which describes technologies that are intentionally designed to counteract the climate effects of past greenhouse gas emissions to the atmosphere.² The basket of concepts and technologies generally included in this category vary widely in scope, application, and impact. Therefore, they raise quite different scientific, technical, political, and ethical questions. Some of those technologies are thought to be high leverage (i.e., small interventions that may result in large effects on climate), but those technologies are also ones that could produce large, adverse side effects. Technologies that may be both high leverage and high risk present special challenges for research oversight. There are also potentially important technologies that are not high-leverage ones but that, nonetheless, present their own set of environmental risks. Those climate remediation approaches are discussed in detail in Chapter II.

Managing risk is a central principle of effective climate policy. This task force strongly believes that climate remediation technologies are no substitute

The task force defines the term “climate remediation” to mean intentional actions taken to counter the climate effects of past greenhouse gas emissions to the atmosphere.

This contrasts with the term “climate mitigation,” which we define as actions taken to reduce future net greenhouse gas emissions.³

lead—the important international conversations that are likely to emerge around such issues and activities in the years ahead.

With that in mind, the task force believes the federal government should embark on a focused and systematic program of research about climate remediation. The federal government is the only entity that has the incentive, responsibility, and capacity to run a broad, systematic and effective program; it can also play an important role in effectively establishing international research norms.

THIS TASK FORCE STRONGLY BELIEVES THAT CLIMATE REMEDIATION TECHNOLOGIES ARE NO SUBSTITUTE FOR CONTROLLING RISK THROUGH CLIMATE MITIGATION (I.E. REDUCING EMISSIONS OF CARBON DIOXIDE AND OTHER GREENHOUSE GASES) AND CLIMATE ADAPTATION (I.E. ENHANCING THE RESILIENCE OF MAN-MADE AND NATURAL SYSTEMS TO CLIMATE CHANGES).

for controlling risk through climate mitigation (i.e., reducing emissions of carbon dioxide and other greenhouse gases) and climate adaptation (i.e., enhancing the resilience of human-made and natural systems to climate changes). Most climate remediation concepts proposed to date involve some combination of risks, financial costs, physical limitations, or a combination of the three that make the concepts inappropriate to pursue except as complementary or emergency measures—for example, if the climate system reaches a “tipping point” and swift remedial action is required. The United States needs to be able to judge whether particular climate remediation techniques could offer a meaningful response to the risks of climate change. But even if it decides not to deploy any climate remediation technology, the United States needs to evaluate steps that others might take and to be able to effectively participate in—and

Because of the new and unique issues it raises, research into many climate remediation techniques will require new governance structures to engage the public and to set parameters for the research. Those parameters must change over time as understanding of the risks of climate remediation evolves.

This task force has not recommended deployment of climate remediation technologies, because far more research is needed to understand the potential impacts, risks, and costs associated with specific technologies. The purpose of this report, rather, is to describe how the task force believes the U.S. government should go about improving its understanding of climate remediation options and how it should work with other countries to foster procedures for research based on that understanding.

Our report is offered as an exploration of what might be appropriate responses to changes in the global climate measured in recent decades. This report and its recommendations focus on options for addressing climate change risks, regardless of the sources of those risks.

This report is not the first one written on the topic of climate remediation (and is unlikely to be the last). The task force particularly suggests that readers

Climate Change) that includes a chapter strongly supporting research into solar radiation management options. Our report can be seen as a preliminary implementation plan for the National Academy recommendations.

This report is organized as follows: Chapter II provides an overview and essential context, including a functional definition of climate remediation and the rationale for undertaking research in this area,

THIS TASK FORCE HAS NOT RECOMMENDED DEPLOYMENT OF CLIMATE REMEDIATION TECHNOLOGIES BECAUSE FAR MORE RESEARCH IS NEEDED TO UNDERSTAND THE POTENTIAL IMPACTS, RISKS, AND COSTS ASSOCIATED WITH SPECIFIC TECHNOLOGIES.

consult the 2009 report released by the United Kingdom Royal Society and titled *Geoengineering the Climate: Science, Governance and Uncertainty* for a more in-depth description of technologies associated with such approaches. Furthermore, the 2010 National Academy study on America's Climate Choices produced a report (titled *Advancing the Science of*

along with a set of general principles for guiding federal research efforts. Chapter III provides specific recommendations and the next steps for organizing effective federal research programs. Chapter IV briefly outlines important topics for research. Chapter V discusses international issues and engagement.

THE TASK FORCE BELIEVES THE FEDERAL GOVERNMENT SHOULD EMBARK ON A FOCUSED AND SYSTEMATIC PROGRAM OF RESEARCH INTO CLIMATE REMEDIATION.



II. Definition of "Climate Remediation" and the Rationale for Research

A. DEFINITION OF "CLIMATE REMEDIATION"

The Task Force on Climate Remediation Research defines the term "climate remediation" as intentional actions taken to counter the climate effects of past greenhouse gas emissions on the atmosphere.

This definition contrasts with the term “climate mitigation,” by which the task force means actions taken to diminish future net greenhouse gas emissions. For both of those terms, the task force means *past* or *future* relative to the time that the action is taken.

Climate remediation technologies differ markedly in their approach, their impact, and the speed with which they might act.

B. CATEGORIES OF CLIMATE REMEDIATION TECHNOLOGIES

Researchers are interested in pursuing two major categories of climate remediation technologies today: (a) those that are designed to remove carbon dioxide or other greenhouse gases from the atmosphere (carbon dioxide removal, or CDR) and (b) those that are designed to reduce the Earth’s absorption of the energy from sunlight (solar radiation management, or SRM). Some SRM technologies are thought to be high leverage in that they may produce large effects with small (but continuous) interventions and may have relatively low costs. At the same time though, they

could result in large, unintended side effects. CDR and SRM are very different in terms of their scale, speed, costs, interactions with the environment, and nature and magnitude of risks they might pose. Therefore, they present a wide spectrum of policy challenges.

It should be noted that, for many years, the federal government has supported studies of some CDR approaches. Those studies include efforts to understand the effects of changes in agricultural practices (e.g., no-till agriculture) and the effects of land-use changes (e.g., reforestation). In reports by the Intergovernmental Panel on Climate Change (IPCC) (e.g., IPCC’s 2007 report) and in the America’s Climate Choice Reports (released in 2010) by the National Academy, CDR approaches have been considered in the context of climate change mitigation options (i.e., reducing net emissions of greenhouse gases to the atmosphere caused by human activities). Consequently, CDR can be considered as a mitigation approach when it is connected to an energy technology or as a climate remediation approach when it is independent of energy choices. In this report, we discuss the research required to use CDR for climate remediation.

FIGURE 1: CLIMATE STRATEGY CONTEXT CIRCLE

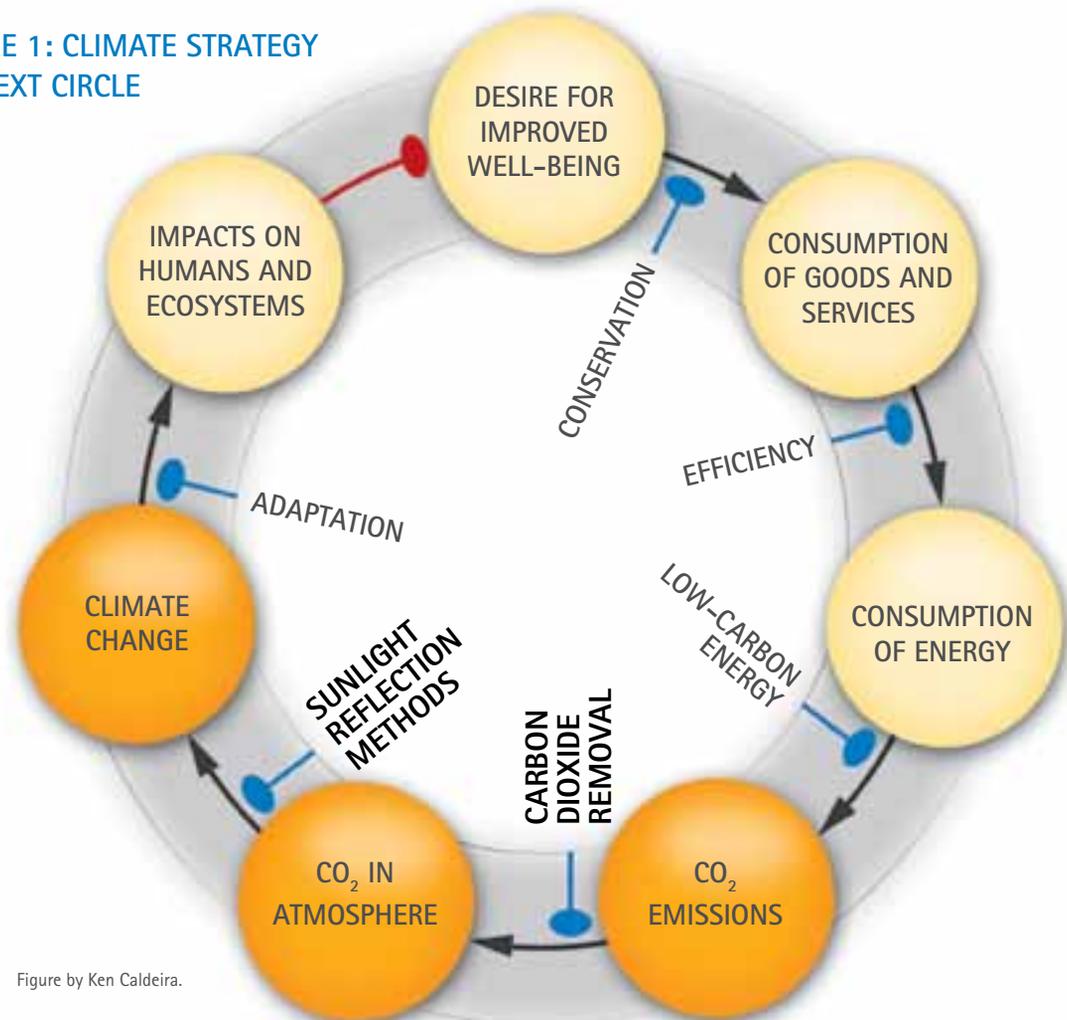


Figure by Ken Caldeira.

THE URGENT NEED FOR RESEARCH

Interest in climate remediation is motivated, in part, by concern that global climate change could unfold in ways that would be very difficult to manage. This difficulty could occur if, for example, feedbacks in the climate system amplify the rate of warming in a nonlinear or unexpected manner, thus causing very rapid changes and triggering potentially severe adverse impacts. Generally, an amplifying feedback occurs when rising temperatures cause a change that further increases greenhouse gas emissions or that enhances the Earth's absorption of heat, thereby accelerating further warming and exacerbating climate instability. Scientists have identified a number of adverse climate change impacts and potential amplifying feedbacks that could—if sufficiently severe—prompt countries to consider undertaking climate remediation.

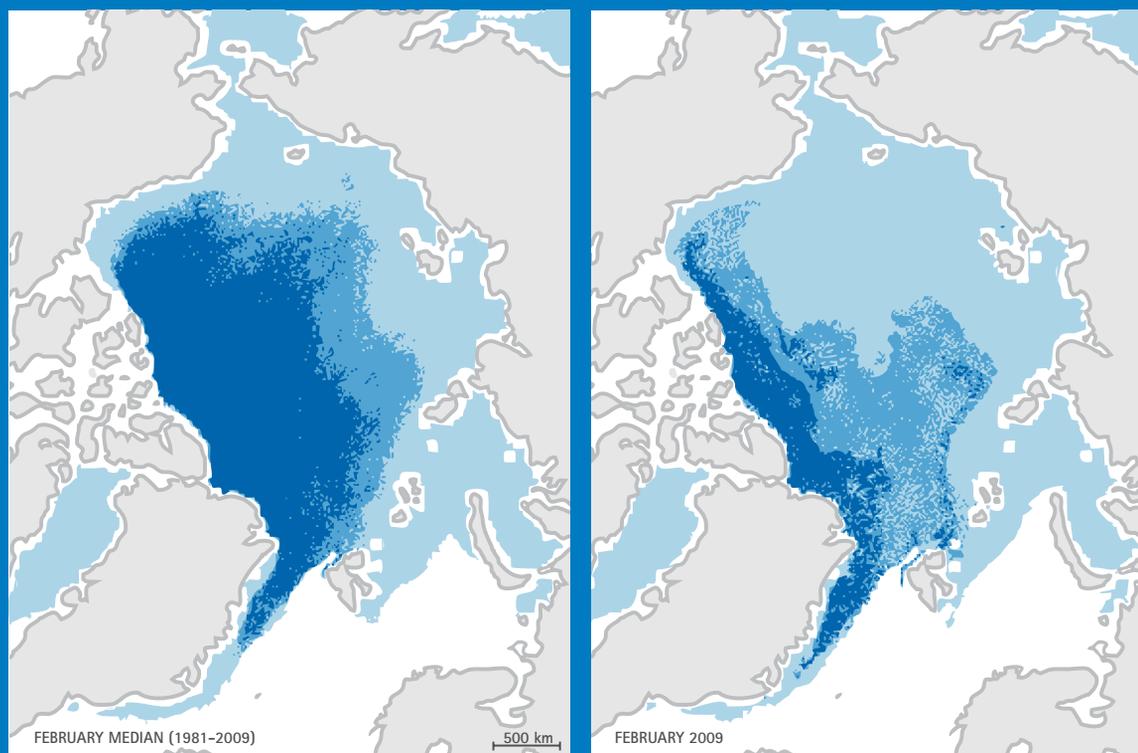
THREATS TO FOOD SUPPLY. Changes in temperature and rainfall patterns could negatively affect food supplies over large regions. For example, greater heat stress could limit plant growth. Where climate change causes flooding or delays the onset of the rainy season, crop yields would likely decline. An increase in the severity and frequency of droughts would have obvious implications for agriculture. Changes to ocean chemistry and temperature could affect

ocean ecosystems and reduce the supply of fish. Measures can be taken to adapt to these changes, but if the changes occurred quickly, world food supplies could be disrupted.

THREATS TO WATER SUPPLY. More than one billion people worldwide already suffer from inadequate access to clean water. As global temperature increases, people and animals will need more water even as warming causes water resources in some regions to decline. Better water management will continue to be critical, but the combination of continued population growth and rising temperature could dramatically increase the number of people with inadequate access to water. If climate change causes severe water shortages in some parts of the world, it will be important to know whether promising options exist for intervening in the hydrologic cycle.

LOSS OF ARCTIC FLOATING ICE. Warming of the oceans and the atmosphere is increasing the rate of loss of floating ice on the Arctic Ocean (see figure 2). As the ice melts, darker ocean water is exposed to the sun. This dark water absorbs more solar energy than the more reflective ice, leading to warmer oceans that, in turn, radiate more energy to the atmosphere. The result is an amplifying feedback that accelerates the rise in global temperature. The rapid loss of Arctic floating ice observed in recent years was not

FIGURE 2: OLD VERSUS NEW ICE IN THE ARCTIC OCEAN, FEBRUARY 2009



THESE MAPS SHOW THE MEDIAN AGE OF FEBRUARY SEA ICE FROM 1981 TO 2009 (LEFT PANEL) AND IN FEBRUARY 2009 (RIGHT PANEL). AS OF FEBRUARY 2009, ICE OLDER THAN TWO YEARS ACCOUNTED FOR LESS THAN 10 PERCENT OF THE ICE COVER.⁴

forecast nor is it quantitatively well understood. It is possible that feedbacks intrinsic to the Arctic climate system are causing the second half of the Arctic's permanent ice to disappear more quickly than the first half did. (The first half of the permanent ice was lost between 1980 and 2010.)

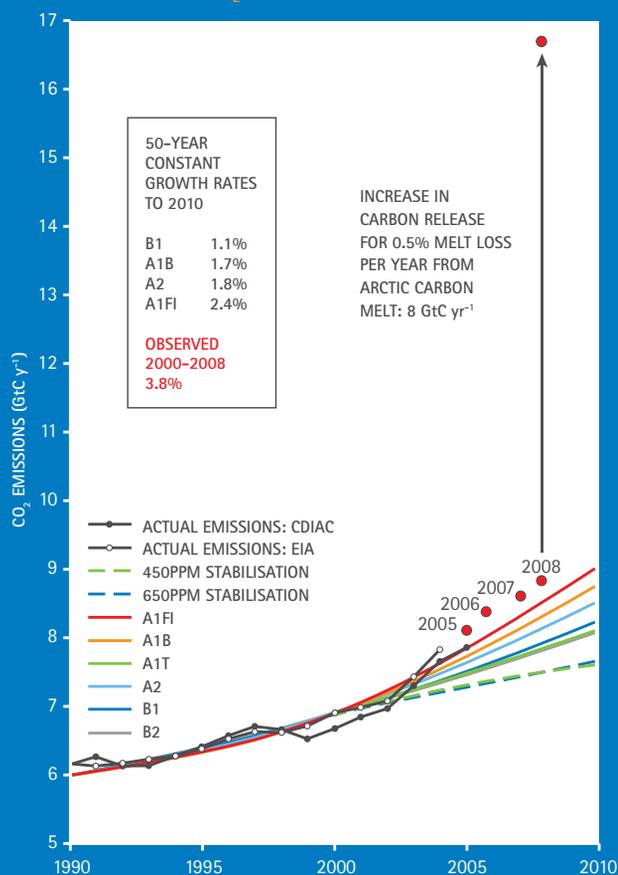
MASSIVE RELEASE OF GREENHOUSE GASES FROM THE ARCTIC REGION. Alaska and Siberia contain vast reservoirs of carbon (about 2,000 gigatons of carbon total) that could be released into the atmosphere as carbon dioxide (CO_2) and methane, two important greenhouse gases. This release could occur if warming of the Arctic basin (as a result of both rising temperatures and loss of permanent sea ice) has the effect of destabilizing those carbon reservoirs. A key uncertainty concerns how much of the carbon in frozen soils will be released as methane versus released as CO_2 ; each molecule of methane released to the atmosphere has 75 times the warming effect of a molecule of CO_2 . This phenomenon has the

potential to increase the rate of climate forcing dramatically, but no comprehensive observation system currently exists to measure the release of methane and CO_2 from melt zones in the high Arctic region. If methane and CO_2 start degassing rapidly from Siberia, it will be important to understand whether there are possible interventions that could address this potentially very potent feedback mechanism.

MELTING OF THE GREENLAND AND WEST ANTARCTIC ICECAP AND RISING OF THE SEA LEVEL. The presence of permanent floating ice in the Arctic prevents warm seawater from flowing into Greenland's glaciers. As the floating ice melts, icecaps will be more vulnerable to melting. The volume of water locked in Greenland ice alone would be sufficient to cause about 20 feet of sea level rise. Melting of the West Antarctic ice shelf (which is based below sea level) could cause sea level rise of a similar magnitude. To understand the potential for glacial melting and to predict associated sea level rise, the scientific community needs (a) a comprehensive system to observe changes in the ice structure, (b) a comprehensive mapping of the bedrock topography under the ice to better predict how the glacier will slide over this terrain, and (c) a much improved ability to predict how glaciers break up. If parts of these ice sheets start to collapse, it will be important to understand whether potential interventions are available that could prevent further collapse.

LOSS OF OZONE. The addition of greenhouse gases to the atmosphere does not just cause warming; it also causes an increase in water vapor in the stratosphere, which amplifies the ozone-destroying potential of halogens. Current halogen concentrations in the atmosphere remain high, despite the effects of the Montreal Protocol on Substances That Deplete the Ozone Layer, which regulates ozone-destroying chemicals such as chlorofluorocarbons (CFCs) and other gases. The increase in water concentrations in the stratosphere in the presence of continued halogen loading may destroy enough ozone to eliminate any gains made by the Montreal Protocol. Additionally, the destruction of ozone by halogens can take place in the presence of sulfur particles, as was observed following the eruption of Mount Pinatubo. This occurrence suggests that ozone destruction could be exacerbated by the climate remediation methods that involve injecting sulfur into the stratosphere as a way to reflect solar radiation. Impacts on ozone are a major issue for climate remediation research, particularly for those options that involve sulfate aerosols.

FIGURE 3: CO_2 EMISSIONS



THE BLACK LINES GIVE PAST CO_2 EMISSIONS AND THE COLORED PROJECTIONS SHOW FUTURE EMISSION SCENARIOS USED BY THE IPCC. THE RED DOT AT THE TOP SHOWS AN ESTIMATE OF CO_2 EMISSIONS THAT MIGHT RESULT FROM THE MELTING OF THE ARCTIC REGION.⁵



1. Carbon Dioxide Removal (CDR) Technologies and Techniques

CDR technologies and techniques are designed to remove greenhouse gases from the atmosphere, thereby addressing the root causes of climate change. Some proposed approaches for CDR include the following:

- Store carbon biologically by planting more trees (afforestation).
- Induce the growth of more plankton in the ocean to store carbon biologically. This induction could be done by “fertilizing” the ocean with iron or other nutrients.
- Create machines that could collect carbon dioxide or other greenhouse gases from the air. The captured gases could then be stored underground or through other techniques.
- Enhance natural chemical processes, such as terrestrial and oceanic rock weathering, to enable more carbon dioxide to react chemically with rock minerals.

CDR approaches could reduce climate change if they could be deployed successfully, affordably, and safely at scale. Researching CDR is critically important for a number of reasons, including for determining if the techniques can be affordable at scale. For instance, some CDR technologies currently exist, such as chemical processes that could remove carbon dioxide from the air, but they are very expensive.

The risk profiles of CDR technologies vary by technique. Some CDR technologies pose mostly local or regional risks, many of which are analogous to the existing energy infrastructure of the United States. If these processes were carried out on a globally significant scale, however, they may reveal risks that are not apparent or not significant at the scale of a single facility. For example, a single facility for

capturing CO₂ from the atmosphere would, in many respects, look like any other industrial facility, such as a refinery or a chemical plant. However, there is also a set of CDR techniques that could pose global risks, because they would be designed to interfere with large, complex, global ecosystems. For example, ocean fertilization would involve seeding large marine areas with iron or other nutrients to foster the growth of plankton blooms. The plankton would draw significant quantities of CO₂ from the atmosphere and incorporate CO₂ into organic matter or carbonate shells, which—if they sink deep into the ocean or to the ocean floor—would remove this carbon from the atmosphere for centuries. The risk, though, is that such interventions presumably could have big effects on ocean ecosystems. Other biological techniques that rely on monocultures or genetically modified plants or soil microorganisms could also risk changing ecosystems in unintentional and unpredictable ways.

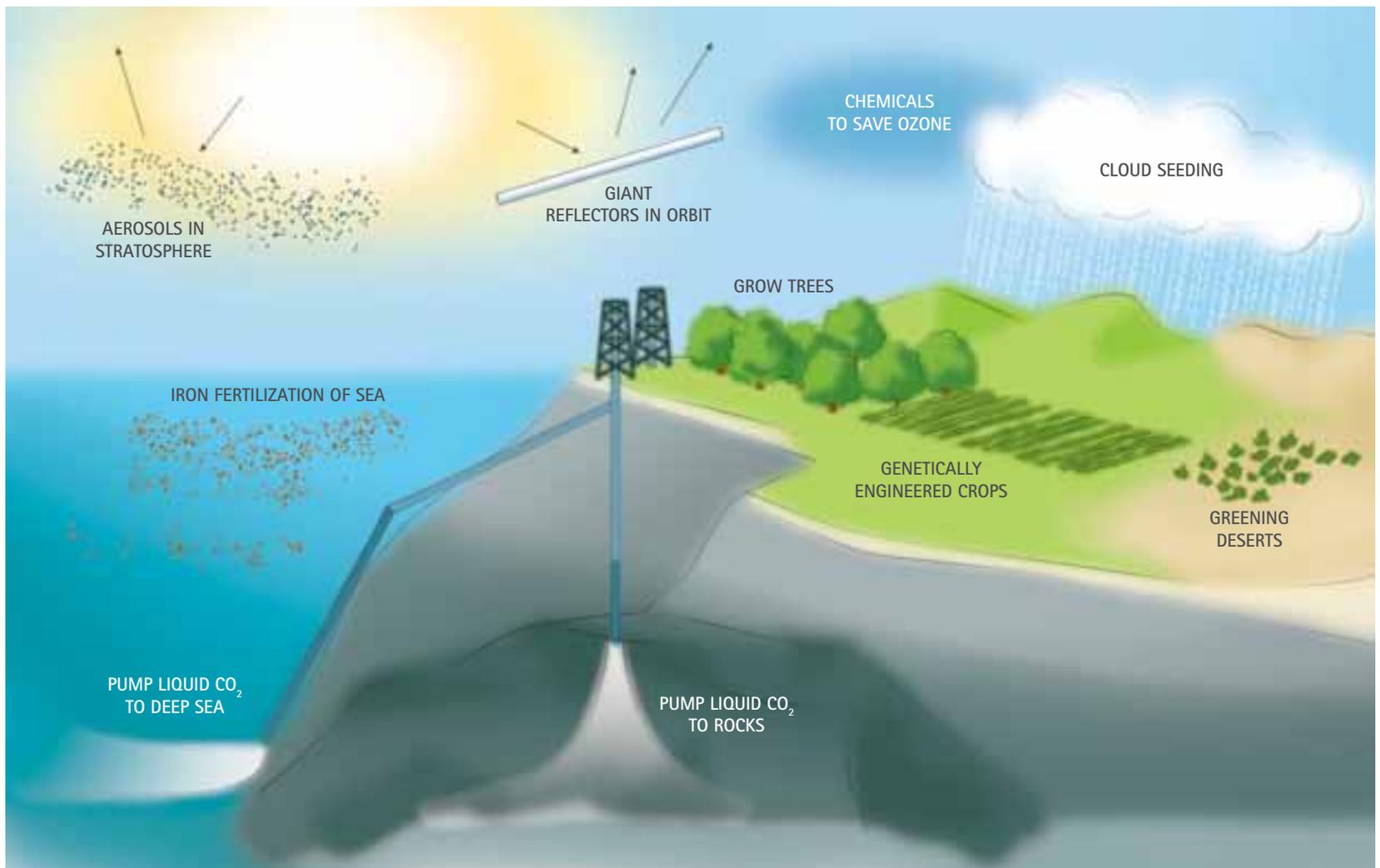
The 2009 United Kingdom Royal Society report evaluated many CDR techniques in terms of current understanding of their possible effectiveness, cost-effectiveness, timeliness, and safety.⁶

2. Solar Radiation Management (SRM) Techniques

SRM strategies aim to counteract or mask the effect of rising greenhouse gas concentrations in the atmosphere by increasing the amount of solar energy that is reflected back into space. This category of climate remediation options includes a range of ideas, but most current research is focused on two distinct concepts:

- Introducing very fine particles or liquid droplets—known as aerosols—into the stratosphere to deflect incoming solar radiation, and
- Altering the reflectivity of clouds by means such as spraying droplets of seawater into the atmosphere to make cloud droplets more numerous and smaller and to make the clouds more reflective (i.e., brighter).

FIGURE 4: CLIMATE REMEDIATION (GENERAL)⁷
Schematic representation of various climate remediation proposals



The idea of SRM is based on natural processes. Volcanic eruptions that have injected large quantities of aerosols into the stratosphere have reduced global temperatures for extended periods of time. For example, the Mount Pinatubo eruption of 1991 injected 20 million tons of sulfur dioxide into the atmosphere and reduced global average temperature by at least 0.5 degrees Celsius (0.9 degrees Fahrenheit) over 15 months.⁸ The “natural experiment” of Mount Pinatubo also highlighted the potential risks of SRM, because the eruption resulted in a dramatic reduction in precipitation.⁹ Although those observations of natural events lend credence to the idea that humans could introduce particles into the stratosphere and achieve similar effects, there is less certainty that it would be feasible to alter the reflectivity of clouds on a scale sufficient to produce such effects.

In theory, SRM could offer an opportunity to cool the planet rapidly and inexpensively. For this reason, SRM options could be especially important if climate remediation were needed on an emergency basis—that is, if it looked as if climate change was going to cause imminent severe, or even catastrophic, impacts. The cooling effect would stop rapidly if deployment were suddenly halted, however; therefore, the approach would need to be maintained continuously unless and until greenhouse gas concentrations in the atmosphere declined. Absent efforts to reduce the concentration of greenhouse gases in the atmosphere through mitigation or CDR, SRM (assuming it was a safe and effective technique) would have to be used continuously for centuries to stave off further climate change.

Although SRM may be able to mask some impacts of greenhouse gases on the climate system, it would do nothing to deal with the chemical consequences of increased CO₂ concentrations in the atmosphere, including ocean acidification—a phenomenon that poses significant risks, particularly for marine life.¹⁰ If deployed, SRM would almost certainly have uneven effects and might harm some regions while helping others.¹¹ If an SRM system were ever deployed, it could

1. The Physical Risks of Climate Change Are Real and Growing

The CO₂ that humans have already put into the atmosphere is inducing changes in the Earth's climate; moreover, CO₂ persists in the atmosphere for hundreds of years. Mitigation measures currently being considered, regardless of their pace or efficacy, will not be able to return atmospheric greenhouse

THE RISKS OF CLIMATE CHANGE CONTINUE TO INCREASE. ALTHOUGH WE DO NOT KNOW EXACTLY HOW MUCH THE CLIMATE WILL CHANGE OR HOW FAST, GLOBALLY DISRUPTIVE OR EVEN CATASTROPHIC RESULTS ARE POSSIBLE. RESEARCH IS NEEDED TO DETERMINE IF CDR AND SRM COULD BE POTENTIAL TOOLS TO COUNTER CLIMATE CHANGES THAT OTHERWISE MAY BE INEVITABLE AND COULD BE SEVERE.

result in decreased precipitation and evaporation, altered monsoon rains and winds, and perhaps delayed recovery of the ozone hole.¹² In addition to these anticipated risks, there may be further risks that scientists have not yet been able to identify.

Finally, deployment of SRM could raise particularly difficult national security questions and could create challenges for international policy coordination because it could help some regions while harming others. The crudest of SRM techniques could be deployed relatively easily and by a country with modest financial or technical capabilities. Those attributes of SRM technology raise the specter of possible unilateral decisions by countries to deploy such systems, thereby exposing other nations to side effects and to the burden of long-term management of SRM systems that cannot be stopped without creating harmful, sudden increases in global temperature.

Note: Essentially no work has been done to test SRM as a climate remediation concept beyond basic computer modeling. Whether SRM could ever be effectively used at all can be assessed only through further research. Although this report argues that research on climate remediation is needed on multiple fronts, the task force is particularly focused on SRM options because of the potential, the risks, and the management difficulties this set of options presents.

C. THE RATIONALE FOR FEDERAL CLIMATE REMEDIATION RESEARCH

The task force believes that the federal government has an essential role to play in initiating and managing a concerted research effort on SRM and CDR for the following reasons.¹³

gas concentrations to pre-industrial levels for centuries. Meanwhile, the risks of climate change continue to increase. Although we do not know exactly how much the climate will change or how fast, globally disruptive or even catastrophic results are possible. Research is needed to determine if CDR and SRM could be potential tools to counter climate changes that otherwise may be inevitable and could be severe.

2. The Geopolitical and National Security Risks of Some Climate Remediation Technologies Are Real

Governments and private entities in Germany,¹⁴ India,¹⁵ Russia,¹⁶ and the United Kingdom¹⁷ are exploring or moving ahead with their own climate remediation research efforts. Controversies about climate remediation have already arisen in the international diplomatic arena.¹⁸ The United States needs to understand SRM and CDR to engage in—and lead—international discussions and to evaluate how other nations or private entities may act. Engagement needs to begin immediately, given the pace of developments and the complexity of the issues involved. If the United States chooses not to engage these issues, international conversations and actions will proceed without us.

RECOMMENDATION 1: THE FEDERAL GOVERNMENT SHOULD INITIATE A COORDINATED RESEARCH PROGRAM ON CLIMATE REMEDIATION. THE OVERALL RESEARCH PROGRAM SHOULD ADHERE TO THE PRINCIPLES IDENTIFIED IN THE FOLLOWING SECTION.

D. PRINCIPLES FOR RESEARCH IN CLIMATE REMEDIATION

The only way for the United States to have an adequate, comprehensive, systematic, and open program of research on CDR and SRM is for the federal government to initiate such efforts. The federal government is the primary sponsor of basic research in the United States and is the primary sponsor of research related to climate change. If the federal government does not undertake such efforts, CDR and SRM research efforts are likely to be small, ad hoc, and—more critical—less available to public participation in decision making. Additionally, the federal government is well suited to establish widely accepted norms for the conduct of controversial research.

Research programs on CDR and SRM necessarily require building on existing efforts to better understand climate dynamics and the climate changes that the government is already supporting. It will be difficult to determine the impacts of future field experiments of SRM and CDR, for example, without a deeper understanding of what is happening in their absence. Consequently, the following requisites exist.

- Mitigation (which includes some forms of CDR) and adaptation must remain the first priorities for climate policy.
- Research on technologies to remediate the climate is urgently needed to advance societal and scientific understanding of these methods.

- Climate remediation research will require a strong effort in basic climate science.

U.S. climate remediation research programs should be established in accordance with the following principles and adhere to the following guidelines:

PRINCIPLE 1: PURPOSE OF CLIMATE REMEDIATION RESEARCH

The fundamental purpose of the research should be to protect the public and the environment from both the potential impacts of climate change and from the potentially damaging impacts of climate remediation technologies.

Climate remediation technologies can affect humans and ecosystems across the entire globe. The research program must consider the impacts (positive and negative) of climate remediation on all societies and ecosystems—not just those of the United States.

PRINCIPLE 2: TESTING AND DEPLOYING CLIMATE REMEDIATION TECHNOLOGIES

Given current scientific uncertainties about the efficacy, impacts, and risks associated with global-scale SRM interventions, the field deployment of SRM systems by the U.S. government or by any other government or entity would be inappropriate at this stage. This principle also holds for those CDR technologies that pose significant environmental risks.

Research can help illuminate the environmental, scientific, and social-political-economic issues with high-risk climate remediation, but research into

those methods should not be seen as inevitably progressing to deployment. The purpose of research is to inform future decisions, not preempt them. Careful consideration should be given to low-probability, high-consequence risks and to the distribution of potential effects across different regions and populations in the context of the risks posed by climate change itself.

**PRINCIPLE 3: OVERSIGHT
ISSUES FOR RESEARCH PROGRAMS**

The direction of CDR and SRM research should be based on advice from a range of experts outside the government, as well as advice from government officials, and should be informed by a robust process of public engagement.

Effective research programs must examine more than just the potential impacts, effectiveness, and risks of CDR and SRM technologies. They must also help develop appropriate governance structures for research into those technologies, domestically and internationally.

PRINCIPLE 5: INTERNATIONAL COORDINATION
The United States should work with other nations to promote cooperation and communication regarding the design, execution, evaluation, and oversight of climate remediation research.

The United States should, in launching and organizing its own research efforts, reach out to other nations and begin to build a common understanding of options and issues. A well-managed federal research program with appropriate governance can provide a template for international research collaboration—for example, by emphasizing transparency, public dialogue, and rigorous adherence to the principles of sound science. International research collaboration can help develop (a) international codes of conduct, (b) means for effective information sharing, and (c) modes of evaluation and decision making.

THE ONLY WAY FOR THE UNITED STATES TO HAVE AN ADEQUATE, COMPREHENSIVE, SYSTEMATIC AND OPEN PROGRAM OF RESEARCH ON CDR AND SRM IS FOR THE FEDERAL GOVERNMENT TO INITIATE SUCH EFFORTS.

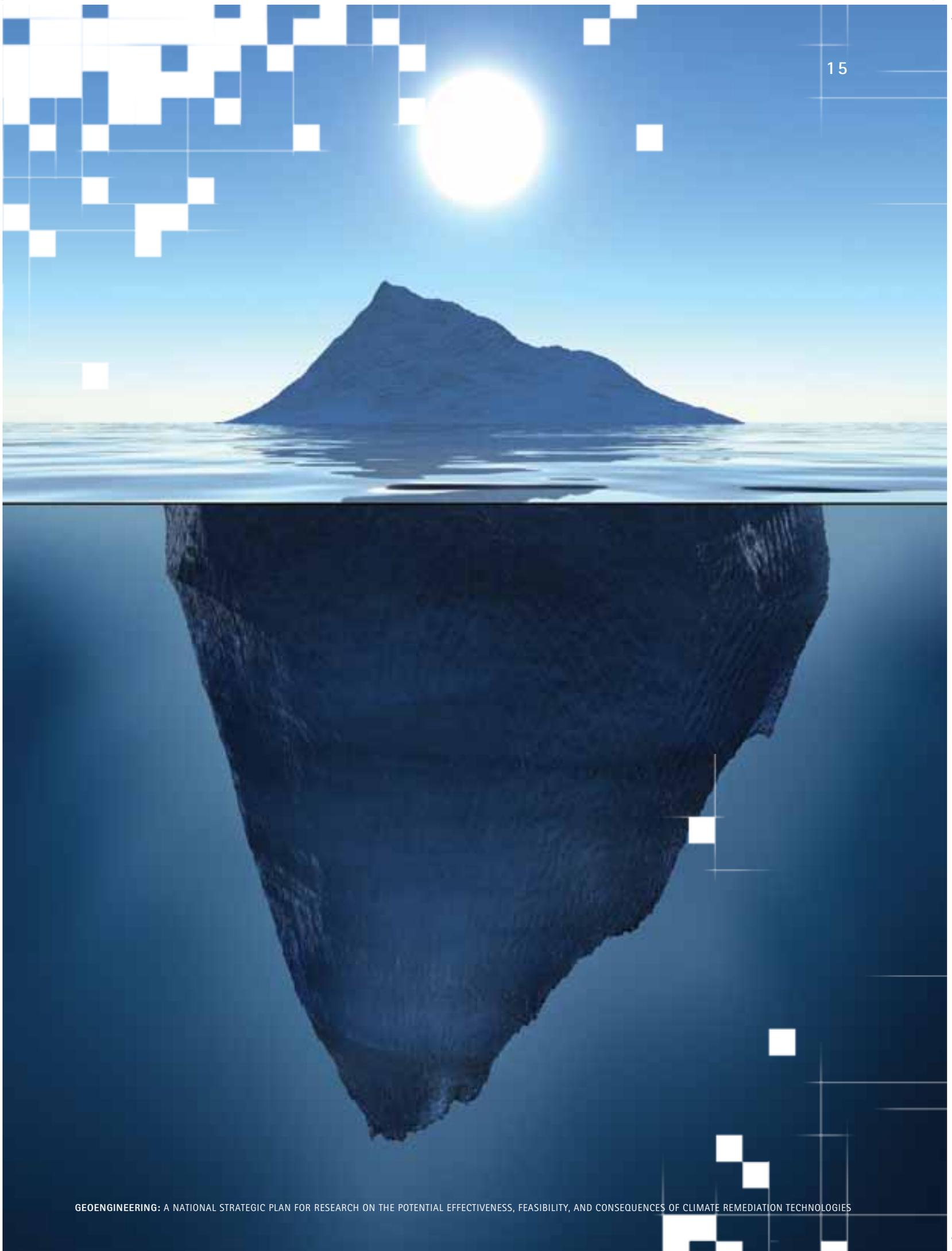
Robust and durable mechanisms for public engagement should be established early in the research programs. Public engagement will help to promote accountability among government officials and will help build public trust. It will also help ensure that societal values and concerns are incorporated into research priorities and parameters for what kinds of research are acceptable.

PRINCIPLE 4: IMPORTANCE OF TRANSPARENCY
Federal officials and federally funded scientists must keep the public informed about CDR and SRM research, especially when that research itself could be harmful or the method could be implemented at scale without substantial effort. Research plans and research results, both positive and negative, should be made public.

The federal government should develop transparency protocols for all potentially risky forms of climate remediation research. Those protocols should be appropriate for the magnitude and extent of potential impacts for the specific experiment under consideration—that is, protocols should be based not only on the risks posed by related research, but also on the risks that would be posed by deployment.

PRINCIPLE 6: ADAPTIVE MANAGEMENT
Research programs must evolve as more is learned about CDR and SRM and as more is learned about how to govern research in those areas.

The allocation of research funds should be based on evolving assessments of climate remediation technologies in the context of all climate change strategies. The environmental, scientific, technological, and social context for climate remediation research is likely to evolve significantly over time in unpredictable ways. Federal research programs should be required to review those changing conditions on a regular basis. The program must establish a transparent process for changing focus, direction, or research procedures in response to changing conditions. Institutions involved in climate remediation research should have the responsibility to evaluate assumptions and to test predictions against new information and actual observations.



III. Organization of U.S. Climate Remediation Research

No existing federal agency has all the resources (technical or financial) or all the expertise needed to address the diverse aspects of the many climate remediation techniques.¹⁹ In light of this, the Task Force on Climate Remediation Research focused on mechanisms for organizing a range of research activities that use existing government structures, rather than contemplating ways to reorganize the government that would be difficult and time consuming and that are unlikely to be implemented.

The government will need to coordinate research across a number of agencies, each with its own strengths, approaches, biases, research capabilities, constituencies, funding models, methods for evaluating proposals, and ways of encouraging the translation of research into practice. This diversity of capabilities and approaches presents a challenge but, if managed appropriately, can also be an asset.

Some research on climate remediation is already occurring, especially on carbon dioxide removal (CDR) techniques that can also contribute to mitigation. But the key to conducting a successful, broad research program on climate remediation technologies will be whether closely related research elements are effectively coordinated—that is, whether the government develops an overarching agenda and funding strategy as part of a coordinated effort, rather than simply yoking together disparate programs and projects that emerge on an ad hoc basis. With that approach in mind, the task force believes that a climate remediation research program must be coordinated by the White House.

RECOMMENDATION 2: THE WHITE HOUSE OFFICE OF SCIENCE & TECHNOLOGY POLICY (OSTP) SHOULD ASSUME THE LEAD ROLE IN COORDINATING THE FEDERAL GOVERNMENT'S CLIMATE REMEDIATION RESEARCH.

Basing coordination in the White House can ensure that (a) the larger goals of the program are maintained rather than the more narrow interests of particular agencies and (b) the political support of the president is clearly established over the course of the initiative. The White House is the best place to coordinate research and to ensure research is linked to other relevant government activities, such as international relations and environmental regulation. Finally, any controversies over experimentation by the United States or by other countries could certainly require White House engagement, which would benefit from having been involved from the outset. OSTP is, perhaps, the only entity in the federal government in a position to realistically coordinate this research enterprise and navigate the technical and political challenges. Despite its limitations and history, OSTP was specifically established, by statute and practice, to carry out high-level interagency coordination. Still, OSTP does not have the capability or responsibility to actually carry out research programs; that endeavor is the job of the research agencies.

OSTP should work closely with the other relevant White House offices, particularly with the Office of Management and Budget (OMB). No research effort will be successful without the serious involvement of OMB, which will be instrumental in establishing the program and ensuring its budgetary coherence. If all the budgets involving climate remediation research are reviewed as a single coordinated effort, a coherent program can result. If OMB does not take such an integrated approach, then this effort is likely to fail because the strategic coordination will not be meaningful. The Council on Environmental Quality will also need to play an important role because environmental agencies will be involved in the research and because that research could eventually raise regulatory issues.

A. LAUNCHING A CLIMATE REMEDIATION RESEARCH PROGRAM

OSTP and OMB should begin working immediately to put together a coordinated program for SRM and CDR research that should be proposed as part of the president's fiscal year 2013 budget.

As mentioned previously, some federally funded research into CDR and, to a lesser extent, SRM is already occurring on an ad hoc basis.²⁰ The task force emphasizes the urgent need for expanding and accelerating this research and for providing strategic coordination. We believe that ongoing but disparate climate remediation research will be improved only by establishing a coordinated and strategic approach to federal funding.

Ideally, this research would be funded with “new money” rather than by depleting the already overburdened research budgets of federal agencies.

OSTP and OMB, in their budgetary guidance, should emphasize the following points:

1. Climate remediation research depends on robust climate science research and is not a substitute for mitigation and adaptation research and implementation efforts.
2. No decision has been made or is imminent concerning the deployment of technologies that present large new risks.
3. Governance institutions and processes will need to be developed in tandem with the expansion of research.
4. Public engagement must inform the program agenda.

5. Establishing a coherent research program requires a coordinated effort to draw effectively on each agency's strengths and to ensure those strengths are applied in an integrated fashion across a range of research activities, including natural and social sciences, engineering, and the humanities.

The research of both CDR and SRM overlaps with existing research programs, but the existing programs do not offer a logical home for all climate remediation research. Some CDR technologies—particularly direct air capture of CO₂—clearly fall within the purview of the U.S. Climate Change Technology Program (USCCTP), which coordinates research on the development of climate change mitigation technology. Air capture is an extension of the carbon capture and sequestration research currently conducted by USCCTP. Other CDR research may have little connection to existing mitigation technology.

Effective research on other climate remediation approaches, primarily those related to SRM techniques, overlaps significantly but not fully with the goals, structure, and function of the U.S. Global Change Research Program (USGCRP), which is the country's main existing mechanism for coordinating research on climate change.²¹ Climate remediation research will require much better understanding of the

climate system; gaining this understanding is also a core mission of USGCRP. However, effective research in SRM will also require support for many distinct elements beyond basic climate science, including support for engineering research to determine if and how various methods could be implemented. The USGCRP is conducted as a bottom-up science program to increase understanding. This structure is not amenable to the focused strategic requirements of climate remediation research. There is also a clear need for a more extensive integration of social sciences than has been achieved so far under either the USGCRP or USCCTP. In addition, the controversies surrounding climate remediation research could distract from or even undermine the important mission of USGCRP. Consequently, the task force concludes that most climate remediation research should be coordinated closely but be kept distinct from the USGCRP and USCCTP.

If climate remediation research were, nonetheless, to be placed within the USGCRP, the task force would strongly urge that this program not be divided among USGCRP's existing working groups. Rather, a separate subcommittee for this research area should be constituted under the National Science and Technology Council's Committee on Environment, Natural Resources, and Sustainability.

B. DEVELOPING MECHANISMS FOR OVERSIGHT AND PUBLIC INVOLVEMENT

Some research on climate remediation—not to mention climate remediation efforts themselves—could pose risks and raise new ethical, legal, and social issues of broad public concern. For those reasons, some kinds of research will require more robust forms of oversight than usual, thereby involving more diverse kinds of experts and more public involvement. For example, for high-risk field experiments of any technology,

the problem and to identify dimensions of the problem that are being overlooked.

2. Advise the government on social, ethical, legal, strategic, and other issues that may emerge from conducting a research program on climate remediation and from the results of such a program.
3. Identify and recommend policies and practices that ensure that effective scientific research is conducted in a manner consistent with the principles articulated in this report.

SOME RESEARCH INTO CLIMATE REMEDIATION, NOT TO MENTION CLIMATE REMEDIATION EFFORTS THEMSELVES, COULD POSE RISKS AND RAISE NEW ETHICAL, LEGAL, AND SOCIAL ISSUES OF BROAD PUBLIC CONCERN. FOR THESE REASONS, SOME KINDS OF RESEARCH WILL REQUIRE MORE ROBUST FORMS OF OVERSIGHT THAN USUAL.

policy guidance will have to engender public trust. These needs will be particularly acute for the risky, high-leverage, relatively low-cost technologies that could possibly result in large, unintended side effects and that also present opportunities for unilateral action. (An example would be the injection of reflective particles into the stratosphere.) No existing government institution has the capacity to foster a trusted form of oversight in this arena, and doing so will also require the involvement of outside experts and the general public. Although decisions on governance must ultimately rest in the hands of government officials who are politically accountable for their actions, an advisory commission should help set standards of oversight in this field.

4. Recommend criteria for federal agencies to use in deciding whether to approve field research that is based on the level of risk posed by the proposed activity. Such criteria could also become the basis for international norms.
5. Conduct public communication and engagement activities.

The advisory commission should be administered through, and report to, OSTP, but it should advise all the agencies involved in the coordinated research program. The commission should be able to hire staff members, including an executive director, and should be authorized to hold hearings, take testimony, and receive evidence.

RECOMMENDATION 3: A NEW ADVISORY COMMISSION SHOULD BE ESTABLISHED BY THE WHITE HOUSE TO HELP GUIDE CLIMATE REMEDIATION RESEARCH. THE COMMISSION SHOULD BE MADE UP OF NATURAL SCIENTISTS, ENGINEERS, SOCIAL SCIENTISTS, LAWYERS, AND OTHERS WITH EXPERTISE RELEVANT TO DEVELOPING THE PARAMETERS FOR CLIMATE REMEDIATION RESEARCH, AND IT SHOULD REPORT TO THE DIRECTOR OF OSTP.

The commission's set of initial responsibilities should be the following:

1. Advise the government on how to set up an effective and adequately funded scientific program that is commensurate with the scale of

Initially, the advisory commission should work to develop guidance on the kinds of research that pose little, if any, risk of harm and that, therefore, do not require additional approval beyond existing agency processes. The goal would be for federal agencies to jointly define, on the basis of guidance from the commission, a class of experiments or projects that presumably would not raise any unusual risks and, therefore, would not require any special federal review beyond normal practice. For example, computer modeling studies would not risk incurring any actual adverse environmental impacts; presumably, the same could be said for most laboratory experiments and for the deployment of some technologies (such as chemical facilities that capture CO₂ directly from the atmosphere). This initial categorization is required so that critical research can be conducted with appropriate levels of governance as soon as possible.

The process of developing research guidelines will also serve as an opportunity to learn how to evaluate a range of approaches from a scientific, ethical, and social perspective. The commission will have to pay

special attention to those technologies that are high leverage; have relatively low cost; could possibly result in large, unintended side effects; and could be deployed unilaterally by other countries.

This low-risk early research should require little, if any, special scrutiny on a project-by-project basis. As research moves from individual small-scale and low-risk activities to more coordinated and higher risk research that requires scrutiny, the commission should begin to consider how to manage and regulate higher-impact research and should prepare recommendations in this area for OSTP and federal research agencies to discuss and vet broadly. The development of these recommendations will require the commission to conduct public outreach and engagement activities.

remediation research program must be responsive to evolving social conditions and norms. Consequently, it must integrate tools and expertise from multiple disciplines within the natural and social sciences, engineering, and humanities, while also fostering engagement with important stakeholders. To accomplish this, funding should be directed in ways that support broad collaboration among researchers who are working across an array of disciplines and who are focused on particular CDR or SRM techniques and groups of techniques. As the programs develop, research centers that engage a wide array of disciplines and that work on climate remediation technologies in an integrated fashion might also merit federal funding.

THE TASK FORCE ENDORSES A PRAGMATIC, INCREMENTAL APPROACH TO THE INITIAL ORGANIZATION OF RESEARCH PROGRAMS ON CDR AND SRM.

Climate remediation research programs should be careful to have separate functions for developing and assessing technologies. The commission should advise the agencies on policies and procedures for accomplishing this goal.

Beyond organizing and overseeing a national research program, the U.S. government—presumably, though not necessarily, the Department of State—should take the lead in developing international norms of behavior for testing. (See Chapter V.) The commission should advise this lead department or agency on the issues encountered in the U.S. domestic climate remediation research program and the measures being taken to address those issues.

C. MAKING INSTITUTIONAL ARRANGEMENTS FOR INTEGRATING RESEARCH ACROSS RELEVANT DISCIPLINES

The task force endorses a pragmatic, incremental approach to the initial organization of research programs on CDR and SRM. We note that significant research related to some CDR techniques is already underway but that work on SRM, especially, is still in its infancy. Because time is of the essence in establishing a thoughtful research program—especially in SRM where a sustained research effort is overdue—we urge the federal government to draw on existing financial and institutional resources to jumpstart the effort. Such support should initially concentrate on individual investigator-initiated research projects. Eventually, some of these projects may require substantial resources and involve large research teams, especially where they involve field experimentation.

The knowledge output from an effective climate

The aim of these integrating activities would be to (a) build expertise in the underlying natural science, engineering, humanities, and social science disciplines relevant to climate remediation problems; (b) provide time for teams to develop integrative research capacity, including connections and channels of communication with and among different institutions; (c) foster the ability to organize, participate in, and learn from public engagement activities; and (d) provide resources for universities and other research institutions to build capacity so that they can, in time, compete to host full-scale, integrated climate remediation research centers. The approach of funding decentralized investigator-driven research along with integrative research centers has worked well in other emerging or uncertain areas, such as nanotechnology, to ensure that research responds to societal issues and to enhance the ability of nonscientists to interpret the science.

RECOMMENDATION 4: THE FEDERAL GOVERNMENT SHOULD, FROM THE OUTSET, INTEGRATE RESEARCH ACROSS THE NATURAL AND SOCIAL SCIENCES FOR RESEARCH IN PARTICULAR CLIMATE REMEDIATION AREAS.

It is important that the problem to be solved is the primary determinant in developing the appropriate research team. Establishing national climate remediation research centers—which could be focused on particular technologies or groups of technologies—would be one effective mechanism for achieving this integration.



IV. Topics for a Climate Remediation Research Agenda

The task force believes the overall federal climate remediation research program should investigate a variety of techniques, including both carbon dioxide removal (CDR) and solar radiation management (SRM). Research should be designed to improve scientific understanding of the potential capabilities and risks of any technology and, if the technology offers benefits that justify its risks, should be designed to carry out the science and engineering needed to improve its effectiveness and lower its cost.

SRM has a number of potential risks, many of which are not well understood, so characterizing those risks must be an essential part of the research program. Many CDR technologies (such as air capture of carbon) may carry little potential risk, so research on those technologies could focus on reducing costs. Any research should be conducted using a phased approach, starting with low-risk and low-cost exploratory research in the laboratory and only gradually considering larger-scale, higher-risk research (including field experiments) as more is understood about the technology.

One area where work should begin immediately involves developing the capacity to rapidly respond to and study—in an extremely focused and sophisticated manner—any naturally occurring experiments (such as volcanic eruptions or natural changes in ocean fertilization) as they relate to climate remediation research. The instruments, equipment, protocols and personnel involved in managing a scientific response team for this purpose could be developed today at a modest cost with potentially enormous scientific value.

the pace and magnitude of future climate effects remain hard to predict.

The complicated nature of the climate system could make it difficult for scientists to confidently predict the pace and magnitude of climate impacts in the coming decades. Research on climate remediation will necessarily reveal those critical gaps in scientific understanding and will steer the science toward the answers. Consider the five following knowledge gaps:

1. Scientists, until recently, failed to detect or predict the rapid loss of permanent ice in the Arctic Ocean—a system that is dominated by potent feedbacks and that also initiates a cascade of coupled feedbacks in other climate sub-systems.
2. No comprehensive observation system exists to quantitatively map the flux of methane and CO₂ isotopes from melt zones in the high Arctic region.

ONE AREA WHERE WORK SHOULD BEGIN IMMEDIATELY INVOLVES DEVELOPING THE CAPACITY TO RAPIDLY RESPOND TO AND STUDY ANY NATURALLY OCCURRING EXPERIMENTS AS THEY RELATE TO CLIMATE REMEDIATION RESEARCH, SUCH AS VOLCANIC ERUPTIONS.

A. CLIMATE SCIENCE AND CLIMATE REMEDIATION

Any strategic research on climate remediation must be founded on as comprehensive an understanding as possible of the Earth's climate system. Without that understanding, it will be hard to judge if and when SRM or CDR would be warranted and how well they are working (either in experiments or if ever fully deployed). Climate remediation research should not come at the expense of fundamental climate research. In particular, SRM research cannot succeed—and technologies can never be reasonably deployed—without the necessary grounding in a basic understanding of the climate.

Major gaps exist in the U.S. climate science research agenda that must be addressed if we are to gain a fundamental understanding of the powerful feedback mechanisms that drive the climate system. As a result, significant uncertainties remain about how sensitive the Earth's climate is to changes in greenhouse gas levels (i.e., by exactly how much a particular increase in greenhouse gas concentrations in the atmosphere will affect temperature, precipitation, and other aspects of the climate) and how quickly the climate will respond to increased concentrations of the gases. Climate remediation research will also help focus climate scientists on the specific questions that must be answered to assess climate remediation options. Although the evidence is overwhelming that the Earth's climate is changing because of human activity,

3. No observation system exists that is capable of defining potential changes in ocean circulation around Antarctica and their impact on the flow of internal energy into the West Antarctic Ice Sheet.
4. No observation system exists to identify changes in the glacial structure of Greenland or the underlying topography of Greenland's bedrock. An understanding of both elements is necessary to define the region's ice dynamics, which in turn control the rate at which melt water is added to the world's oceans.
5. No observational foundation exists to determine how the troposphere-stratosphere coupling will respond to an increase in CO₂ forcing. This response, in turn, controls the amount of water vapor in the stratosphere and is crucial to determining the rate of ozone destruction in the stratosphere.

This list is only a very partial one, but it is emblematic of the scientific challenge at hand. Discussion of climate remediation will bring such limitations into high relief. The first four knowledge gaps listed, for example, would limit the ability to predict, with certainty, how much carbon would have to be removed to attain a particular climate effect. The fifth gap is relevant for SRM research, because the addition of sulfate aerosols to the lower stratosphere could lead to very significant reductions in lower stratospheric ozone and to consequent increases in ultraviolet dosage at the mid-latitudes of the Northern Hemisphere. Thinking

seriously about specific CDR and SRM options will result in a more strategic approach to climate research.

One of the major challenges posed by SRM strategies, in particular, is the need to be able to detect and attribute the marginal impacts of climate interventions. Without a strong base of climate science, evaluating—not to mention deploying—any of those options will amount to “flying blind.”

B. RESEARCH ON SRM TECHNOLOGIES

Research on SRM should balance the effort to develop feasible technologies with a continuous and rigorous evaluation of those technologies’ effectiveness and risks. Concurrently, research must integrate the scientific and technical aspects of SRM with the political, social, and ethical issues raised by researching (and, if it ever came to pass, deploying) those systems. A research program should be structured to minimize the likelihood of “groupthink”—whether it is for or against SRM interventions. There may be value in the “blue team/red team” approach: one team could be charged with making an SRM system as effective and low-risk as possible, while the other would seek to identify ways the system could fail for technical, ecological, and social reasons.



The task force has identified a number of potential objectives for an SRM research program in physical sciences as well as in social science and humanities.

Research in the physical sciences is needed to address three fundamental questions about SRM:

1. **Could SRM methods effectively mitigate specific consequences of climate change and reduce climate risks?** A world cooled by managing sunlight will not be the same as a world cooled by lowering emissions. How would the effects of specific SRM techniques be distributed geographically? How well could those effects be predicted or controlled? For example, how might the injection of sulfate aerosols in the stratosphere reduce global temperatures, and would this method reduce the harmful effects of climate change on tropical crop productivity or biodiversity?
2. **What are the risks and side effects of various SRM techniques?** For example, would stratospheric aerosols accelerate the catalytic destruction of ozone? How would ecosystems be affected by the rain-out of injected substances? Aerosol injection will diffuse the light reaching the Earth and alter the visible appearance of the sky. How will this affect plant growth and ecosystem health as well as humans?
3. **Is it possible to accurately detect and monitor the implementation of SRM techniques and can we have confidence that it will be possible to distinguish resulting effects on the global climate from natural variability?** This evaluation will determine whether the effects of SRM could be measured well enough to successfully manage an intervention in the global climate.

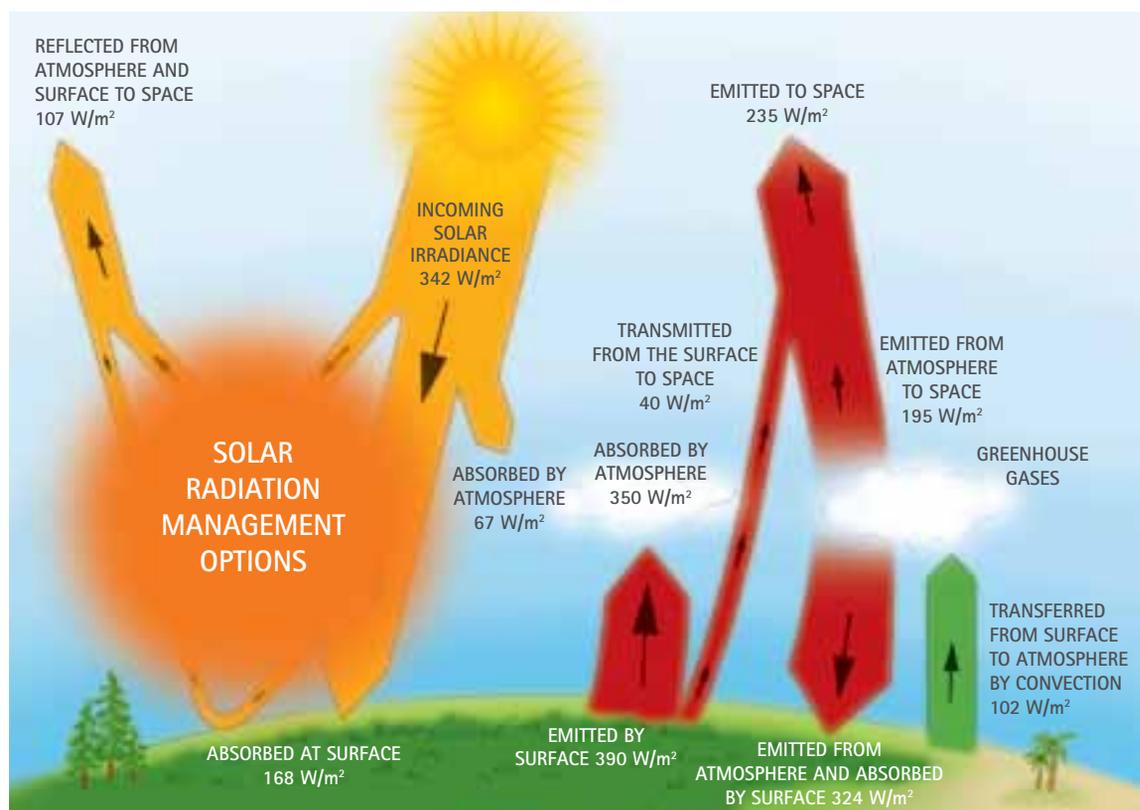
Social science and humanities research must also be part of an SRM research program to ensure that the political, economic, ethical, and other social dimensions of SRM research and deployment are understood. Social science research can help the government decide how to engage the public and how to ensure that SRM decisions reflect public values. It can also help officials develop domestic and international governance structures for SRM activities. A social science research program should encompass qualitative and quantitative methods and draw from a range of relevant disciplines. Federal policy should encourage work in cross-disciplinary teams.

Social science and humanities research on SRM needs to cover at least three sets of key questions:

1. **What are the important historical, social, economic, legal and ethical issues for climate remediation, and how should those issues inform related technical research and public policy?**

FIGURE 5: SOLAR RADIATION MANAGEMENT (SRM)

Stratospheric Aerosol Injection²²



2. What institutions—both within countries and internationally—are likely to provide oversight for the research, development, and potential deployment of SRM systems? What kinds of reforms or efforts to build new institutions may be needed in light of the potential benefits and risks of SRM field research? Where is it likely that these institutions will focus on governance and where are distinct (perhaps central) roles for civil society likely?
3. How will various societies perceive the risks and opportunities in SRM research? What risk constructs are various stakeholders adopting, and how are those constructs influencing scientific and societal agendas?

We are mindful that research of this type has potentially large implications for the design of effective public policy. The United States needs to develop the institutional capacity to conduct climate remediation research, and—should society ever decide there are beneficial remediation options available—this capacity will be necessary to deploy those methods with minimal negative impacts. Although there are many public policy aspects of managing SRM research, some of the most difficult issues will arise in relation to decision making at the international level. If some governments become convinced that SRM is inexpensive and offers the prospect of fast reductions in climate change, how will the United States and other countries ensure that decisions about testing and deployment are made with adequate regard for

the risks in the face of what will certainly be growing pressure to just make the “quick fix”?

Moreover, it is important to phase in an SRM research program, which should proceed gradually and cautiously. It should start with relatively small projects as part of an effort to identify, focus, mobilize, and build research capacities.

Exploratory research and assessment and small-scale experiments that are not intended or expected to have noticeable climate or other large-scale impacts should come first. If this work reveals promise, if expected risks are limited, and if the social and climate context warrants it, a subsequent phase should follow in which the aim is to determine the engineering feasibility of various SRM technologies and to develop the capacity for large-scale experiments. Experiments of this type could take decades as scientists attempt to sort out the “signal” of SRM effects from natural variations in climate. The advisory commission recommended in this report would play an important role in guiding decisions about research in those phases.

C. RESEARCH ON CDR TECHNOLOGIES

Further work is also needed to understand the potential and limitations of CDR technologies and to answer a number of critical research questions.

Because there are significant differences in the risks posed by different CDR techniques (industrial air capture poses different risks than ocean fertilization, for example) and in the technical issues required for development, the research agenda and governance issues for CDR will vary by method.

Some general research questions for CDR technologies are the following:

1. **Can CDR technologies be applied on the scale needed to achieve meaningful results?** Although plausible mechanisms for capturing CO₂ are well known and can, in many cases, be demonstrated in a test tube or small experiment, scaling those mechanisms to the point where they could have a significant impact on atmospheric CO₂ concentrations within a reasonable time period is very difficult. In some cases, the question demands an engineering answer; in other cases, it requires advances in basic science.
2. **Will deployment on the scale needed to produce a meaningful impact be feasible at a reasonable cost?** To the extent that the cost of CDR exceeds the cost of emissions mitigation, CDR techniques will not compete economically until other mitigation options have been exhausted.²³
3. **What are the environmental or ecosystem impacts and risks of large-scale CDR deployment?** Those impacts will be specific to the particular CDR technology being deployed. Ocean fertilization could interfere with ocean ecosystems, the introduction of artificial or bioengineered trees could raise concerns with respect to terrestrial ecosystems, and rock weathering or deep ocean disposal of CO₂ might affect important environments. In short, each technology will require a specific evaluation of potential environmental impacts and risks.
4. **What are the social, political and legal impacts and issues associated with specific CDR technologies?** Some CDR technologies may raise siting issues; other CDR technologies may raise legal or policy questions.

As noted in the previous chapter, research needed to advance some CDR options can be undertaken mostly within existing federal programs and institutions—if their scope were expanded in manageable ways. This ability exists, in part, because several proposed CDR

technologies are quite similar to those already under investigation for emissions mitigation. Air capture of CO₂, for example, is tightly linked to work on carbon capture and sequestration, which is under an ongoing investigation as a technology for mitigating CO₂ emissions from fossil fuel-based electricity generation. Carbon cycle interventions, such as afforestation, are also currently being investigated. With that said, a CDR research program should accommodate concepts

RESEARCH NEEDED TO ADVANCE SOME CDR OPTIONS CAN MOSTLY BE UNDERTAKEN WITHIN EXISTING FEDERAL PROGRAMS AND INSTITUTIONS, IF THEIR SCOPE WERE EXPANDED IN MANAGEABLE WAYS. [...] SEVERAL PROPOSED CDR TECHNOLOGIES ARE QUITE SIMILAR TO THOSE ALREADY UNDER INVESTIGATION FOR EMISSIONS MITIGATION.

that are not currently being addressed under the heading of emissions mitigation. For this reason, a CDR research program will also require some new programmatic guidance. For example, work on the concept of enhanced rock weathering as a way to absorb CO₂ might become a focus for the U.S. Geological Survey (USGS) and does not fit well into a program on CO₂ capture conducted by the U.S. Department of Energy.



V. International Engagement

The testing and deployment of climate remediation technologies is intended to have beneficial impacts on climate. The consequences of climate remediation activities, however, are likely to transcend national boundaries. Climate remediation research, therefore, implicitly has international ramifications.

Because unilateral actions by one or more individual countries could have far-reaching consequences, early efforts to engage other major nations and to launch an international dialogue on relevant policy issues are essential. The United States must play a pivotal role in this process.

As an open democracy with a large and independent scientific community and with the active involvement of civil society, the norms the United States establishes are likely to influence other nations. A major objective of the U.S. government in collaborating with other members of the international community should be to encourage other countries to undertake research activities in ways that are consistent with the principles and recommendations in this report.

A. ASPECTS OF CLIMATE REMEDIATION THAT REQUIRE INTERNATIONAL COOPERATION

The international consequences of certain solar radiation management (SRM) and carbon dioxide removal (CDR) technologies must be taken into account in U.S. policy because the technologies may (a) be relatively inexpensive and fast-acting, (b) involve unknown risks, and (c) be accessible to countries that lack sophisticated scientific capacities.

Countries May Have Divergent Attitudes Concerning the Testing and Use of SRM and Other Climate Remediation Technologies, But All Countries Could Potentially Be Affected by Deployment

Some governments may be inclined to test and deploy systems with less regard for side effects, whereas others may reject all forms of deliberate climate remediation, even for research purposes. Because the subject is so complex and potential risks are still unclear, it will likely be difficult or impossible to reach a global consensus on common policies and ground rules. It is important, however, to start early to develop international research and policy collaboration, at least among major actors.

Some Nations May Be Tempted to Deploy SRM Technologies Unilaterally

A number of countries (perhaps already at least a dozen) currently have the technological and economic potential to deploy SRM technologies. If the growing effects of climate change prove sufficiently severe, some of those countries may decide, out of self-interest, that the benefits of deploying SRM

A MAJOR OBJECTIVE OF THE U.S. GOVERNMENT IN COLLABORATING WITH OTHER MEMBERS OF THE INTERNATIONAL COMMUNITY SHOULD BE TO ENCOURAGE OTHERS TO UNDERTAKE ANY RESEARCH ACTIVITIES IN WAYS THAT ARE CONSISTENT WITH THE PRINCIPLES AND RECOMMENDATIONS IN THIS REPORT.

International cooperation will be required, and efforts to achieve it will be affected by the following contextual factors:

SRM Technology Is Still Undeveloped

Although many SRM schemes have been proposed, virtually no work has been undertaken to test those concepts beyond basic computer modeling. A substantial amount of further research is needed to learn how SRM technologies might be deployed, what impact they might have on climate, and what side effects they might produce. However, it would not be appropriate to design protocols or other formal oversight mechanisms for the use of SRM technologies until there is greater understanding of those and other issues.

Advanced Research Will Require Field Testing

In the early phases of research, progress can be made using small-scale tests to evaluate discrete concepts, technologies, and engineered components such as delivery mechanisms. At some point, however, large-scale field tests will be needed to evaluate the effectiveness of SRM systems and to assess their potential impacts on regional and global climate and ecosystems. Field tests, regardless of scale, are likely to raise questions about risk and, hence, could be controversial both domestically and internationally.

outweigh the risks—particularly if potential adverse consequences seem likely to fall more heavily, or even entirely, outside the countries' borders.

Climate remediation (under the title of geoengineering) has already emerged as a subject of international concern at a recent meeting of Parties to the United Nations Convention on Biodiversity in October 2010 in Nagoya, Japan. A group of nongovernmental organizations and (mostly developing) countries recommended that governments adopt a vaguely worded moratorium on all climate remediation “activities.”

The task force considers such blanket restrictions to be misplaced at this time, because they could impede research that would lead to better decisions about whether, when, and how to use remediation technologies. A poorly worded research ban might also block potentially promising technologies that pose little or no significant risk. Such a moratorium (a) could stifle the development of international research norms, (b) could impede understanding of critical issues, and (c) would not effectively discourage unilateral deployment.

Some of the “activities” discussed in Nagoya may already be technically covered by existing international regimes. For example, climate



interventions that involve seeding materials into the oceans could possibly fall under the London Dumping Convention or related regional agreements. Other SRM techniques might be considered under international treaties on transboundary air pollution—notably the Long-Range Transboundary Air Pollution family of treaties that covers mainly Europe. Because some SRM activities might affect the ozone layer, they could possibly be regulated under the Montreal Protocol on Substances That Deplete the Ozone Layer. Realistically, however, none of the existing international forums were designed for, or are capable of, effectively governing climate remediation research.

B. ELEMENTS OF A STRATEGY FOR INTERNATIONAL ENGAGEMENT

Initial U.S. efforts to promote international dialogue and cooperation on climate remediation technologies and techniques could include the following components, which are:

- Agency-to-agency communication between U.S. research organizations and government institutions and their counterparts in other nations
- Diplomatic discussions by the U.S. Department of State
- Support for dialogue within the international research community, especially through the National Academy of Science, the National Academy of Engineering, and the U.S. agencies involved with funding or conducting climate-related research
- Development of collaborative international programs through, for example, the International Council of Scientific Unions (ICSU) and the International Geosphere-Biosphere Programme (IGBP)

Agency-to-Agency International Outreach

U.S. research agencies should begin reaching out to counterparts abroad to discuss potential collaboration in research agendas, protocols for experiments that might have transnational or global effects, and practices for establishing transparency and other norms. Direct communications between university and other scientists working in different countries can also contribute importantly to the evolution of transnational norms.

Scientific outreach can be effective even when formal relations between nations are cool. An important element in achieving the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer was a collaboration by National Aeronautics and Space Administration (NASA) with the former Soviet Union's space agency during the height of the Cold War. Scientific comity with other key nations (including Germany and Japan) was a significant part of the State Department's diplomatic strategy in the complex international negotiations that resulted in an unexpectedly strong, lasting, and successful treaty to protect the stratospheric ozone layer.²⁴

The National Science Foundation's Office of International Science and Engineering could play a critical role in promoting international agency-to-agency dialogue on climate remediation. Other federal agencies, including NASA, the Department of Energy, the Environmental Protection Agency, and the National Oceanographic and Atmospheric Administration—as well as the new advisory commission proposed by this task force—could also initiate opportunities to work with their counterparts in other countries.

The State Department

The State Department should play its customary role both in leading U.S. multiagency delegations at international meetings and in conducting informal bilateral discussions with counterpart foreign ministries of selected governments. The State Department, therefore, needs to maintain active participation in climate remediation discussions within the U.S. government. Domestic decisions on SRM and CDR could serve as international models and set the tone for subsequent discussions with other nations.

The National Academy of Science and the National Academy of Engineering

The National Academies have cooperative relationships with similar scientific bodies in many other countries. These connections are of special value in cases where the National Academies' counterparts are also the lead institutions for funding and managing cutting-edge scientific research in their home countries. This is the case, for example, in

China and the Russian Federation.²⁵ Cooperation and dialogue at this level will help to ensure that early climate remediation initiatives are science-based and knowledge-focused while also promoting international adherence to broad-based research norms.

C. AN INCREMENTAL BUT PROACTIVE APPROACH TO INTERNATIONAL ENGAGEMENT

RECOMMENDATION 5: THE UNITED STATES SHOULD PROMPTLY COMMENCE WORKING WITH NATIONS THAT HAVE THE REQUISITE SCIENTIFIC, TECHNOLOGICAL, AND FINANCIAL QUALIFICATIONS TO ESTABLISH COMMON NORMS AND EXPECTATIONS FOR CLIMATE REMEDIATION RESEARCH. SUCH A PROCESS WOULD FACILITATE FUTURE FORMAL OR INFORMAL AGREEMENTS AMONG PARTICIPATING NATIONS ON NORMS FOR CONSIDERING THE DEPLOYMENT OF CLIMATE REMEDIATION TECHNOLOGIES. THE TASK FORCE RECOMMENDS, HOWEVER, THAT, FOR THE FORESEEABLE FUTURE AND AS A PRACTICAL MATTER, A LESS FORMAL PROCESS WOULD BE CONSIDERABLY MORE PRODUCTIVE THAN A FORMAL MULTILATERAL DISCUSSION OR NEGOTIATION OF CLIMATE REMEDIATION.

Formal multilateral negotiations have proved an inherently difficult mechanism for making timely progress on issues characterized by some urgency, and those institutions are particularly problematic when dealing with issues that are heavily dependent on scientific information when the scientific knowledge is at a very early stage.

Historically, instances of successful international cooperation on complex scientific or technical issues have generally engaged only a relatively small group of committed countries that determine to solve practical international problems in ways that are more closely linked to scientific research and assessment than to broad foreign policy considerations or aspirations. Examples include successful international efforts (a) to eliminate malaria on a global scale, (b) to manage stockpiles of smallpox virus, (c) to cooperate on space programs and nuclear proliferation, and (d) to promote the worldwide “Green Revolution” in agriculture. None of those historic cooperative scientific accomplishments in the international arena required a formal United Nations global treaty.²⁶

The United States can and should play a central role in this process of international engagement, because it has the technical and financial capabilities to undertake advanced scientific research and because—as an open democracy with a large and independent scientific community and the active involvement of civil society organizations—the norms that the United States establishes are more likely to be favorably considered on an international scale by other countries.

At some point, nations willing to financially and scientifically support research on climate remediation techniques could form a coalition. Such a coalition could play a progressive role in future debates about the development, regulation, and potential use of remediation technologies. The coalition could also take the lead in diplomatic discussions to resolve international disagreements or crises, for example, in the event that a country acts unilaterally to begin testing or deploying high-risk climate remediation systems.

D. MODELS FOR INTERNATIONAL COOPERATION IN THE REALM OF SCIENTIFIC RESEARCH

Conducting research in an internationally cooperative manner is not always easy or efficient, but it can be productive—both in terms of advancing the science and in terms of developing common perspectives and agendas. If large-scale field tests do go forward—ideally in a transparent fashion with the acquiescence and involvement of the international community—it may be desirable or even necessary to enlist international fleets of aircraft, satellites, and hardware as well as international sources of funding and management capabilities.

A number of models for international scientific cooperation of this sort already exist (see text box, next page). These models suggest some useful lessons for the organization of a successful international research effort, particularly one directed to SRM technologies:

- One country (or a small group of countries) takes the lead, but a wide array of countries may contribute to the effort.²⁷
- Research is funded and conducted primarily at the national level, with international coordination.²⁸
- A clear mission guided by an international group of scientific experts helps keep the endeavor connected to the frontier of knowledge.
- The process of collaboration to set research goals, design and fund experiments, and analyze data helps foster dialogue and trust among nations on complex and contentious issues.

EXAMPLES OF INTERNATIONAL RESEARCH COLLABORATION

International collaboration on climate science, which could form the basis of progress in developing multinational climate remediation options, is not new. One of the earliest examples was the International Geophysical Year of 1957–58, which was the first sustained multinational research program on the global environment.

Another more recent and directly relevant example is the World Climate Research Programme (WCRP), which was established in 1980 by the International Council for Science and the World Meteorological Organization to “determine the predictability of climate and to determine the effect of human activities on climate.” An 18-member joint scientific committee formulates overall scientific goals and concepts for the WCRP, while a joint planning staff organizes WCRP conferences, working groups, and projects. The research is conducted by individual scientists working in various types of research institutions in different countries. During more than 30 years of existence, the WCRP has made substantial contributions to advances in climate science. Its current core projects seek to enhance understanding of the cryosphere (i.e., portions of the globe where water exists in solid form), the variability and predictability of the climate, the global energy and water cycle, and the role of stratospheric processes in the climate.

The European Organization for Nuclear Research provides a model for a closely integrated operational partnership on highly technical research subjects.

Nuclear waste management and disposal are also areas that have benefited from international collaboration. As with SRM, the topics raise complex questions of technology, earth science, long-term stewardship, and public engagement. A number of inter-country collaborations, notably with the Swedish nuclear waste program, allowed the international community to share the burden of technology development and to formulate technical norms for characterizing and analyzing the behavior of nuclear waste repository sites. Much of this collaborative



technical work was used in Sweden and other countries (though not in the United States) as a basis for licensing facilities and for securing public acceptance of individual countries' nuclear waste management plans. Countries that participated in this program provided funding, agreed on research goals, and established a formal process for adaptive management, which allowed the program to take credit for the results it achieved.

Finally, efforts to halt the proliferation of nuclear weapons have likewise benefited from extensive international research collaboration. As with climate remediation, those efforts involved a problem that threatened the existence of the world as we know it and that would have been difficult to address through consensus-based treaties. In the process, countries have improved their ability to communicate around these issues and have built confidence, not only in their ability to detect detonations, but also in the behavior and values of other participant countries.²⁹

ENDNOTES

- ¹ It should be noted that the term "geoengineering" is used in other disciplines to describe any engineering applied to a geological problem or in a geological setting, including in water resources management; extraction of minerals, oil, and natural gas; environmental restoration; and earthquake diagnostics, just to name a few areas.
- ² Our group was originally called the Task Force on Geoengineering Research, but as we have come to the conclusion that "climate remediation" is a much more useful term for describing the activities and issues under consideration, we have decided to modify the name to the Task Force on Climate Remediation Research.
- ³ In both of those cases, we mean *past* or *future* relative to the time that the action is taken.
- ⁴ Data are provided by James Maslanik and Charles Fowler of the University of Colorado's Center for Astrodynamic Research. The original figure can be found at the following website: http://nsidc.org/sotc/sea_ice.html.
- ⁵ For carbon added as a function of calendar year, see IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp. For carbon added as a result of melting of the Arctic region, see McGuire, A.D. et al. Sensitivity of the carbon cycle in the Arctic to climate change, *Ecological Monographs* 79(4), 523-555, 2009.
- ⁶ The Royal Society "Geoengineering the Climate: Science, Governance, and Uncertainty," 2009, <http://royalsociety.org/Geoengineering-the-climate/>.
- ⁷ D. W. Keith (2001). Geoengineering. *Nature*, 409: 420.
- ⁸ NASA (National Aeronautics and Space Administration), "Global Effects of Mount Pinatubo," *Visible Earth* 8 (June 2006), http://visibleearth.nasa.gov/view_rec.php?id=1803.
- ⁹ Kevin E. Trenberth and Aiguo Dai, "Effects of Mount Pinatubo Volcanic Eruption on the Hydrological Cycle as an Analog of Geoengineering," *Geophysical Research Letters* 34, no. 15702 (2007), doi:10.1029/2007GL030524.
- ¹⁰ Oceanic absorption of carbon dioxide from fossil fuels will make the ocean more acidic over the next several centuries with unknown consequences, particularly for marine life. (Ken Caldeira and Michael Wickett, "Anthropogenic Carbon and Ocean pH," *Nature* 425 (2003): 365. <http://crecherche.ulb.ac.be/facs/sciences/biol/biol/CaldeiraWickett2003.pdf>).
- ¹¹ Climate change itself may present these same uneven distributional impacts. (Mohammed H. I. Dore, "Climate Change and Changes in Global Precipitation Patterns: What Do We Know?," *Environment International* 31, no. 8 (2005): 1167-81.
- ¹² David Keith, "Learning to Manage Sunlight: Research Needs for Solar Radiation Management," Testimony before the Energy and Environment Subcommittee of the U.S. House of Representatives Committee on Science and Technology, Washington, DC, February 4, 2010, http://science.house.gov/sites/republicans.science.house.gov/files/documents/hearings/020410_Keith.pdf.
- ¹³ The task force notes that these rationales need not be coupled and that either rationale in isolation is significant enough to justify the recommendations that follow in this report.
- ¹⁴ AWI (Alfred-Wegener-Institut Für Polar- Und Meeresforschung), "An Indo-German Iron Fertilization Experiment: What Are the Effects on the Ecology and Carbon Uptake Potential of the Southern Ocean?," AWI, Bremerhaven, Germany, April 27, 2011, http://www.awi.de/en/news/press_releases/detail/item/lohafex_an_indo_german_iron_fertilization_experiment_what_are_the_effects_on_the_ecology_and_carb/?cHash=2191f49105.
- ¹⁵ Ibid.
- ¹⁶ Yuri A. Izrael, V. Zakharov, N. Petrov, A. Ryaboshapko, V. Ivanov, A. Savchenko, Yu. Andreev, B. Danelyan, and V. Kulyapin, 2009. "Field Experiment on Studying Solar Radiation Passing through Aerosol Layers," *Russian Meteorology and Hydrology* 34, no. 5 (2009.): 265-73.
- ¹⁷ In the United Kingdom, this entity is the Integrated Assessment of Geoengineering Proposals (IAGP). For more information on IAGP, visit <http://iagp.webapp3.uea.ac.uk/about-iagp>.
- ¹⁸ There has already been one effort at the international level toward restricting geoengineering activities despite the limited state of current information. At the October 2010 meeting of parties at the United Nations Convention on Biological Diversity in Nagoya, Japan, environment ministers from more than 100 countries asked governments to impose a moratorium on further geoengineering projects or experiments until the risks of those technologies could be fully assessed. Although the practical implications of the Nagoya decision are still hard to determine, the outcome is a sign of how international policy in this area could evolve in suboptimal directions if important countries, including the United States, are not actively leading with alternative strategies. The task force elaborates on this point in Chapter V of this report.
- ¹⁹ GAO (U.S. Government Accountability Office). "Climate Change: A Coordinated Strategy Could Focus Federal Geoengineering Research and Inform Governance Efforts," 2010, GAO-10-903, Washington, DC, <http://www.gao.gov/new.items/d10903.pdf>.
- ²⁰ A 2010 GAO report, "Climate Change: Preliminary Observations on Geoengineering Science, Federal Efforts, and Governance Issues," states the following: "Our observations to date indicate that federal agencies such as DOE [the Department of Energy], National Science Foundation (NSF), U.S. Department of Agriculture (USDA), and others have funded some research and small-scale technology testing relevant to proposed geoengineering approaches on an ad-hoc basis." The report is available at <http://www.gao.gov/new.items/d10546t.pdf>.
- ²¹ For an assessment of the USGCRP by the National Research Council of the National Academies' 2009 report "Restructuring Federal Climate Research to Meet the Challenges of Climate Change," see http://www.nap.edu/openbook.php?record_id=12595&page=1.
- ²² Modified from Kiehl and Trenberth (1997).
- ²³ If the costs can be reduced to compete with mitigation, CDR may become a good way to create offsets for continued fossil fuel use and, thus, would become a mitigation technology.
- ²⁴ Richard Elliot Benedick, *Ozone Diplomacy: New Directions in Safeguarding the Planet*, enlarged ed. (Cambridge, MA: Harvard University Press, 1998) .
- ²⁵ The National Academy of Science collaborates with the Chinese Academy of Engineering through the International Council of Academies of Engineering and Technological Sciences, as well as with the Russian Academy of Sciences through the International Council for Science.
- ²⁶ Richard Elliot Benedick, "Considerations on Governance for Climate Remediation Technologies: Lessons from the 'Ozone Hole'," *Stanford Journal of Law, Science and Policy* 4 (2011.): 6-9.
- ²⁷ For example, in the 1960s, the United States led a deep-sea research effort—in the first phase by supplying a ship with funding from the National Science Foundation—that eventually evolved into an ongoing international ocean-drilling program. Japan later supplied a ship for the third phase of the program, which ultimately involved about 24 nations in one way or another.
- ²⁸ The degree of international coordination needed varies with the style of research. When research involves a single platform or set of machines (e.g., the Ocean Drilling Program or the European Organization for Nuclear Research) then coordination is intense. When research involves the sharing of results and joint planning of agendas, coordination can take the form of an umbrella organization (e.g., the World Climate Research Programme). We think that climate remediation research, at present, falls in the latter category. In time, however, joint funding and management of technology and equipment (e.g., high altitude aircraft for particle testing or measurement satellites) might require more centralized systems for coordination.
- ²⁹ Arian L. Prenger, "Advancing the Goals of NPT Article VI," *Nonproliferation Review* 15, no. 3 (2008): 529-38.

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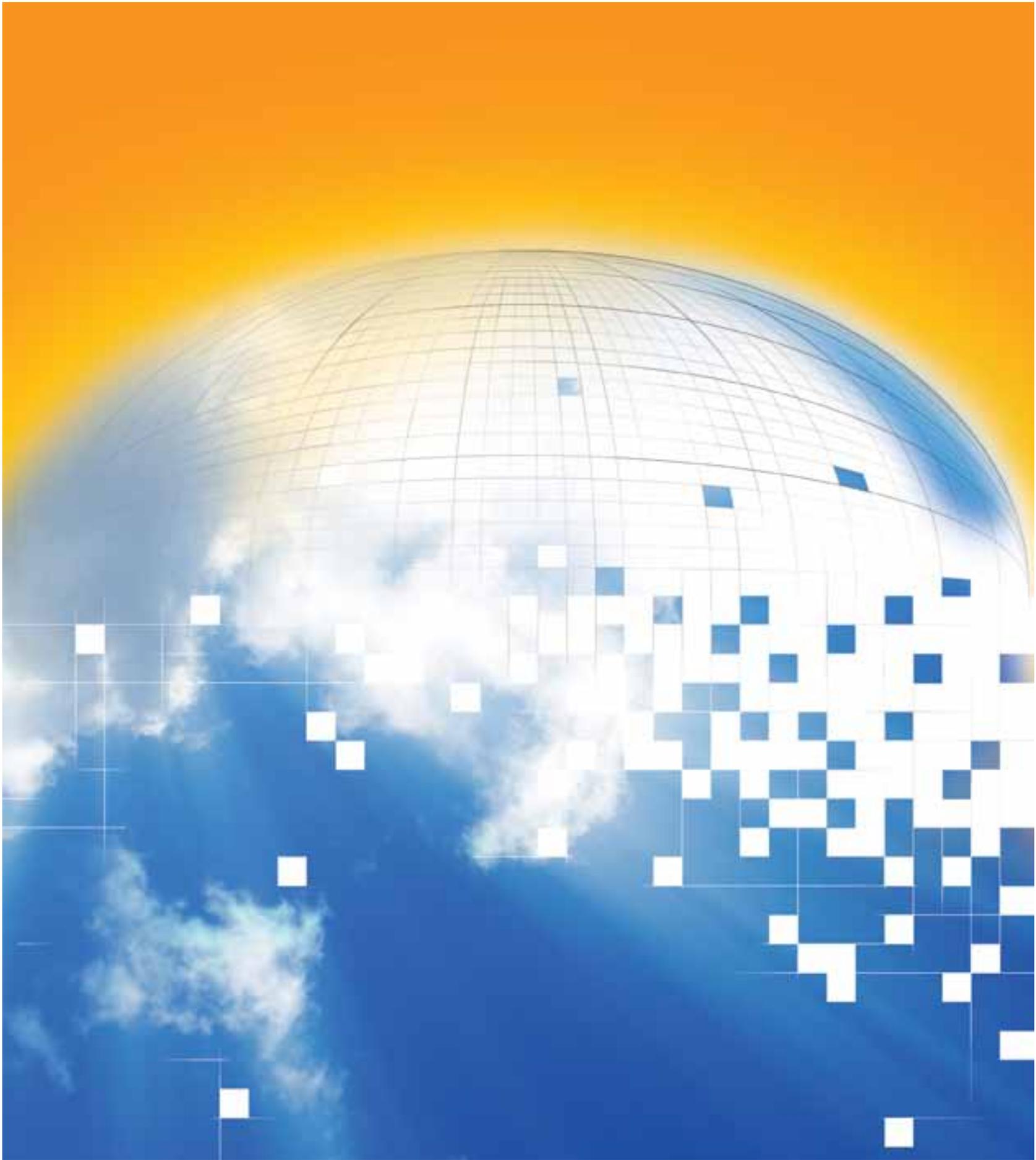
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