COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

"*Geoengineering: Assessing the Implications of Large-Scale Climate Intervention*"

Thursday, November 5, 2009
10:00 a.m.
2318 Rayburn House Office Building

Purpose

On Thursday, November 5, 2009, the House Committee on Science & Technology will hold a hearing entitled "***Geoengineering: Assessing the Implications of Large-Scale Climate Intervention.***" Geoengineering can be described as the deliberate large-scale modification of the earth's climate systems for the purposes of counteracting climate change. Geoengineering is a controversial issue because of the high degree of uncertainty over potential environmental, economic and societal impacts, and the assertion that research and deployment of geoengineering diverts attention and resources from efforts to reduce greenhouse gas emissions. The purpose of this hearing is to provide an introduction to the concept of geoengineering, including the science and engineering underlying various proposals, potential environmental risks and benefits, associated domestic and international governance issues, research and development needs, and economic rationales both supporting and opposing the research and deployment of geoengineering activities. This hearing is the first in a series on the subject to be conducted by the Committee, with subsequent hearings intended to provide more detailed examination of these issues.

Witnesses

- **Professor John Shepherd, FRS** is a Professorial Research Fellow in Earth System Science at the University of Southampton, and Chair of the UK Royal Society working group that produced the report *Geoengineering the Climate: Science, Governance and Uncertainty*.

- **Dr. Ken Caldeira** is a professor of Environmental Science in the Department of Global Ecology and Director of the Caldeira Lab at the Carnegie Institution of Science at Stanford University, and a co-author of the Royal Society report.

- **Dr. Lee Lane** is a Resident Fellow and the Co-director of the Geoengineering Project at the American Enterprise Institute (AEI) and former Executive Director of the Climate Policy Center.

- **Dr. Alan Robock** is a Distinguished Professor of Climatology in the Department of Environmental Sciences at Rutgers University and Associate Director of Rutgers Center for Environmental Prediction.

- **Dr. James Fleming** is a Professor and Director of Science, Technology and Society at Colby College and the author of *Fixing the Sky: The Checkered History of Weather and Climate Control.*

Background

Climate

Global warming is caused by a change in the ratio between the amount of incoming shortwave radiation from the sun and the outgoing longwave radiation. Greenhouse gases (GHG's), such as carbon dioxide and methane, decrease the ability of longwave radiation to escape earth's atmosphere. This makes it more difficult for radiation to "escape" and therefore, causes higher radiation absorption. The trapped energy causes higher global temperatures. Proposals for geoengineering typically include activities that alter the earth's climate system by either directly reflecting solar radiation back into space or removing greenhouse gases from the atmosphere to stabilize the intake-output ratio.

In pre-industrial times, the atmospheric concentration of carbon dioxide (CO_2) remained stable at approximately 280 parts per million (ppm). Today the concentration stands at approximately 385 ppm and is steadily increasing. While some industrialized countries' emissions have remained flat in recent years – due in part to slowing economic growth and reduction of economic energy-intensity - overall global emissions are still growing more rapidly than most 1990's climate projections had anticipated,[1] currently increasing CO_2 concentrations by approximately 2 ppm per year.

Estimates on safe and plausible CO_2 concentration targets vary greatly. Climate scientists at the National Oceanic and Atmospheric Administration (NOAA) and a consensus of other scientific authorities identify 350 ppm as the long-term upper limit of atmospheric carbon concentrations that avoid significant environmental consequences. A climate panel led by NASA's Dr. Jim Hansen identified the ecological "tipping point," the level at which atmospheric carbon, without additional increases, would produce rapid climate changes outside of our control, to be 450 ppm.[2][3] The U.S. Global Change Research Program has also identified a stabilization target of 450 ppm in order to "keep the global temperature rise at or below…2˚ F above the current average temperature, a level beyond which many concerns have been raised about dangerous human interference with the climate system."

Pending U.S. climate legislation and international initiatives under the United Nations Framework Convention on Climate Change (UNFCCC) would establish goals for reducing

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[1] The Global Carbon Project's CO2 emissions trends notes that CO2 emissions from fossil fuels and industrial processes have increased from 1.1% a year from 1990-1999 to 3.0% a year from 2000-2004. This growth represents a faster rate of increase than projected by even the most fossil-intensive scenarios projected in by the IPCC in the late 1990s. Archived at http://www.globalcarbonproject.org/global/pdf/TrendsInCO2Emissions.V15.pdf as of October 20, 2009.

[2] Michael McCracken notes that the lowest concentration at which economic analyses [suggest] that stabilization seem even remotely possible is 450 ppm. See McCracken p. 2.

[3] Hansen, James et al. *Target Atmospheric CO2: Where Should Humanity Aim?* Open Atmospheric Science Journal., **2**, 217-231, doi:10.2174/1874282300802010217.

domestic and global greenhouse gas emissions and accelerating development of low-carbon or zero-carbon energy technologies. However, many in the international climate community hold that even the most aggressive achievable emissions reductions targets will not result in the avoidance of adverse impacts of climate change and ocean acidification. Given global economic growth trends, many consider reaching 450 ppm and temperature increases of more than 2˚C to be imminent. The Intergovernmental Panel on Climate Change (IPCC) estimated in its 2007 assessment report that, under various emissions scenarios, the global temperature average will rise between 1.1 and 6.4 °C by the year 2100, resulting in sea level rise of 18 to 59 cm in the same time frame.

Further complicating these projections is the possibility of non-linear, "runaway" environmental reactions to climate change. Two such reactions that would amount to climate emergencies are rapidly melting sea ice and sudden thawing of Arctic permafrost. Sea ice reflects sunlight, and as it melts it exposes more (darker) open ocean to sunlight, thus absorbing more heat and accelerating melting and sea level rise. Likewise, as Arctic permafrost thaws it releases methane, a more powerful greenhouse gas than $CO_{2,}$ which then further decreases the Earth's albedo and accelerates warming.

Geoengineering

It is for these reasons that geoengineering activities are considered by some climate experts and policymakers to be potential "emergency tool" in a much broader long-term and slower acting global program of climate change mitigation and adaptation strategies. Dr. John Holdren, director of the Office of Science and Technology Policy and President Obama's lead science advisor, asserted that while geoengineering proposals are currently problematic due to potential environmental side effects and financial costs, the possibility "has got to be looked at" as an emergency approach.[4] While the deployment of geoengineering will likely remain a very controversial subject, an increasing number of experts are calling for a robust and transparent international research and development program to help determine which, if any, geoengineering proposals have potential for slowing climate change, and which carry unacceptable environmental or financial risk.

Scientific hypotheses resembling geoengineering were published as early as the mid 20th century, but serious consideration of the topic has only begun in the last few years. In 1992 the National Academies of Sciences published a brief review of climate engineering concepts[5] and provided rough cost estimates for injecting aerosols into the stratosphere to reflect sunlight.[6] The Academies will also finalize a report in early 2010 which, in part, formally addresses geoengineering. The Intergovernmental Panel on Climate Change (IPCC) plans to do the same in its 5th report, to be finalized in 2014. The U.S. Department of Energy penned a White Paper in 2001 recommending a $64 million, five-year program for research as part of the National Climate Change Technology Initiative, but it was not published. NASA held a workshop in April 2007 to discuss solar radiation management options. In May 2008, the Council on Foreign

[4] Associated Press Interview with Seth Borenstein, April 8, 2009. See also his clarifying follow up email, published by Andrew C. Revkin, New York Times, April 9, 2009.
[5] National Academy of Sciences. "Chapter 28: Geoengineering." In *Policy Implications of Greenhouse Warming: Mitigation, Adaptation and the Science Base*, 422-464. National Academies Press, 1992.
[6] Council on Foreign Relations, workshop notes, May 2008

Relations held the forum *Geoengineering: Workshop on Unilateral Planetary Scale Geoengineering.* Earlier in 2009, the Defense Advanced Research Projects Agency (DARPA) began consideration of funding certain geoengineering research initiatives, and NSF has funded independent research projects on potential implications.[7] Last Friday, the Massachusetts Institute of Technology hosted a public symposium, "*Engineering a Cooler Earth: Can We Do It? Should We Try?*"

In September of this year, the United Kingdom's Royal Society – an equivalent to the U.S. National Academies - published what many consider to be the most significant report on geoengineering entitled *Geoengineering the Climate: Science, Governance and Uncertainty*, which outlines various geoengineering methods and the associated challenges in research, ethics and governance. Otherwise, in general, the body of work on geoengineering consists of a limited number of individual scientific papers exploring variations of a few potential strategies, and the body of evaluative information on specific topics remains modest and mostly theoretical. The specific ecological safety issues and ethical considerations, similarly, have been assessed by only a handful of scientists and ethicists. Cost estimations for the various strategies are generally rough. Some are inexpensive enough to be undertaken unilaterally by independent nations or even wealthy individuals, while others entail immensely expensive technologies that would likely only be carried out through international partnerships.

The Royal Society report and other studies divide geoengineering methods into two main categories: **Solar Radiation Management (SRM)** methods that reflect a portion of the sun's radiation back into space, reducing the amount of solar radiation trapped in the earth's atmosphere; and **Carbon Dioxide Removal (CDR)** methods that involve removing CO_2 from the atmosphere. SRM and CDR present fundamentally different challenges of governance, ethics, economics, and ecological impacts and experts most often assess them as wholly separate topics.

Carbon Dioxide Removal (CDR) or Air Capture (AC)

CDR purports to remove greenhouse gases from the atmosphere, either by displacement or by stimulating the pace of naturally occurring carbon-consuming chemical processes. CDR strategies have the advantage of lowering the carbon content of the atmosphere. However, several of the options would be slow to implement and may be impossible to reverse. Those strategies involving a release of chemicals could also have a significant effect on vulnerable oceanic and terrestrial ecosystems. In addition, the chemical strategies would require increased mining efforts and the transportation of needed materials, which would carry its own environmental implications. Some of the potential strategies include:

Afforestation/avoided deforestation – planting new trees on earlier deforested lands or otherwise promoting forest growth results in greater carbon absorption. In addition, old growth forests are

[7] For example, Rutgers University received a research grant in May 2008 to be led by Alan Robock and Richard P. Turco to perform collaborative research on the implications of stratospheric aerosols and sun shading.

efficient carbon consumers. Many believe a more comprehensive plan for avoiding old-forest destruction could be a useful contribution to greenhouse gas management.[8]

Biological sequestration – Because terrestrial vegetation removes atmospheric carbon, carbon sinks can sequester carbon as biomass or in soil. This biomass could be used for fuels or sequestered permanently as biochar or other organic materials. The Committee held a hearing entitled *Biomass for Thermal Energy and Electricity: A Research and Development Portfolio for the Future* on October 21, 2009 that addressed this among other topics.

Enhanced weathering techniques – Silicate materials react with CO_2 to form carbonates, thereby reducing ambient CO_2. Silicate rocks could be mined and dispersed over agricultural soils, or released and dissolved into ocean waters (discussed below).

Carbon capture and sequestration (CCS) – Already the subject of several U.S. and international research and development initiatives for electric power plant applications,[9] in this case CCS describes the capture of ambient GHGs and storage in geologic reservoirs, such as natural cave systems and depleted oil wells. Some geoengineering papers refer to this strategy as Carbon Removal and Storage (CRS).

Oceanic upwelling and downwelling – the natural ocean circulation processes are increased and accelerated in order to transfer atmospheric GHGs to the deep sea, a kind of carbon sequestration, using vertical pipes.

Chemical ocean fertilization – The addition of iron, silicates, phosphorus, nitrogen, calcium hydroxide and/or limestone could enhance specific natural chemical processes which consume carbon, such as carbon uptake by phytoplankton.

Solar Radiation Management (SRM) or Sunlight Management

Solar Radiation strategies do not modify CO_2 levels in the atmosphere. Instead, they reflect incoming radiation to reduce the atmosphere's solar energy content and restore its natural energy balance. Proposed reductions of solar radiation absorption are usually 1-2%[10]; around 30% is already reflected naturally by the earth's surface and atmosphere.[11] The methods are space, land, or ocean-based and involve either introducing new reflective objects within or outside of the atmosphere, or an increase in the reflectivity or *albedo*[12] of existing structures and landforms. SRM could reduce increases in temperature, but it may not address the non-temperature aspects

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[8] The Canadian Forest Service's Forest Carbon Accounting Program educates land managers and the public on forestry's contribution to GHG management and establishes a National Forest Carbon Monitoring Accounting and Reporting System (NFCMARS). Archived online at http://carbon.cfs.nrcan.gc.ca/CBM-CFS3_e.html as of October 20, 2009. Scientific sources on the impact of trees on atmospheric carbon generally attribute between 15 and 20% of global GHG emissions to deforestation.

[9] For example, FutureGen and the Clean Coal Power Initiatives (CCPI) at DOE support RD&D for carbon capture and sequestration.

[10] The Royal Society report suggests a reduction of 1.8% (RS 23).

[11] Novim 8. This inherent reflectivity of the earth is often referred to as "planetary albedo."

[12] Albedo is usually presented as a number between 0 and 1, 0 representing a material in which all radiation is absorbed and 1 a material which reflects all radiation.

of greenhouse-induced climate changes. SRM strategies would generally take effect more quickly than CDR strategies. However, once started, some would likely require constant maintenance and/or replenishment to avoid sudden and drastic increases in temperature. Some SRM proposals include:

Stratospheric Sulfate Injections – A spray of sulfates into the second layer of earth's atmosphere[13] could reflect incoming solar radiation to reduce absorption. This process occurs naturally after a volcanic eruption, in which large quantities of sulfur dioxide are released into the stratosphere.[14]

White roofs and surfaces – Painting the roofs of urban structures and pavements of urban environments white would increase their albedo by 0.15-0.25 (15-25%). This strategy was suggested by DOE Secretary Steven Chu in May of 2009 at the St. James Palace Nobel Laureate Symposium.

Cloud brightening / Tropospheric Cloud Seeding – A fine spray of salt water or sulfuric acid is injected into the lowest level of our atmosphere to encourage greater cloud formation over the oceans, which would increase the local albedo.

Land use changes – Portions of the earth's natural land cover could be modified for more reflective growth patterns, such as light colored grasses. Also, existing agricultural crops could be genetically modified to reflect more sunlight.

Desert reflectors – Metallic or other reflective materials could be used to cover largely underused desert areas, which account for 2% of the earth's surface.

Space-based reflective surfaces – One large satellite or an array of several small satellites with mirrors or sunshades could be placed in orbit to reflect a portion of sun radiation before it reaches the earth's atmosphere. Reflectors could also be placed at the sun-earth Lagrange (L1) point, where the gravitational pulls from each body act with equal force and therefore allow objects to "hover" in place.

Key Strategies for Levying Assessments of Geoengineering Methods

Very little applied research to demonstrate the efficacy and outside consequences of geoengineering proposals has been conducted so far; study has largely been limited to computer simulations. According to the Royal Society, outside of the existing RD&D programs for carbon sequestration and forest management, the only proposals that have undergone sustained research by the scientific community are certain types of ocean fertilization.[15] Such research will likely need to be conducted over many years. Thus, experts argue that broad, collaborative discussions

[13] Roughly 6 to 30 miles above the earth's surface
[14] The naturally-occurring sulfur emissions from the 1991 eruption of a volcano in the Philippines, Mt. Pinatubo, are thought to have decreased the average global temperature by ~0.5˚ C for a 1-2 year period by increasing global albedo. Another example of such short term atmospheric cooling is often attributed to the eruption of El Chicón in March 1982.
[15] Royal Society 19

of proposed geoengineering methods should happen in the near term so policymakers can be sufficiently informed of their options well in advance of potential emergency climate events.

The primary costs for program deployment can be determined with some measure of accuracy, but a program's secondary costs (ecological, political, etc) and economic benefits will be more difficult to measure. Strenuous modeling is required to identify potential ecological impacts on, among other considerations: precipitation patterns and the hydrological cycle, ozone concentrations, agricultural resources, acid rain, air quality, ambient temperatures, and species extinction. Other factors to be examined include human health impacts, the costs incurred on consumers and taxpayers, impacts on minerals markets and increased mining needs,[16] job creation or dissolution, international opinion/consensus, data collection and monitoring needs, sources of technology and infrastructure, and the energy demands incurred by large scale deployment. Many of these criteria can be quantified in relatively absolute scientific and economic terms, but others will be difficult to measure and even more difficult to weigh against one another.

Geoengineering methods with more encapsulated impacts (e.g. reforestation and white roofs) are expected to be easier to research and implement from a governance standpoint, but the evaluation of concentrated impacts on community natural resources and microeconomies remains a challenge.

The reversibility of any geoengineering proposal is also a factor. Reversibility includes both the time it takes to end the program itself (e.g. the time it takes for stratospheric sulfate injections to dissipate) and the time in which the externalities will be ended and/or remediated (e.g. the time it takes for additional sulfates in the ecosystem to recede). Identifying the party responsible for reversing a geoengineering application, should it become necessary, is also a key front end consideration.

Lastly, both the cost of carbon credits and public opinion are expected to heavily impact which strategies would be most viable. Just as a significant price on carbon would encourage the development of carbon-neutral energy sources, a higher price per ton of CO_2, paired with offsets allowances, would likely increase the economic viability of many CDR options such as reforestation and CCS. Similarly, public preference for particular strategies will affect the viability of application for different methods.

Experts in the field believe that the risks and costs associated with the various geoengineering strategies must not only be assessed in comparison to one another, but also relative to the potential costs of inaction on climate change or insufficient mitigation efforts.

Risks and Detriments

Unilateral deployment - It is possible for a non-governmental group or individual to undertake one of the higher-impact, lower-cost geoengineering initiatives unilaterally, perhaps without scientific support or any risk management strategy. As recognized in the Royal Society report,

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[16] For example, stratospheric injections and ocean fertilization would require large chemical inputs of mined materials.

the materials for stratospheric injections, for example, would be readily available and affordable to a small group or even a wealthy individual. For this reason and others, national and global security are also key concerns with geoengineering and international governance may be needed at the front end.

Moral hazard - Another concern is that the public knowledge of widespread implementation of geoengineering represents a moral hazard, in which a person or group perceiving itself insulated from risk is more likely to engage in risky or detrimental behavior. The Royal Society suggests that there is significant risk in large-scale efforts being treated as a “get out of jail free card,” in which carbon sensitive consumer decision-making for mitigation will wane. Federal funding and political momentum for mitigation could also be compromised if geoengineering is seen as a superior substitute for traditional mitigation and adaptation.

Ocean Acidification - A clear and significant disadvantage of geoengineering is that, unlike carbon mitigation strategies, most strategies do not reduce the progress of ocean acidification or destruction of coral reefs and marine life due to higher ocean temperatures. CDR methods address ambient carbon levels and could indirectly affect ocean carbon levels by slowing the rate of carbon uptake, but it is not clear that decreases in atmospheric carbon would help reverse ocean acidification. SRM methods do not address carbon levels at all.

Accidental Cessation of SRM - One critical drawback of SRM methods specifically is that, because they do not modify atmospheric carbon concentrations, a disruption of service could result in large and rapid changes in climate, i.e. a return to the unmitigated impact of increased carbon levels. If SRM methods are undertaken without congruent controls on GHG emissions, then we would be constantly at risk of dramatic climate changes if the SRM program ends. These potential rapid, potentially catastrophic impacts must be carefully considered before implementation at any scale. A concurrent charge against geoengineering is that we may not have the political power, funds, foresight or organization, either domestically or internationally, for long-term governance of projects of this scale without incurring unacceptable negative impacts.

Food and Water Security – A large-scale initiative impacting weather patterns could greatly modify the precipitation patterns in particular geographic areas, jeopardizing local food and fresh water supplies for local populations. For example, a drought incurred by unforeseen impacts of artificial cloud formation could suppress crop growth. Poor and developing nations may be particularly susceptible to such impacts.

Butterfly Effect - Ultimately, there is near certainty that some consequences of geoengineering methods cannot be anticipated and will remain unseen until full-scale deployment. Skeptics have alleged the possibility of an ecological “butterfly effect,” in which the secondary effects of geoengineering are so wildly unforeseen that a large scale ecological crisis could occur. Some scientists argue that the possibility that such harmful side effects may be larger than the expected benefits should deter consideration of some or all geoengineering proposals.

Governance and International Issues

Any effective, large-scale modification of the climate will necessarily have global consequences. While the technical aspects of essentially every geoengineering method will require a great deal of additional research and examination, the legal, governmental, socio-political and ethical issues may ultimately be greater challenges to deployment. There are several fundamental questions on geoengineering governance that would need to be addressed: Who decides what methods are used? What regulatory mechanisms are there, and who establishes them? Who pays for the research, implementation, and surveillance? Who decides our ultimate goals and the pace in which we take toward achieving them? While some international treaties or agreements may be applicable to certain geoengineering applications, there are currently no regulatory frameworks in place aimed at geoengineering specifically.[17] Furthermore, several proposed geoengineering strategies may directly violate existing treaties. These frameworks may pose an additional challenge for geoengineering implementation, but they may also provide guidance on ways to address the complex issues of jurisdiction and responsibility at the international scale.

One challenge to address is the likelihood of inequitable effects on particular localities. Large-scale efforts conducted in a particular place may produce greater net impact on that region. For example, stratospheric aerosols injections in the Midwest United States might result in decreased crop outputs in the region. In addition, a weather pattern, ecosystem balance or wildlife population modified as an effect of geoengineering could yield a disproportionate effect somewhere outside the source area. This could, for example, cause erratic precipitation patterns in a non-participatory nation.

It is not clear whether one or more existing international frameworks such as the Intergovernmental Panel on Climate Change (IPCC) or the United Nations Framework Convention on Climate Change (UNFCCC) could be the appropriate managing entity of global geoengineering governance issues, or if the unique features of geoengineering would require the creation of a new international mechanism. In addition, as geoengineering is multidisciplinary, several domestic agencies at the federal level have clear jurisdiction over topics imbedded in all or some of the suggested geoengineering methods as well as their immediate research and development needs. A number of cabinet-level departments and federal agencies may be directly pertinent to the concurrent agricultural, economic, international security, and governance issues.

Analogous Government Initiatives

The early years of nuclear weapons testing display a number of similarities to geoengineering, including the difficulties of levying cost-benefit analyses of their impacts, uncertain ecological impacts, an unknown geographic scope of impact, and potential intra- and intergovernmental liability issues. This relationship is noted by the ETC Group for the U.S. National Academies workshop on geoengineering held earlier this year.[18] Before the Limited Test Ban Treaty was signed in 1963, several nations regularly performed nuclear tests underwater and in the atmosphere without international agreement, regulation, or transparency. Of course, the consequences of nuclear radiation and the potential for creating weapons are inherently

[17] Royal Society 5
[18] *Geoengineering's Governance Vacuum: Unilateralism and the Future of the Planet*. For the National Academies workshop Geoengineering Options to Respond to Climate Change: Steps to Establish a Research Agenda. Washington, D.C. June 15-16, 2009.

international, but domestic experimentation preceded diplomatic considerations. The global impacts on both human health and international diplomacy, incurred without international consent, were considerable.

Human-engineered weather modification shares these characteristics as well. The most commonly used strategy is cloud-seeding, in which particles[19] are sprayed into the air to stimulate condensation and cloud formation. This practice is thought to modify precipitation patterns[20] in order to enhance crop growth, manage water resources and promote human safety from natural hazards like floods and droughts. In 2003, the National Academies' National Research Council published its fourth report on weather modification, *Critical Issues in Weather Modification Research.* As of report publication there were 23 countries engaging in weather modification on a large scale, and China is the nation most aggressively pursuing it, with an annual budget of over $40 million for hail suppression and precipitation enhancement. However, NAS concluded that "there is still no convincing scientific proof of the efficacy of intentional weather modification efforts. In some instances there are strong indications of induced changes, but this evidence has not been subjected to tests of significance and reproducibility."[21] No consensus on the cause-and-effect relationship between cloud seeding and weather patterns has been determined, but it still continues to be practiced worldwide.

Public Perception and Ethical Implications

Due to the large uncertainties associated with most geoengineering methods, the opinions of the general public and the scientific community at this time generally vary from cautiously optimistic to unequivocally opposed. While a portion of the scientific community is committed to investigating the possibilities of geoengineering, another portion is resistant because geoengineering and carbon mitigation could be seen by some as direct substitutes[22] and therefore in competition with one another, as discussed above.

The general public may have qualms with geoengineering for several reasons. A given method's efficacy and safety may not coincide with the general public's perception, which then may unduly influence momentum toward an unjustified strategy. However, negative public perceptions of geoengineering may also prove to be a powerful catalyst for emissions reductions.[23] A study by the British Market Research Bureau found that while participants were cautious or hostile toward geoengineering, "several agreed that they would actually be more motivated to undertake mitigation actions themselves" after a large-scale geoengineering application was suggested.[24]

One major ethical issue is that even in a best case scenario, some nations are expected to benefit more than others. Moreover, the effects won't necessarily reflect which nations have contributed

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[19] Usually silver iodide or frozen CO_2
[20] A highly visible example of an application of weather modification occurred during the 2008 Summer Olympic Games in China, when the Beijing Weather Engineering Office used cloud seeding to delay rainfall for several hours in order to accommodate the Games' opening ceremonies.
[21] NAS 3
[22] Barrett 1
[23] Barrett 2
[24] Royal Society 43

the most to the carbon problem (the debtors), nor those agent nations who devise, fund and execute the geoengineering activities. Another is the "Dr. Frankenstein" ethical concern, in which some believe deliberate human modification of the global climate is both a dangerous and inappropriate activity in the first place.

Because geoengineering threatens to alter biological processes at a large scale, many are concerned that inequitable negative impacts may occur. Undue burdens may be placed on a particular locality, even if the locality or nation neither engaged in geoengineering nor produced a disproportionate share of anthropogenic carbon emissions. Because deployment and even applied research can hold global implications, open information access and an open equitable forum for international dialogue are expected to be requisite for a responsible approach to geoengineering.

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