Climate Science

Climate Mitigation and Adaptation Strategies / Geo-engineering the Climate

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Climate Mitigation and Adaptation Strategies

Driving Questions: *What are climate change mitigation and adaptation? What strategies can be applied to lessen the effects of climate change?*

Educational Outcomes: To describe climate change mitigation and adaptation in terms that address the causes of climate change and tackle the effects of climate change. To identify and explore possible mitigation strategies. To recognize that adaptation strategies are essential to reduce the severity and costs of climate change, although adaptation alone will not adequately meet the challenges of climate change. To understand that climate mitigation and adaptation are not alternative strategies; both must be developed and implemented.

Objectives: After completing this investigation, you should be able to:

- Describe climate change mitigation and adaptation.
- Explain mitigation and adaptation strategies for reducing the impacts of climate change within the context of sustainable development.

The Climate Change Challenge

Observational data show that climate change is unequivocal and global warming over the past 50 years is primarily the result of heat-trapping gas emissions due to human activity. This places all of us in the position of making choices at individual, local, regional, national and global levels that will have profound impacts on our Earth environment and on society.

We can ignore or deny that climate change is taking place and follow a "business as usual" path. To do nothing is a choice. It is a choice that will force us to fatalistically accept whatever impacts climate change delivers to us and to future generations. Doing nothing ignores science-based projections that foretell dire consequences for hundreds of millions of people and major impacts on all of Earth's inhabitants.

Or, we can consider and implement options in response to the climate challenge. The two general categories for responding are through mitigation and adaptation. Mitigation addresses the causes of climate change and adaptation tackles the effects. Essentially, mitigation is about reducing heat-trapping gas emissions to prevent dangerous climate change whereas adaptation is coping with those impacts that cannot be avoided.

Mitigation and adaptation are not alternatives. Both are necessary in addressing the climate challenge. The longer the delay in doing both, the greater the magnitude of negative consequences, and the greater the costs. The lack of response to changing conditions has already committed Earth's climate system to change, including some that are irreversible (e.g., species extinction, sea level rise).

The IPCC defines **mitigation** as a human intervention to reduce the sources or enhance the sinks of greenhouse gases. More specifically, mitigation is a human action that (a) reduces any process, activity or mechanism that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol into the atmosphere, or (b) enhances any process, activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere.

1. An example of climate change mitigation that fits the (a) part of the IPCC's mitigation definition is **[(*decreasing*)(*increasing*)]** the amount of gasoline burned in cars and trucks, thereby reducing carbon dioxide emissions.

2. An example of climate change mitigation that fits the (b) part of the IPCC's mitigation definition is **[(*decreasing*)(*increasing*)]** land areas covered by forests, thereby having the net effect of removing carbon dioxide from the atmosphere.

The IPCC defines **adaptation** as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

As noted in the IPCC report (2007), two existing U.S. instances involve lands and shorelines where public actions affect change issues. The first is the New Jersey Coastal Blue Acres land acquisition program. Its purpose is to acquire coastal lands damaged or prone to damage by storms or providing buffer for other lands. The second is the common law establishment of a "rolling easement" in Texas. This is an entitlement to public ownership of property that can "roll" inland with the coastline as sea level rises. Other coastal policies exist to encourage coastal landowners to act in ways that anticipate possible sea-level rise.

3. These land acquisition and management programs are examples of climate change **[(*mitigation*) (*adaptation*)]** strategies.

Climate Change Mitigation Strategies

Identifying and implementing mitigation strategies is a complex challenge. While the goal of ultimately reducing the concentrations of heat-trapping gases in Earth's atmosphere is clear, the path towards its achievement is not. First, the goals of stabilizing and then reducing global emissions must be met. Realization of these goals must occur via complex interactions among environmental, social, and technological processes within the context of broader societal goals such as sustainable development and equity.

Figure 1 identifies by sector the greenhouse gas emissions in the United States (2009). Emissions by sector gives focus to where mitigation efforts need to be directed to be most effective.

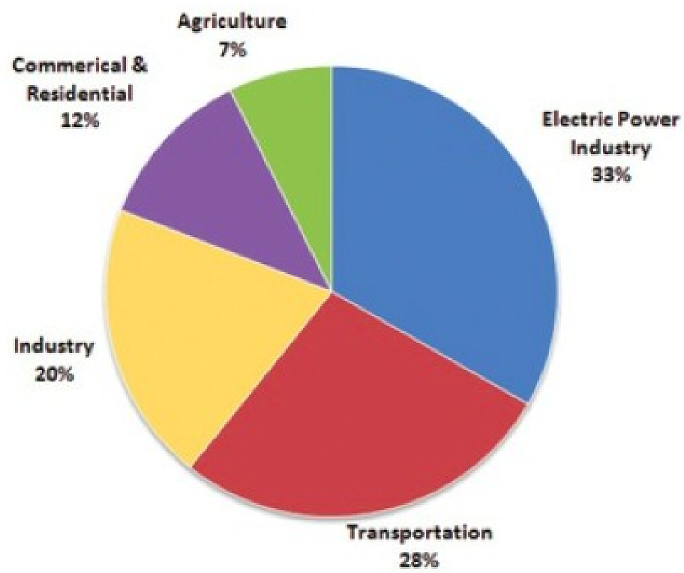

Figure 1.
U.S. greenhouse gas emissions by sector (2009). [Pew Center on Global Climate Change and EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009, Table ES-7, 2011]

4. According to Figure 1, it appears that while mitigation efforts should be directed to all sectors, those likely to have the greatest impact on reducing emissions would center on the **[(*agricultural and industrial*)(*electrical generation and transportation*) (*industrial and transportation*)]** sectors.

One strategic approach to mitigation that relies on current technology has been proposed by Stephen Pacala and Robert Socolow of the Carbon Mitigation Initiative. The principle is that an effective overall policy can be constructed by combining a series of modest actions utilizing current technology. This approach breaks down the mitigation problem into "wedges," with each wedge representing a strategy that can reduce carbon emissions in increasingly greater quantities over time. The stabilization wedges concept is a simple framework for understanding carbon emission cuts that are necessary and the tools already available to make the cuts. This is shown in **Figure 2**. The wedges they propose include (a) building two billion cars with gas mileage of 60 miles per gallon instead of 30 miles per gallon, (b) building two million 1-megawatt wind turbines to displace coal power, (c) doubling nuclear power generation to displace coal power, and (d) capturing and storing greenhouse gas emissions at 800 large coal-fired plants.

5. Figure 2 indicates that current global emissions are about 8 gigatons (billions of tons) of carbon equivalent per year, and the current (business as usual) projected path shows that in 50 years the annual emission is likely to be approximately **[(*1.6*)(*8*)(*16*)]** gigatons.

6. As drawn, Figure 2 shows that the each of the wedges will be tasked to reduce emissions by **[(*1*) (*8*) (*16*)]** gigaton(s) per year by the end of the 50-year period.

7. With the wedge approach as shown in Figure 2, the result will be that during the 50-year period the annual amount of actual emissions will **[(*increase*)(*decrease*)(*remain the same*)].**

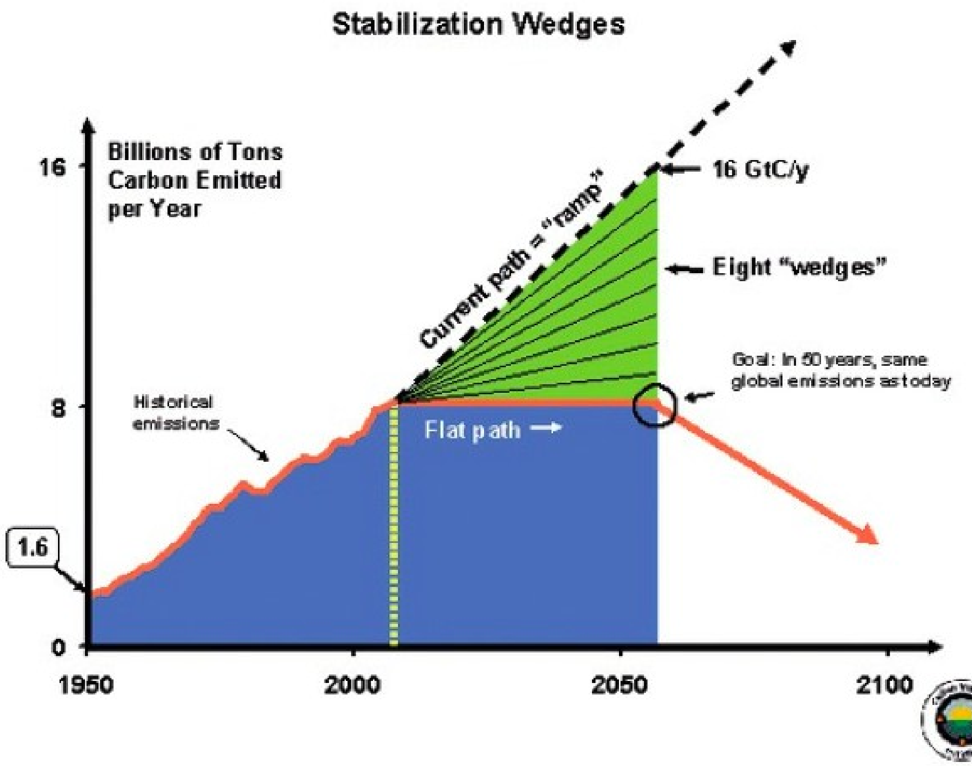

Figure 2.
The “wedge” approach to stabilizing and reducing global emissions. [Carbon Mitigation Initiative, Princeton University]

Even with implementation of the wedge approach, the concentration of carbon dioxide in the atmosphere will exhibit a significant increase over the 50-year period. An associated increase in global average surface temperature can be assumed. To lower temperature will require a decrease in atmospheric CO_2 concentration. Even then, there will be a considerable lag time between lowering CO_2 emissions (as shown in Figure 2) and lowering temperature. However, the necessary first step is to stabilize CO_2 concentrations. The Carbon Mitigation Initiative’s stabilization wedges concept shows a practical way to formulate mitigation strategies, at least as a way to lessen the magnitude of climate change.

Regardless of the mitigation strategies that are implemented, it is a certainty that earlier cuts in emissions would have a greater effect in reducing climate change than comparable reductions made later [USGCRP]. A wait-and-see strategy, or simple procrastination, can carry great cost.

Climate Change Adaptation Strategies

As greater atmospheric concentration of heat-trapping gases likely leads to higher surface temperatures, Earth is committed to additional warming no matter what emission mitigation strategies are implemented. Adaptation efforts are essential to reduce the severity and costs of climate change impacts for decades (and perhaps centuries) to come.

Whereas mitigation is more global, adaptation tends more towards regional and local perspectives and actions. Adaptive actions are by individuals or systems in order to avoid, withstand, or take advantage of current and projected climate changes and impacts. Adaptation decreases a system's vulnerability, or increases its resilience to impacts (Pew Center on Global Climate Change).
The USGCRP's ***Global Climate Change Impacts in the United States*** report (p. 12), available via the RealTime Climate Portal "Societal Interactions and Climate Policy" section, presents Key Findings that summarize the current and projected climate changes and impacts that require national and local adaptation strategies.

8. According to the USGCRP's listing of Key Findings, the nation's water resources will be stressed by climate change. The geographical area likely to be most impacted by drought associated with climate change will be **[(*the Northeast*)(*the Southeast*)(*the West*) (*Alaska*)]**.

9. According to the USGCRP's listing of Key Findings, coastal areas are at increasing risk from sea-level rise and storm surge, especially along the **[*Atlantic and Gulf Coasts*) (*Pacific Islands*) (*parts of Alaska*)(*all of these*)]**.

On 28 March 2012, the IPCC published a detailed report on ***Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)*****,** available at: *http://www.ipcc-wg2.gov/SREX/*. The press release announcing the publication states, "Evidence suggests that climate change has led to changes in climate extremes such as heat waves, record high temperatures and, in many regions, heavy precipitation in the past half century." The report (on page 2 of *Summary for Policymakers)* points out that, "The character and severity of impacts from climate extremes depend not only on the extremes themselves but also on exposure and vulnerability. … Disaster risk management and adaptation to climate change focus on reducing exposure and vulnerability and increasing resilience to the potential adverse impacts of climate extremes, even though risks cannot fully be eliminated."

The SREX report points out that some, but not all, extreme weather and climate lead to disasters. Actions taken to avoid, prepare for, respond to, and recover from the risks of disaster can reduce the impacts of these events and increase the resilience of people caught up in the extreme occurrences. **Figure 3** delineates the SREX adaptation and disaster risk management approaches for facing the extreme events associated with climate change. These approaches can be overlapping and simultaneously pursued.

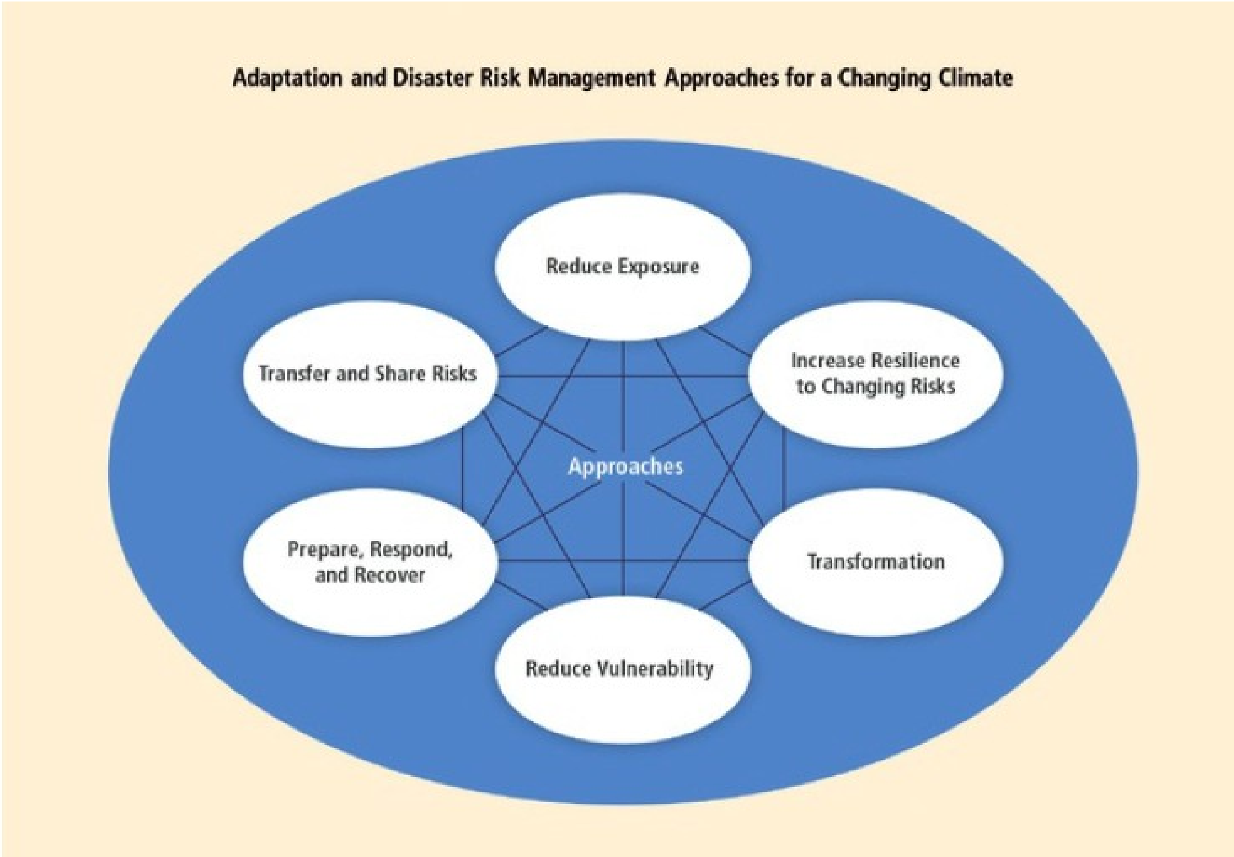

Figure 3.
Depiction of complementary adaptation and disaster risk management approaches. [IPCC SREX report, Figure SPM.2]

10. The IPCC SREX report assesses the implications of climate extreme events for society and sustainable development. It points out that adaptation and disaster risk management approaches should focus on **[(*increasing societal resilience*)(*reducing exposure*) (*reducing vulnerability*) (*all of these*)],** even though risks cannot be totally eliminated.

On the global scale, adaptation strategies take on additional significance for developing countries. Good adaptation and good development policy cannot be separated. It is especially important that developed countries provide assistance to these countries as their development and their response to climate change might not be in alignment due to their inadequate resources.

Unfortunately, there are limits to adaptation. Particularly, some developing small island states have few options to adapt to rising sea level. Some ecosystems can be irretrievably lost.

Summary: Adequate response to climate change requires both mitigation and adaptation to lessen impacts. In general, the more mitigation that takes place, the less the impacts to which we will have to adjust through adaptation. Time is of the essence in responding to climate change as some changes will have great impact on hundreds of millions of people and some changes are irreversible.

GEOENGINEERING THE CLIMATE

Driving Questions: *What are some of the geoengineering methods that have been proposed to moderate climate change? What is their potential in terms of possible effectiveness, costs, and environmental impacts?*

Educational Outcomes: To define what is meant by geoengineering the climate. To explain proposed geoengineering strategies that reduce atmospheric concentration of carbon dioxide or lower the amount of solar radiation that is absorbed in Earth's climate system. To become aware that geoengineering techniques are as yet unproven and their use is very likely to have associated limitations, uncertainties, and risks.

Objectives: After completing this investigation, you should be able to:

- Describe what is meant by geoengineering the climate, and identify the scientific bases on which geoengineering schemes would operate.
- Present examples of geoengineering-scale carbon dioxide removal and solar radiation management techniques that have been proposed, including their potential, limitations, uncertainties, and risks.

Figure 1.
The original climate conference.
[With permission. *http://www.geekculture.com/joyoftech/joyarchives/1332.html*]

Human Impacts on Earth's Climate System

People have been transforming Earth's climate system in increasingly aggressive ways since the beginning of the industrial age and the exponential growth in the global human population. With the burning of fossil fuels, concentrations of atmospheric heat-trapping gases and aerosols have increased. At the same time, about half of Earth's land surface has been reshaped by human activity, thereby impacting the flow of radiant energy to and from our planet. Additionally, numerous other climate mechanisms have been impacted in direct and indirect ways by human activity. The net result has been anthropogenic global warming, with the prospect of greater climate change looming in the future. The likelihood is almost certain of major negative (including catastrophic and irreversible) impacts on human society and Earth's terrestrial and marine ecosystems in the decades and centuries ahead.

Recent science suggests that it may still be possible to avoid the most disastrous impacts of climate change through mitigation and adaptation. However, this requires immediate and decisive efforts to both cut emissions and assist vulnerable countries to adequately adapt. As the results of the

December 2009 United Nations Climate Change Conference (COP15) in Copenhagen demonstrate, such immediate and decisive actions appear unlikely. (See **Figure 1** for a depiction of what the first climate conference might have been like.)

Even with a rapid response to climate change, mitigation and adaptation may not be sufficient to prevent dangerous anthropogenic climate change. Additional, not alternative, schemes may be required and merit serious consideration. These additional strategies, planetary in scale, are grouped under the term **geoengineering**. Geoengineering could lessen global climate change, but with the risk of unanticipated consequences.

Anticipating that the response of the world community will be too-little and too-late, some scientists have been exploring more drastic last-ditch actions to cool a runaway climate. They propose serious consideration of physical interventions, or technological fixes, on a global scale. Proposed is **geoengineering** with the ultimate goal of manipulating the global climate by correcting Earth's radiative imbalance with space.

The American Meteorological Society, the professional scientific society representing the atmospheric and related oceanic and hydrologic sciences that form the core of climate and climate change science, has issued ***A Policy Statement on Geoengineering the Climate System.*** This has been done in recognition that the time has arrived to address a planetary-scale issue related to manipulating Earth's climate system—a profound issue which was unthinkable until recently. The ***Statement*** follows:

AMS Policy Statement on Geoengineering the Climate System

(*Adopted by the AMS Council on 20 July 2009*)

Human responsibility for most of the well-documented increase in global average temperatures over the last half century is well established. Further greenhouse gas emissions, particularly of carbon dioxide from the burning of fossil fuels, will almost certainly contribute to additional widespread climate changes that can be expected to cause major negative consequences for most nations[1].

Three proactive strategies could reduce the risks of climate change: 1) mitigation: reducing emissions; 2) adaptation: moderating climate impacts by increasing our capacity to cope with them; and 3) geoengineering: deliberately manipulating physical, chemical, or biological aspects of the Earth system[2]*. This policy statement focuses on large-scale efforts to geoengineer the climate system to counteract the consequences of increasing greenhouse gas emissions.*

Geoengineering could lower greenhouse gas concentrations, provide options for reducing specific climate impacts, or offer strategies of last resort if abrupt, catastrophic, or otherwise unacceptable climate-change impacts become unavoidable by other means. However, research to date has not determined whether there are large-scale geoengineering approaches that would produce significant benefits, or whether those benefits would substantially outweigh the detriments. Indeed, geoengineering must be viewed with caution because manipulating the Earth system has considerable *potential to trigger adverse and unpredictable consequences.*

Geoengineering proposals fall into at least three broad categories: 1) reducing the levels of atmospheric greenhouse gases through large-scale manipulations (e.g., ocean fertilization or afforestation using non-native species); 2) exerting a cooling influence on Earth by reflecting sunlight (e.g., putting reflective particles into the atmosphere, putting mirrors in space, increasing surface reflectivity, or altering the amount or characteristics of clouds); and 3) other large-scale manipulations designed to diminish climate change or its impacts (e.g., constructing vertical pipes in the ocean that would increase downward heat transport).

Geoengineering proposals differ widely in their potential to reduce impacts, create new risks, and redistribute risk among nations. Techniques that remove CO_2 directly from the air would confer global benefits but could also create adverse local impacts. Reflecting sunlight would likely reduce Earth's average temperature but could also change global circulation patterns with potentially serious consequences such as changing storm tracks and precipitation patterns. As with inadvertent human-induced climate change, the consequences of reflecting sunlight would almost certainly not be the same for all nations and peoples, thus raising legal, ethical, diplomatic, and national security concerns.

Exploration of geoengineering strategies also creates potential risks. The possibility of quick and seemingly inexpensive geoengineering fixes could distract the public and policy makers from critically needed efforts to reduce greenhouse gas emissions and build society's capacity to deal with unavoidable climate impacts. Developing any new capacity, including geoengineering, requires resources that will possibly be drawn from more productive uses. Geoengineering technologies, once developed, may enable short-sighted and unwise deployment decisions, with potentially serious unforeseen consequences.
Even if reasonably effective and beneficial overall, geoengineering is unlikely to alleviate all of the serious impacts from increasing greenhouse gas emissions. For example, enhancing solar reflection would not diminish the direct effects of elevated CO_2 concentrations such as ocean acidification or changes to the structure and function of biological systems.

Still, the threat of climate change is serious. Mitigation efforts so far have been limited in magnitude, tentative in implementation, and insufficient for slowing climate change enough to avoid potentially serious impacts. Even aggressive mitigation of future emissions cannot avoid dangerous climate changes resulting from past emissions, because elevated atmospheric CO_2 concentrations persist in the atmosphere for a long time. Furthermore, it is unlikely that all of the expected climate-change impacts can be managed through adaptation. Thus, it is prudent to consider geoengineering's potential benefits, to understand its limitations, and to avoid ill-considered deployment.

Therefore, the American Meteorological Society recommends:

1. *Enhanced research on the scientific and technological potential for geoengineering the climate system, including research on intended and unintended environmental responses.*

2. *Coordinated study of historical, ethical, legal, and social implications of geoengineering that integrates international, interdisciplinary, and intergenerational issues and perspectives and includes lessons*

from past efforts to modify weather and climate.

3. *Development and analysis of policy options to promote transparency and international cooperation in exploring geoengineering options along with restrictions on reckless efforts to manipulate the climate system.*

Geoengineering will not substitute for either aggressive mitigation or proactive adaptation, but it could contribute to a comprehensive risk management strategy to slow climate change and alleviate some of its negative impacts. The potential to help society cope with climate change and the risks of adverse consequences imply a need for adequate research, appropriate regulation, and transparent deliberation.

[1] *For example, impacts are expected to include further global warming, continued sea level rise, greater rainfall intensity, more serious and pervasive droughts, enhanced heat stress episodes, ocean acidification, and the disruption of many biological systems. These impacts will likely lead to the inundation of coastal areas, severe weather, and the loss of ecosystem services, among other major negative consequences.*

[2] *These risk management strategies sometimes overlap and some specific actions are difficult to classify uniquely. To the extent that a geoengineering approach improves society's capacity to cope with changes in the climate system, it could reasonably be considered adaptation. Similarly, geological carbon sequestration is considered by many to be mitigation even though it requires manipulation of the Earth system.*

1. The AMS Statement defines geoengineering as the deliberate manipulation of the **[(*physical*) (*chemical*)(*biological*)(*any or all of these*)]** aspects of the Earth system.

2. Overall, the Statement describes that at the present time geoengineering of the climate system is **[(*proven and low risk*)(*proven and high risk*)(*unproven and high risk*)].**

3. The Statement considers the threat of climate change to be serious and unlikely to be managed adequately by mitigation and adaptation. Further, it states that it **[(*is*)(*is not*)]** "prudent to consider geoengineerings's potential benefits, to understand it limitations, and to avoid ill-considered deployment."

4. Following the listing of three recommendations concerning geoengineering of Earth's climate system, the Statement emphasizes that "Geoengineering will not substitute for either aggressive mitigation or proactive adaption, but it **[(*could*)(*could not*)]** contribute to a comprehensive risk management strategy to slow climate change and alleviate some of its negative effects."

As stated early in this course, our global climate is fundamentally the story of solar energy received by Earth being absorbed, deflected, stored, transformed, put to work, and eventually emitted back to space. The three fundamental ways in which this energy balance of Earth with space can be perturbed are by: 1) changing the incoming solar radiation; 2) changing the fraction of solar radiation that is reflected by the Earth system; or, 3) altering the longwave (infrared) radiation from the Earth system to space. Geoengineering strategies primarily seek to address on a global scale the perturbations caused by greenhouse gas emissions by either (1) capturing and sequestering heat-trapping carbon out of the atmosphere or (2) through reflecting a small percentage of the solar energy entering Earth's climate system back into space. Respectively, these are called carbon dioxide removal (**CDR**) techniques and solar radiation management (**SRM**) techniques. Examples of CDR and SRM techniques follow.

5. Serious consideration has been given to emulating explosive volcanic eruptions by injecting SO_2 continuously into the stratosphere, producing a sulfuric acid cloud to scatter solar radiation back to space. This is an example of a **[(*CDR*)(*SRM*)]** geoengineering technique, which would be expected to lower the average global surface temperature.

6. The unintended consequences of cooling the planet by injecting SO_2 into the atmosphere include no impact on the increasing acidification of the ocean by increasing CO_2 concentrations, and the **[(*increase*)(*decrease*)]** in direct solar radiation for use as solar power.

Based on volcanic eruption studies, the injection of SO_2 into the atmosphere would also produce drought in some parts of the world as well as acid rain which could decimate land and water ecosystems. The strategy does have the advantage of allowing for quick response—added in sufficient quantities it could lower the global temperature within a year or two of deployment. It is also relatively inexpensive compared to other temperature moderating strategies. So inexpensive, in fact,
that it could be accomplished by a single country acting alone. This makes it also very dangerous as it could bring about radical and uneven shifts in climate around the world.

7. This sulfur-aerosol injection plan demonstrates a common characteristic of all geoengineering efforts. It has the potential of producing **[(*beneficial*)(*damaging*)(*both of these*)]** results.

As terrestrial vegetation grows, it removes large quantities of carbon from the atmosphere during photosynthesis. When plants die and decompose, most of the carbon they stored returns to the atmosphere. Under these conditions, the overall growth and decay cycle is essentially neutral in terms of CO_2 emissions into the atmosphere.

8. The biomass resulting from plant growth may be harvested and sequestered as organic material through burial of trees, crop wastes, or as charcoal (biochar). This is an example of a **[(*CDR*)(*SRM*)]** geoengineering technique, which would be expected over time to lower the average global surface temperature.

Biochar, as with other forms of charcoal, is created when organic matter decomposes in a low or zero oxygen environment. Once formed, it is resistant to decomposition. It is known from archaeological sites that biochar can remain in soils for hundreds to thousands of years. Studies have shown that significant biomass sequestration is possible in principle, although it would be a partial solution at best. Biochar, however, has the added advantage of making soils more fertile.

IPCC begins assessment of geoengineering proposals: Geoengineering experts met in Lima, Peru in late June 2011 under the auspices of the Intergovernmental Panel on Climate Change (IPCC) to assess proposals for manipulating Earth's climate system to avoid climate disaster. Their singular goal is to assess whether the proposals are sound science.

The understanding of the physical science basis is still limited and the IPCC will address this through three of its working groups preparing the forthcoming Fifth Assessment Report (AR5) on Climate Change to be published in 2013-14. The IPCC expert group emphasizes it is merely comprehensively evaluating the technologies proposed for geoengineering applications, including all their possible impacts. The IPCC will make no recommendations concerning geoengineering.

In advance of the June 2011 meeting, environmental and human rights organizations from 40 countries sent an open letter to the IPCC protesting against the use of geoengineering to change the climate, especially at a time when there is no real progress on mitigation and adaptation.

Summary: Proposed geoengineering techniques are unproven and potentially dangerous. Like medicines, their desirable benefits are likely to be accompanied by undesirable side effects. Yet, they must be considered in the event that actions are needed to allow time for mitigation and adaptation strategies to take hold or because last-ditch options are needed to counteract devastating effects of climate change.

Want to know more about geoengineering the climate? The United Kingdom's Royal Society (the world's oldest scientific academy) has published a comprehensive report of the topic, entitled ***Geoengineering the Climate: Science, Governance and Uncertainty.*** The entire report is available online at: *http://royalsociety.org/geoengineeringclimate/.*