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

HEARING CHARTER

Geoengineering II: The Scientific Basis and Engineering Challenges

Thursday, February 4, 2010
10:00 a.m.
2325 Rayburn House Office Building

Purpose

On Thursday, February 4, 2010, the House Committee on Science & Technology, Subcommittee on Energy and Environment will hold a hearing entitled "***Geoengineering II: The Scientific Basis and Engineering Challenges.***" The purpose of the hearing is to explore the science, engineering needs, environmental impact(s), price, efficacy, and permanence of select geoengineering proposals.

Witnesses

- **Dr. David Keith** is the Canada Research Chair in Energy and the Environment at the University of Calgary.
- **Dr. Philip Rasch** is a Laboratory Fellow of the Atmospheric Sciences and Global Change Division and Chief Scientist for Climate Science, Pacific Northwest National Laboratory, U.S. Department of Energy.
- **Dr. Klaus Lackner** is the Ewing Worzel Professor of Geophysics and Chair of the Earth and Environmental Engineering Department at Columbia University.
- **Dr. Robert Jackson** is the Nicholas Chair of Global Environmental Change and a professor of Biology at Duke University.

Background

This hearing is the second of a three-part series on geoengineering. On November 5, 2009 the Full Committee held the first hearing in the series, entitled "*Geoengineering: Assessing the Implications of Large-Scale Climate Intervention.*" This Subcommittee hearing will examine the scientific basis and engineering challenges of geoengineering. In the spring of 2010 the Committee will hold the final hearing in this series in which issues of governance will be discussed. This series of hearings serves to create the foundation for an informed and open dialogue on the science and engineering of geoengineering.

As discussed in the first hearing, strategies for geoengineering typically fall into to major categories: Solar Radiation Management and Carbon Dioxide Removal (hereafter SRM and CDR, respectively). The objective of Solar Radiation Management (SRM) methods is to reflect a portion of the sun's radiation back into space, thereby reducing the amount of solar radiation trapped in Earth's atmosphere and stabilizing its energy balance. Methodologies for SRM include: installing reflective surfaces in space; and increasing reflectivity, or albedo[1] of natural surfaces, built structures, and the atmosphere. To balance the impacts of increased atmospheric carbon levels, most SRM proposals recommend a goal of 1 - 2% reduction of absorbed solar radiation from current levels. Carbon Dioxide Removal (CDR) methods propose to reduce excess CO_2 concentrations by capturing, storing or consuming carbon directly from air, as compared to direct capture from power plant flue gas and storage as a gas. CDR proposals typically include such methods as carbon sequestration in biomass and soils, ocean fertilization, modified ocean circulation, non-traditional carbon capture and sequestration in geologic formations, and distributing mined minerals over agricultural soils, among others.

Geoengineering Strategies

Atmospheric solar radiation management (SRM)

One approach to atmospheric SRM is known as 'marine cloud whitening' in which a fine spray of particles, typically via droplets of salt water, would be injected into the troposphere (the lowest level of our atmosphere) to increase the number of cloud-condensation nuclei and encourage greater low level cloud formation. The objective is to increase the albedo of existing clouds over the oceans, thus reflecting more sunlight into the atmosphere before it reaches Earth. To achieve the necessary radiative forcing to stabilize global temperatures, cloud cover would need to increase 50 - 100% from current levels.[2]

Stratospheric sulfate injection is another atmospheric SRM approach.. The objective is to mimic the large quantity of sulfuric emissions and the consequent albedo increase that a volcanic eruption would naturally create. For example, the 1991 eruption of Mt. Pinatubo in the Philippines is thought to have caused a 1-2 year decrease in the average global temperature by ~0.5˚C by increasing global albedo.[3] To accomplish this effect via stratospheric sulfate injections, a spray of sulfate particles would be injected into the stratosphere, which is between six and 30 miles above the Earth's surface. This proposal has typically garners the most attention among geoengineering's scientific community.

Drawbacks and challenges

Both atmospheric SRM approaches described here could be quickly deployed at a relatively low cost and shut down if necessary; however, both approaches require further research and may carry significant unintended consequences for ocean ecosystems, agriculture, and the built environment.

Marine cloud whitening deployment strategies could include aerosol distribution from a large fleet of ships, unmanned radio-controlled ocean vessels, or aircraft. Further research is needed to

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[1] Albedo is measured on a scale from 0 to 1, with 0 representing the reflectivity of a material which absorbs all radiation and 1 represents a material which reflects all radiation. Newly laid asphalt has a typical albedo of ~0.05 and fresh snow can have an albedo of 0.90.

[2] *An increase in ocean cloud cover to 37.5 – 50% of ocean surface area.*

[3] Groisman PY (1992)

optimize variables such as droplet size and concentration, cloud longevity, and the necessary increase in cloud cover to achieve desired results. The material itself (i.e. salt water) would be inexpensive for marine cloud whitening as it is abundant, and environmental impacts may be limited and somewhat predictable. However, it has been noted that marine cloud whitening activities could cause changesin local weather patterns, and deployment might be very energy-intensive.

A variety of deployment methods have been suggested for stratospheric sulfate injections, including sprays from aircraft, land-based guns, rockets, manmade chimneys, and aerial balloons.[4] Environmental impacts from sulfate injection could occur because the sulfate materials would eventually fall from the stratosphere into the troposphere and “rain out” onto the land and ocean. This would contribute to ocean acidification and could negatively impact crop soils and built structures.

The SRM strategies discussed here would be long term investments that must be carefully planned and continually maintained in order to achieve their goals and avoid rapid climatic changes. Presumably, greenhouse gas levels could continuously rise while such SRM strategies were deployed. Therefore, in the case of an interruption or termination in service, the actual impact(s) of increased greenhouse gas concentrations would be felt, i.e., the effects of SRM would be quickly negated. . This would present great risk to human populations and natural ecosystems. Apart from these effects, stratospheric injections and marine cloud whitening also run the risk of creating localized impacts on regional climates throughout their deployment.. In addition, the decrease in sunlight over the oceans due to marine cloud whitening could affect precipitation patterns and regional ocean ecosystem function. Furthermore, as with other geoengineering ideas, these SRM approaches are criticized for drawing attention and resources away from climate change mitigation and CO_2 reduction efforts.

Terrestrial - based biological approaches (SRM and CDR)

The terrestrial - based biological approaches to geoengineering discussed here include vegetative land cover and forestry methods (e.g., the biological sequestration of carbon, CDR strategies, and increasing the albedo of terrestrial plants, an SRM strategy). These strategies are at different stages of development and deployment, with carbon sequestration in forest ecosystems[5] likely to be the most effective in the near-term.

Increasing albedo and carbon sequestration potential in forests, grasslands, and croplands

The ability of forests and other vegetative systems such as grasslands and croplands to store CO_2 and to reflect solar radiation is crucial to climate change mitigation efforts. Certain geoengineering strategies propose to leverage these properties through massive-scale planting of more reflective or CO_2-absorbent vegetationIn traditional, terrestrial – based biological carbon sequestration, CO_2 is absorbed by trees and plants and it is stored in the tree trunks, branches,

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[4] Novim (2009)

[5] *The Reduced Emissions Deforestation and Degradation (REDD) carbon trading concept provides a starting point for this discussion. The REDD program employs market mechanisms to compensate communities in developing countries to protect local forests as an alternative income mechanism to logging or farming the same land.*

foliage, roots, and soils. Geoengineers propose to alter the ability of the plants and trees to sequester carbon or to reflect light[6] using non-native species and techniques from traditional plant breeding and genetic engineering. The basic processes of photosynthesis and light reflection would still occur, but geoengineers would either increase the carbon absorption and reflective capacities of existing vegetation, or introduce non-native species with such increased capacity(s). Deployment of these land-cover systems would be both systematic and massive to achieve the desired effect(s).

There are a number of advantages of these approaches. Development and implementation is relatively low cost and the global infrastructure required to create and propagate similar traits in crops and grasses through to large-scale cultivation already exists.[7] There are fewer potential issues concerning irreversibility than other proposed geoengineering schemes. And, the climate impacts are inherently focused in the regions that are most important to food production and to population centers, thus providing more directed benefits even when applied globally. Maintaining the technology is also less of a problem as crops are replanted annually; however, to maintain the mitigation benefit, high albedo varietals must be continually planted and mature forests must be maintained.

Biochar

Biochar[8] may have potential as an efficient method of atmospheric carbon removal (via plant growth) for storage in soil. Biomass[9] is converted to both biochar (solid) and a bio-oil (liquid) by heating it in the absence of air. The bio-oil can be converted to a biofuel after a costly conversion process, and the biochar can serve as bio-sequester (i.e. atmospheric carbon capture and storage). Biochar, is a stable charcoal-solid that is rich in carbon content, and thus can potentially be used to lock globally significant amounts of carbon in the soil.[10] Unlike typical CO_2 capture methods which typically require large amounts of oxygen and require energy for injection, the biochar process breaks the carbon dioxide cycle, releasing oxygen, and removing carbon from the atmosphere and sequestering it in the soil for possibly hundreds to thousands of years.[11]

Drawbacks and challenges

The biological systems discussed here present challenges to the development of effective deployment, accounting, and verification systems for these terrestrial-based approaches to geoengineering. For example, the climate benefits of sequestration practices can be partially or completely reversed because these resources are subject to natural decay, disturbances, and

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[6] *Research suggests that vegetative land cover in the form of crops and grasslands can impact climate by increasing local albedo by up to 0.25 (on a 0 - 1 point scale) and thus reflect more light into the atmosphere.*

[7] *The technology exists, but to deploy it on a commercial scale across the globe could take a decade or more.*

[8] *Biochar is charcoal created by the heating of biomass, trees and agriculture waste, in the absence of air, i.e. pyrolysis.*

[9] *Biomass could consist of trees and agricultural wastes.*

[10] Laird (2008)

[11] *Not only do biochar-enriched soils contain more carbon, 150gC/kg compared to 20-30gC/kg in surrounding soils, but biochar-enriched soils are, on average, more than twice as deep as surrounding soils. Therefore, the total carbon stored in these soils can be one order of magnitude higher than adjacent soils* (Winsley 2007).

harvests, which could result in the sudden or gradual release the carbon back to the atmosphere. Forests plateau[12] in their ability to reflect light and absorb CO_2 as they mature, and they release CO_2 as they decay; therefore, their utilization as geoengineering strategies would require careful monitoring and accounting of CO_2 storage over time as these systems do not provide long-term storage stability. These systems would also need to be maintained even after saturation to prevent subsequent losses of carbon back to the atmosphere. This would also be the case for management of soils.[13,14,15] Addressing these challenges is important if sequestration benefits are to be compared to other approaches.

Sophisticated and verifiable carbon accounting strategies are needed across the board to optimize carbon-sensitive land uses at different climates and geographies. Existing statistical sampling, models and remote sensing tools can estimate carbon sequestration and emission sources at the global, national, and local scales. However, complex spatial-temporal models would be required for each technique described here. For example, estimating changes in soil carbon over time is generally more challenging than those for forests due to the high degree of variability of soil organic matter—even within small geographic scales like a corn field—and because changes in soil carbon may be small compared to the total amount of soil carbon. And, it is not presently clear whether there would be greater carbon savings by planting trees and then converting those trees into biochar or planting trees and allowing them to grow, thereby sequestering carbon in both the soil and in the plant material.

Tradeoffs between immediate climate objectives and environmental quality may be necessary with these techniques. If nitrogen-based fertilizers are applied to crops to increase yields for biological sequestration methods, the benefit would be partially or completely offset by increased emissions of N_2O. The installation of non-native or genetically engineered species could be associated with additional environmental disruption such counteractive changes in reflectivity. For example, a large scale afforestation initiative over snow or highly reflective grasslands would increase carbon consumption but greatly decrease local albedo. Similarly, genetic modification of crops to increase their albedo could reduce their carbon uptake. Lastly, these techniques are likely to replace diverse ecosystems with single-species timber or grass plantations to generate greater carbon accumulation at the cost of biodiversity.

Non-traditional carbon capture and sequestration or conversion

Non-traditional carbon capture and sequestration (i.e. conversion) strategies would utilize geological systems??? to capture carbon. First carbon would be captured by exposing it to chemical adsorbents such as calcium hydroxide ($CaCO_3$, zeolites, silicates, amines, and magnesium hydroxide ($Mg(OH)_2$).[16] Then, heat or agitation would be used to separate the carbon from the adsorbent. The carbon can then be stored in a geologic receptacle or it would be stored as a new chemical compound in a liquid or solid formation.

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[12] *Soils also plateau in their ability to sequester CO_2.*
[13] Lehmann, Gaunt and Rondon (2006)
[14] Lal et al. (1999)
[15] West and Post (2002)
[16] Dubey et al. (2002)

Most geologic carbon removal strategies can be categorized as *in situ* or *ex situ*. *Ex situ* carbonation requires the sourcing and transportation of materials that react with carbon to the source of output (e.g., the smokestack). The energy input may be quite high because the carbon absorbent must be ground up to allow for a sufficient rate of carbon absorption. Air capture is a key component to the geologic carbon sequestration and geochemical weathering of carbon. In this process, a carbon-adsorbent chemical, such as calcium hydroxide, binds to carbon and separates it from the ambient air. The adsorbent chemical is then heated, the bound CO_2 is released, and a pure CO_2 stream is produced. Air capture differs from traditional carbon capture on power plants and other high-intensity carbon emitters in that it is a distributed approach to capture (as many of the main sources of carbon are actually a collection of distributed entities, e.g. vehicles and buildings).

Alternatively, *in situ* carbonation injects carbon into geologic formations suited to the mineralization of carbon.[17] The injected material is then left in the formation to carbonize at a more natural rate. Carbon storage in a liquid or solid represents a more permanent option for carbon management and can be thought of as the mere stimulation of naturally occurring processes that take place over thousands of years instead of months. It would potentially require less stringent regulatory and liability frameworks than traditional carbon storage in a gaseous form. This could make deployment costs more manageable per unit than traditional carbon capture and storage.

Challenges and drawbacks

The scale required for deployment of non-traditional carbon capture and sequestration methods present challenges to their eventual use. Geological capture and storage at a geoengineering scale would represent an immense investment, requiring hundreds or thousands of units and immense land formations suitable for storage. In addition, most suggested geological sequestration strategies require a high input of heat or pressure, either to release the carbon from its adsorbents or to speed the necessary reactions for solid storage, and thus are energy burdens for the deployment of this technology. Deployment of geochemical weathering of carbon

Ambient air is comprised of 0.04% carbon, and the slip streams of exhaust from coal fired power plants are approximately 15%; therefore, the amount of carbon gathered per unit of air processed would be far lower. In addition to issues of scale, in situ storage material may remain as a gas and be released after a period of time, which leads to additional monitoring and verification needs.

Other Strategies

Several geoengineering strategies were not emphasized in this hearing due to projected environmental impacts and project feasibility. Several of these techniques are detailed below.

Enhanced weathering techniques – Silicate minerals would be sourced, ground, and distributed over agricultural soils to form carbonates. Thiscategory of *in situ* carbonation works in the same manner as the non-traditional carbon consumption strategies discussed above. The actual

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[17] Kelemen and Matter (2008)

mineral distribution could be performed at a relatively low direct cost; however, the mining activities would require sizable energy inputs. In addition, introducing large quantities of chemicals to a landmass could incur significant changes, both predictable and unpredictable, to the entire ecosystem.

Chemical ocean fertilization – Similar to enhanced weathering in terrestrial systems, this strategy calls for the distribution of ground minerals over the oceans. Iron, silicates, phosphorus, nitrogen, calcium hydroxide and/or limestone could enhance natural chemical processes that consume carbon, such as photosynthesis in phytoplankton. Mining and environmental impacts are major challenges. Iron is the most popular candidate chemical for this strategy as it would require the smallest quantity to significantly lower carbon concentrations.

Oceanic upwelling and downwelling – Naturally occurring ocean circulation would be accelerated in order to transfer atmospheric greenhouse gases to the deep sea. Atmospheric carbon is absorbed by the ocean at the air-water interface, and it is largely stored in the top third of the water column. This approach would use vertical pipes to transfer the carbon rich surface waters to the deep ocean for storage. It would likely require massive engineering efforts and could significantly alter the ocean's natural carbon cycle and circulation systems.

White roofs and surfaces – Painting the roofs of urban structures and pavements in the urban environment white would increase their albedo by 15 - 25%. A white roofs program would need global implementation to achieve a meaningful impact on radiative forcing, incurring great costs and logistical challenges; however, white roofs can help mitigate the urban heat island problem, which plagues metropolises like Tokyo and New York City.

Desert reflectors – Metallic and other reflective materials would be used to cover largely underused desert areas, which account for 2% of the earth's surface to reflect sunlight. This approach could have large detrimental impacts on local ecosystems and precipitation patterns. Preliminary cost estimates are in the high billions or trillions of dollars.

Space-based reflective surfaces – A large satellite or an array of several small satellites with mirrors or sunshades would be placed in orbit or at the sun-earth Lagrange (L1) point to reflect some percentage of sun radiation. Preliminary cost estimates for this strategy are usually in the trillions of dollars.

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