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Biological and Land-Based Strategies for Geoengineering Earth's Climate

Chairman Baird and other members of the Science and Technology Committee, thank you for the chance to testify today. I appreciate the opportunity and your attention.

Let me first state that a wealth of scientific evidence already shows that climate change is happening and presents a grave threat to people and other organisms. We need to act quickly. The safest, cheapest, and most prudent way to slow climate change is to reduce greenhouse-gas emissions soon. No approach - geoengineering or otherwise - should lead us from that path.

Unfortunately, the world has so far been unable to reduce greenhouse-gas emissions in any substantive way. We therefore need to explore other tools to reduce some of the harmful effects of climate change. That is why we are discussing what was once purely science fiction - the remarkable possibility of geoengineering Earth's climate.

For my testimony, you asked me to discuss biological and land-use-based strategies for geoengineering. Here are **four take-home messages** of my testimony:

1) Some biological and land-use strategies for geoengineering are already feasible, including restoring or planting forests, avoiding deforestation, and using croplands to reflect sunlight and store carbon in soils.
2) Biological and land-based geoengineering alters carbon uptake, sunlight absorption, and *other* biophysical factors that affect climate together.
3) Geoengineering for carbon or climate will alter the abundance of water, biodiversity, and other things we value.
4) A research agenda for geoengineering is urgently needed that crosses scientific disciplines and coordinates research across federal departments and agencies.

Let me begin by describing some of the most common biological and land-use-based strategies for geoengineering and their relative effectiveness and feasibility.

Biological and Land-Based Options for Geoengineering

As described in the recent Royal Society report, *Geoengineering the Climate*, many geoengineering options are possible. One set of activities focuses on carbon dioxide removal. The other examines how to manage systems to reflect sunlight and cool the planet, termed solar radiation management. I will call these approaches "carbon" and "climate", respectively. For biological and land-based sequestration, what constitutes "geoengineering" instead of "carbon mitigation" or "offsets" is sometimes unclear. I will try to focus on strategies that are usually placed in the realm of geoengineering. An example of a land-use strategy that is not usually considered as geoengineering is the production of biofuels (in the absence of carbon capture and storage). I do not have the space to consider biofuels in this brief discussion.

Biological Carbon Dioxide Removal

Biological and land-based strategies provide a meaningful opportunity to remove carbon from the atmosphere and to store it on land. Since 1850, human activities accompanying land-use change have released at least 150 gigatons (10^{15} g) of carbon to the atmosphere, roughly one fifth of the total amount of carbon in the atmosphere today.

Plants and other photosynthetic organisms (hereafter "plants") provide one of the oldest and most efficient ways to remove carbon dioxide from our air. For this reason, they provide a feasible, relatively cheap way to reduce the concentration of carbon dioxide in the Earth's atmosphere – at least in the short term.

Several biological and land-based approaches are possible for removing carbon dioxide from air. Because carbon is lost when a forest is cut or disturbed, *restoring* forests is an important tool for placing carbon back in lands. *Afforestation*, or planting trees in places that were not previously forested (or have not been for many years) is another way to remove carbon from the atmosphere. *Avoided deforestation* is a third tool that improves the carbon balance and is sometimes considered to be geoengineering. If a policy incentive keeps a rainforest in Amazonia or Alaska from being cut, carbon that would have moved to the atmosphere is "removed" from the atmosphere.

Restoring and enhancing *soil organic matter* is another tool for carbon management and removal. Because agriculture tends to release soil carbon to the atmosphere, typically soon after land conversion, incentives to restore native ecosystems or to improve agricultural management are two ways to remove carbon from the atmosphere. Restoring or enhancing the amount of organic matter in soil has many benefits, including improved fertility and crop yield, reduced erosion, and better water-holding capacity.

Three issues or limitations in biological or land-based geoengineering are important. One is the scale of the approach needed to reduce the amount of carbon in our air. For any given project, a single acre of land can be managed or manipulated to remove carbon. Nationally, however, we need to implement these strategies over *millions of acres* if they are to play a meaningful role in policy (remembering that we already manage millions of acres). Otherwise, their net effect will be too small compared to the amounts of carbon entering the atmosphere through fossil fuel emissions.

A second issue is landowner behavior. Land is a valuable commodity, and private landowners will need financial incentives to make geoengineering a reality. How much will these incentives cost, and under what conditions, financial or otherwise, might they change their minds?

A third issue is that biological and land-based management will inevitably alter other resources that we care about, including water and biodiversity. I will return to this point after exploring solar radiation management as a second type of geoengineering.

Solar Radiation Management

Managing solar radiation directly is an alternative to removing carbon dioxide from air. In effect these approaches manipulate "climate" directly, or at least temperature. The most common approach for cooling is reflecting sunlight back into space. You only have to reflect a small percentage of the sun's rays to counterbalance the temperature effects of a doubling of atmospheric carbon dioxide. Managing solar radiation is thus the basis for many geoengineering strategies, including stratospheric dust seeding and whitening clouds over the oceans.

Biological and land-based strategies can also employ solar radiation management. One approach is to select crops, grasses, and trees that are "brighter" in color, reflecting more sunlight into space. This strategy can cool plants locally and save water but will likely reduce plant yields in some cases. The option may be especially valuable in sunny, dry areas of the world.

Like strategies for carbon removal, solar radiation management will need to be applied across large areas to be effective, probably millions of acres, at least. One smaller-scale exception may be when solar radiation manipulations reduce the energy needed to heat or cool buildings. Urban forestry, white buildings, and "green roofs" are examples. The energy savings are local but could play a small but meaningful role in reducing our national energy budget.

A disadvantage of solar radiation management is that it offsets only the climate effects of increased greenhouse gases but does not reduce greenhouse gas concentrations. It does nothing for the pressing problem of ocean acidification, for instance, caused by increased carbon dioxide dissolving into our oceans. Also, changing the amount of sunlight alters not just temperature but atmospheric circulation, rainfall, and many other factors. Less sunlight will almost certainly mean less rainfall globally and is likely to reduce global productivity of plants and phytoplankton.

Geoengineering on Land is Carbon *and* Climate Management

As just discussed, geoengineering strategies are typically lumped into two categories, those that remove carbon from the atmosphere and those that manage solar radiation ("carbon" and "climate", respectively). Unlike some geoengineering strategies, however, every biological and land-based approach will alter carbon storage *and* sunlight absorption. Moreover, sunlight is not the only factor that changes the temperature and energy balance of an ecosystem.

We **need a new framework for geoengineering that includes a full radiative accounting for greenhouse-gas and biophysical changes together**. That long-term framework should include not just reflected sunlight but water evaporation, energy exchange, and other important biophysical factors. Such a framework will then help us make best-practice recommendations for if, when, and where to promote geoengineering activities.

To demonstrate the need for better accounting, consider the following example. Imagine providing landowners with incentives to plant trees on lands that were previously croplands or pasture. Under a carbon management framework, this activity will almost certainly remove carbon dioxide from our air (assuming that planting and management practices do not increase net greenhouse gas emissions). That is what trees do – they grow.

What about the same activity viewed from the standpoint of solar radiation management or "climate"? Trees tend to be darker than grasses or other crop species and thus reflect less sunlight (Figure 1; Jackson et al. 2008). The same plantation that cools the Earth through carbon removal may warm it by absorbing more sunlight. Planting dark trees in snowy areas could cause substantial warming, for instance.

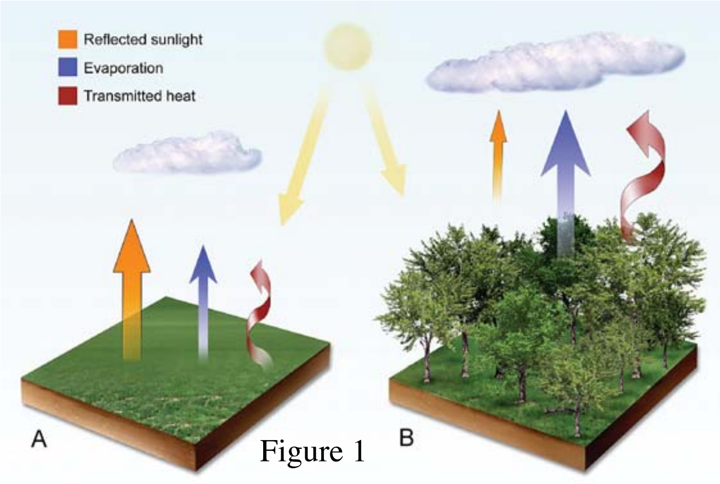


Figure 1

Your new plantation in Figure 1 also affects the Earth's temperature in more ways than just storing carbon and reflecting less sunlight. Trees typically evaporate more water than the grasses or other crops they replace do. This increased evaporation (the blue arrows in Figure 1) cools the land locally. It also loads more energy into the atmosphere and can alter the production of convective clouds that absorb or reflect sunlight and produce rain. Trees also alter the roughness or unevenness of the plant canopy, transmitting more heat into the atmosphere (the red arrows in Figure 1). Overall, such biophysical changes can affect local and regional climate much more than the accompanying carbon sequestration does - and sometimes in a conflicting way.

New research is needed to provide a full radiative accounting for greenhouse-gas changes and biophysics together. Some examples of *gaps in scientific understanding* include the ways that climate models do (and don't) resolve cloud cover, melt snow, supply water for plants to grow, and simulate the planetary boundary layer. The fusion of observations and models is critical for reducing these uncertainties.

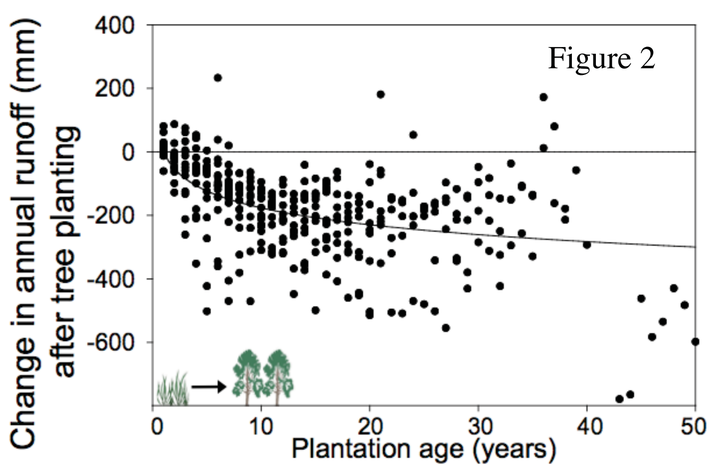
Geoengineering for Carbon or Climate Will Alter Other Valuable Resources

As just described, our lands do many things for us. They store carbon and protect our climate. They also supply and purify water, detoxify pollutants, support a treasure of biodiversity, and produce the food we need to survive. Geoengineering strategies to remove carbon from our air or to reflect sunlight will inevitably change the abundance of these resources. **We need immediate research on the full environmental effects of geoengineering**.

In a best-case scenario, managing lands to store carbon or reflect sunlight will provide additional ecosystem benefits. An example of this win-win scenario is restoring degraded lands. Restoring forests or native grasslands on lands that have been over-used will not just store carbon in plants and the soil; it will slow erosion, improve water quality, and provide habitat for many species. Similarly, avoiding deforestation in the tropics keeps carbon out of the atmosphere, preserves biodiversity, and provides abundant water for streams and for the atmosphere to be recycled in local storms.

In a worst-case scenario, blindly managing lands to store carbon or reflect sunlight will harm ecosystem goods and services. Covering hundreds or thousands of square miles of deserts with reflective surfaces, as has been proposed, may indeed cool the planet. It would also harm many other ecosystem services we value.

The more common reality will lie somewhere in between. One example of a trade-off in services that I have studied is carbon storage and water supply. Continuing the analogy in Figure 1, most trees store carbon for decades after planting. Because they grow quickly, however, trees also use more water than the native grasslands or shrublands they replace (Figure 2; Jackson et al. 2005). These losses are substantial. Yearly streamflow typically drops in half soon after planting. In about one in ten cases the streams dry up completely.



In many real-world scenarios, we will have to choose which ecosystem services we value most. In the specific case of our plantation, which currency should we value more – carbon or water? The answer probably depends on whether you live in a relatively water-rich area or a water-poor one. Unfortunately, you can't always have your cake and drink it, too.

Research into the environmental co-effects of geoengineering is critical for successful policy and for avoiding surprises. In the final section of this testimony, I present a few ideas for designing and coordinating geoengineering research.

Which U.S. Agency Should Lead Geoengineering Research?

Because of the range of geoengineering activities and their environmental consequences, *no single agency has the expertise needed to lead all geoengineering research*. A more feasible approach would build on a model that is sometimes used successfully – a coordinated, inter-agency working group. One example of such a group is the U.S. Global Change Research Program comprised of thirteen departments and agencies.

Choosing a single U.S. agency to lead the research effort is appealing administratively but would duplicate efforts. The Environmental Protection Agency might be one home for geoengineering research, particularly if the EPA is to regulate carbon dioxide emissions. The Department of Agriculture, including its Forest Service and Agricultural Research Service, has a long history of expertise in managing our forests and agricultural lands. The Department of Energy leads federal agencies in life-cycle and energy analysis on the global carbon cycle. The National Aeronautics and Space Administration (NASA) coordinates satellite-based research needed to understand global processes and feedbacks. Many other agencies, including the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Department of the Interior, play important roles in research.

Geoengineering research is most likely to succeed if research agencies agree on a joint research agenda. **The agencies should therefore immediately convene a multi-disciplinary panel of experts to outline an agenda for geoengineering research**. This process must be open and should seek input from the broader research community and from stakeholders outside that community.

Conclusions

To discuss the possibility of engineering the Earth's climate is to acknowledge that we have failed to slow greenhouse gas emissions and climate change. Emitting less carbon dioxide and other greenhouse gases should remain our first goal.

Because our climate is already changing, we need to explore every tool to reduce the harmful effects of those changes. Geoengineering is one such tool. We have some valuable, short-term opportunities at hand, including restoring ecosystems and avoiding deforestation. Overall, though, we need to study the feasibility, cost, and environmental co-effects of geoengineering broadly *before* applying it across the United States and the world. We need to get geoengineering right – as a tool of last resort.

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Robert B. Jackson, Biography

Robert B. Jackson is the Nicholas Professor of Global Environmental Change at Duke University and a professor in the Biology Department. His research examines how people affect the earth, including studies of the global carbon and water cycles and climate change.

Jackson received his B.S. degree in Chemical Engineering from Rice University (1983). He worked four years for the Dow Chemical Company before obtaining M.S. degrees in Ecology (1990) and Statistics (1992) and a Ph.D. in Ecology (1992) at Utah State University. He was a Department of Energy Distinguished Postdoctoral Fellow for Global Change at Stanford University and an assistant professor at the University of Texas before joining the Duke faculty in 1999. He is currently Director of Duke's Center on Global Change. In his quest for solutions to global warming, he also directs the Department of Energy-funded National Institute for Climate Change Research for the southeastern United States and co-directs the Climate Change Policy Partnership, working with energy and utility corporations to find practical strategies to combat climate change.

Jackson has received numerous awards, including a 1999 Presidential Early Career Award in Science and Engineering from the National Science Foundation (honored at the White House), a Fellow in the American Geophysical Union, and inclusion in the top 0.5% of most-cited scientific researchers (http://www.isihighlycited.com/). His trade book on global change, *The Earth Remains Forever*, was published in October of 2002. He has also written two children's books, *Animal Mischief* and *Weekend Mischief*, both published by Boyds Mills Press, the trade arm of Highlights Magazine. Jackson's research has been covered in various newspapers and magazines, such as the Boston Globe, Washington Post, USA Today, New York Times, Scientific American, Economist, and BusinessWeek, and on national public radio. He conceived and organized the Janus Fellowship, an annual undergraduate award to encourage the study of an environmental problem from diverse perspectives; 1999's first recipient traveled down the Nile River to examine water use and water policy in Egypt.