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CONCERNING GEOENGINEERING RESEARCH
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Good morning Chairmen Biggs and Weber, and Ranking Members Bonamici and Veasey, and members of the Committee. I am grateful for the invitation to join you today and the opportunity to share my perspective on geoengineering research.

My name is Joseph Majkut. I am the director of climate policy at the Niskanen Center, located here in Washington, D.C., where my work focuses on climate and energy policy and matters of climate science.[1]

While there is little practical scientific doubt that human activities are behind most of the recently-observed warming of the Earth—with more to come over this century[2]—there is a great deal of uncertainty about the environmental and economic consequences of warming.[3] As such, society should respond to climate change as a risk management problem and seek ways to reduce greenhouse gas (GHG) emissions, minimize societal vulnerability, and otherwise limit the potential costs of a warming planet.

Geoengineering technologies are one prospective means of addressing these challenges. As a class, they would allow people to intervene in the earth system at a large enough scale to deliberately alter the climate. In the near future, these technologies could be deployed to reduce or prevent warming from human (or natural) causes.

Before contemplating such a deployment, a lot more research should be done into the science, engineering, ethics, and politics of intentionally moderating the climate. Without such research, it would be imprudent to deploy these technologies, or even assume their viability.

In my testimony, I would like to emphasize three main points:

1. Climate geoengineering technologies, particularly Solar Radiation Management (SRM), could be used to prevent some degree of global warming and its attendant effects over short timescales, but there are major scientific questions about the trade-offs associated with using them;
2. The potential benefits of addressing those outstanding questions justifies federal research funding; and
3. Given the nature of these technologies, Congress should consider establishing a regulatory governance structure to maximize innovation and scientific progress while protecting the public and environment from ill-informed experiments or premature deployment.

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[1] My writings can be viewed at https://niskanencenter.org/blog/policies/climate/.
[2] For a description, see https://www.climateunplugged.com/articles/the-climate-future/.
[3] For a description, see https://www.climateunplugged.com/articles/understanding-climate-risk/.

Solar Radiation Management Technologies

Generally described as climate geoengineering, technological interventions to reduce the human influence on climate fall into two categories: Carbon dioxide (CO2) capture and SRM, mentioned previously.

Carbon dioxide capture, or negative emissions, describes technologies that would artificially remove CO2 from the atmosphere and thereby limit the warming and chemical effects of excess CO2. These are interesting technologies for research that are already aligned with much of what is done at the Department of Energy (DOE) and other agencies.

SRM describes interventions that would decrease the amount of solar radiation that reaches the surface of the Earth by increasing the planet's reflectivity, or albedo. While there are technical nuances and regionally varying details, the amount of cooling we could expect to see is roughly proportional to the decrease in radiation. These technologies could therefore be tuned to partially or fully offset the warming effects of increased CO2 with an large enough intervention, while very small experiments would have no globally detectable signal.

Two different approaches for SRM are the most thoroughly studied.

The first is stratospheric aerosol injection (SAI), whereby small particles are dispersed in a high part of the atmosphere to create a reflective veil around the Earth. This occurs naturally when very large volcano eruptions shoot sulfates into the stratosphere, where they remain suspended for a year or two, cooling the climate. We witnessed this natural process in 1991/1992, after the eruption of Mt. Pinatubo and we very well may see it again soon, as Mt. Agung in Indonesia is on a level 3 (of 4) eruption watch.[4]

Because SAI is similar to the same natural phenomena observed during volcanic eruptions, we are confident in SAI's ability to cool the planet. However, researchers are not sure if human-driven SAI would have the same temperature effects or if it would induce deleterious side effects. Increased levels of stratospheric aerosols can potentially increase acid rain, deplete stratospheric ozone, dramatically warm the stratosphere, and effect regional temperatures and precipitation. Research will be necessary to better understand the uncertainty and reduce the risks around SAI technologies.

The second method is Marine Cloud Brightening (MCB), which attempts to cool the Earth by brightening the clouds over the ocean, instead of increasing stratospheric albedo. The theoretical basis for MCB lies in the Twomey effect, where the smaller and more numerous a cloud's particles, the brighter it will be.[5] By this theory, spraying thousands of gallons worth of 10 nm-sized particles of saltwater would make existing clouds wider, brighter, and more persistent. Only special kinds of clouds would be affected by MCB, and they tend to occur in specific areas, like the sea off the California coast. This limited

[4] For recent reports on global volcanism, see https://volcano.si.edu/showreport.cfm?doi=GVP.WVAR20171025-264020.

[5] S. Twomey, Pollution and the planetary albedo, In Atmospheric Environment (1967), Volume 8, Issue 12, 1974, Pages 1251-1256.

deployment area means we don't know if MCB would have a very large cooling effect, or a very small one.

In 2015, the National Academies of Sciences published a two-part report that provides a comprehensive discussion of the state of the science in geoengineering research including SAI and MCB and their comparative qualities.[6]

It is important to note that while there is much we still don't understand about SRM technologies, we are sure about some concepts.

SRM introduces a new way to manage climate risk, but it will not directly counteract greenhouse-driven warming. According to modeling studies and basic meteorological theory, a geoengineered world could not replicate the preindustrial one or simultaneously hold regional climates, rainfall patterns, and global temperatures static. Thus, any significant deployment of SRM would involve regional and local tradeoffs whose political, economic, and ecological effects we cannot now predict.[7]

If used for offsetting some of the net warming effect of CO2, SRM deployment will require constant maintenance. Carbon dioxide resides in the atmosphere for centuries to millennia; clouds last a week and aerosols a couple of years. So if SRM was deployed to reduce warming, there would be a relatively sudden warming should the SRM program cease. Thus once humanity starts down the path of slowing or offsetting warming, it will be difficult to walk back while excess CO2 remains in the atmosphere.

Not all of the considerations that will govern decisions to use or refrain from using SRM technologies are scientific. However, numerous scientific and engineering gaps prevent an informed understanding of the costs and benefits or potential unintended consequences. Reducing uncertainties and better characterizing those risks presents the scientific enterprise with the opportunity to add value for future policymakers.

Research Support Justified

Even if GHG emissions reductions proceed rapidly, temperatures will continue to increase over the next few decades, and likely surpass the 1.5C and 2C targets laid out in international agreements. As temperatures increase, the effects of climate change will become more obvious, widespread, and harmful.[8] As climate impacts worsen, policymakers will face increased pressure to consider fast

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[6] National Research Council. 2015. *Climate Intervention: Reflecting Sunlight to Cool Earth*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18988.

[7] Corner and Pidgeon 2010. Geoengineering the Climate: The Social and Ethical Implications. Environment: Science and Policy for Sustainable Development. 52. 24-37.

[8] For a comprehensive discussion of how climate impacts will progress through different levels of warming, see Oppenheimer, M., et al., 2014: Emergent risks and key vulnerabilities. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap19_FINAL.pdf.

responses like SRM. However, without a clear understanding of the trade-offs associated with SRM deployment, future actors will be limited in their ability to judge the merits of deployment.

Better characterizing standing uncertainties as inputs to a risk management strategy is valuable for informed policymaking. The potential scale of climate risks and the costs associated with transitioning to a low-carbon economy mean that the potential value of SRM could register in the trillions of dollars.[9] That value may be accounted as reduced climate damages or a less-costly transition to low-carbon energy. Even reducing the uncertainty in the costs and benefits of deploying SRM could be of great value.[10] Given current limitations on our knowledge, learning that SRM is either acceptably risky or totally unacceptable would be valuable.

Within the scientific community, there is a growing sense that pursuing research to resolve the scientific questions surrounding geoengineering is worthwhile. Many organizations, like the Bipartisan Policy Center (BPC),[11] the Royal Society,[12] the National Research Council,[13] and the Governmental Accountability Office (GAO),[14] express some need to better understand the risks of solar geoengineering through research.

In the 2017 update of its strategic plan, the United States Global Change Research Program (USGCRP) acknowledged that geoengineering research is on the horizon and the federal research enterprise could meaningfully inform research activities and governance.[15] That plan noted that:

> [w]hile climate intervention cannot substitute for reducing greenhouse gas emissions and adapting to the changes in climate that occur, some types of deliberative climate intervention may someday be one of a portfolio of tools used in managing climate change. The need to understand the possibilities, limitations, and potential side effects of climate intervention becomes all the more apparent with the recognition that other countries or the private sector may decide to conduct intervention experiments independently from the U.S. Government.

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[9] Arino, Y., et al. 2016. *Estimating option values of solar radiation management assuming that climate sensitivity is uncertain*, Proc. Natl. Acad. Sci. U. S. A. http://www.pnas.org/content/113/21/5886.full.pdf.

[10] Moreno-Cruz and Keith. 2012. *Climate policy under uncertainty: a case for solar geoengineering.* Climatic Change. https://link.springer.com/article/10.1007/s10584-012-0487-4.

[11] Task Force on Climate Remediation Research. Long, J. (Chair) 2011. https://bipartisanpolicy.org/library/task-force-climate-remediation-research/

[12] The Royal Society. 2009. *Geoengineering the climate: science, governance and uncertainty.* https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2009/8693.pdf.

[13] NRC. 2015. *Climate Intervention.*

[14] United States Government Accountability Office. 2010. *Climate Change: A Coordinated Strategy Could Focus Federal Geoengineering Research and Inform Governance Efforts* http://www.gao.gov/new.items/d10903.pdf.

[15] United States Global Change Research Program. 2017. *National Global Change Research Plan 2012–2021: A Triennial Update.* Washington, DC, USA https://downloads.globalchange.gov/strategic-plan/2016/usgcrp-strategic-plan-2016.pdf.

Questions may arise over whether this type of research is more valuable than other types of climate studies, advanced energy research, or even research in other scientific disciplines. Especially in a time of increased budgetary pressures, Congress faces tough choices about how to allocate public funds.

Research into geoengineering technologies, at least initially, should not be overly costly or supplant other initiatives. Some of the work you can image scientists pursuing will be beneficial to other questions in climate science and to general intellectual inquiry, while some work will likely benefit mainly geoengineering considerations. Both are valuable.

Further, to anyone contemplating deployment of SRM as a risk management tool, an appreciation of how complementary technologies can measure and understand the climate system and atmospheric compensation should be a top priority. That means better observations, modeling tools, and a strong community of climate scientists and interdisciplinary experts. These things are valuable for climate research generally and broader societal decisionmaking, and would be necessary in any world of judicious climate engineering. You can't engineer what you don't measure or understand.

Should Congress decide that funding geoengineering research is desirable, then research dollars should be directed to multiple agencies, such as the National Science Foundation, National Oceanic and Atmospheric Administration, Department of Energy and other participants in USGCRP. At such an early stage of research, we would benefit from have more perspectives looking at this issue.

Governance

Much of the research that can and will be done on geoengineering will be done in supercomputing centers and in controlled experiments at the workbench. But as this science progresses, researchers will need to move into the field to perform experiments in real world conditions. In the near-term, we shouldn't expect to see manipulation of the climate at large scales, but instead small field experiments to evaluate equipment and make measurable, but trivial, changes to the environment.[16] Though small in net effect, proposed experiments aimed at understanding the chemical and physical processes will provide valuable foundational data.[17]

Such experiments, and the researchers who will carry them out, will benefit from clear and fair regulatory guidance. Any regulatory framework should aim to maximize innovation and scientific progress, while protecting the public and environment from premature or ill-informed experiments.

Present-day Governance

It is important to note that Congress has already given limited authority to regulate experiments intent on altering the weather, including changing planetary albedo. At this point, those regulations are limited to reporting requirements.

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[16] Andy Parker, 2014. Governing Solar Geoengineering Research as it Leaves the Laboratory, Royal Society, 2014.
[17] Introductions to conceptual process experiments can be found in the NRC's 2015 report, "Climate Intervention" table 4.1, list items 1 and 3.

In the 1971 National Weather Modification Act, Congress defined the term "weather modification" to mean, "any activity performed with the intention of producing artificial changes in the composition, behavior, or dynamics of the atmosphere".[18] Section 2 of the 1971 Act provided that, "No person may engage, or attempt to engage, in any weather modification activity in the United States unless he submits to the Secretary such reports with respect thereto . . . as the Secretary [of Commerce] may by rule prescribe."

And as far as NOAA is concerned, "any" means "any", and specifically includes SRM. Rules finalized in 1976 provide that "The following, when conducted as weather modification activities, shall be subject to reporting:

> (1) Seeding or dispersing of any substance into clouds or fog, to alter drop size distribution, produce ice crystals or coagulation of droplets, alter the development of hail or lightning, or influence in any way the natural development cycle of clouds or their environment;
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> ...
>
> *(3) Modifying the solar radiation exchange of the earth or clouds, through the release of gases, dusts, liquids, or aerosols into the atmosphere;*[19]

Thus by regulation, anyone intent on engaging in field experimental perturbations of planetary albedo are already required, by law, to submit *ex ante* and *ex post* reports documenting the extent of their activities.

Section 5 of the 1971 Act provides, "Any person who knowingly and willfully violates section 2 of this Act, or any rule issued thereunder, shall upon conviction be fined not more than $10,000." Note the word "conviction"; this is a criminal offense.

Future Governance

As prospective research moves beyond model and bench studies, it will be important to establish a clear regulatory framework for field tests and *in situ* experimentation that goes beyond reporting. Regulatory governance should grow as experiments grow larger.[20] Congress should consider a 3-tier structure for this purpose.

First, there should be a *de minimis* threshold, below which would be experiments—far too small to measurably affect the earth's surface—that should require no federal permission and only be subject to reporting requirements similar to those in effect today. By maintaining a permissive regulatory

[18] P.L. 92-205, https://www.gpo.gov/fdsys/pkg/STATUTE-85/pdf/STATUTE-85-Pg735.pdf.
[19] 15 C.F.R. 908.3(a).
[20] NRC Report, Chapter 4 and references therein.

environment for researchers doing process-level experiments, we would allow a maximum degree of innovation and scientific progress.

Since these *de minimis* experiments would be too small to affect the earth's surface more than many common activities, these experiments—should the government choose to fund them—should be categorically exempted from the National Environmental Policy Act (NEPA).

Second, Congress should consider what degree of climatological effect, duration, or regional impacts could define a maximum threshold for experimental work. Experiments should not cross this cap without Congressional permission. Such a decision would occur once we have developed a better understanding of the scale of impacts, costs and benefits of larger scale research, and the societal and international response to this type of research.

Third, any proposed experiments above *de minimis* but below the cap, should require agency permission and regulatory approval *ex ante*. Congress should instruct the agency to permit such experiments based on a careful weighing of their risks and benefits and coherence with scientific priorities.

If the required permit triggers NEPA, then it should remain applicable to these agency decisions. In cases where the permitted activity does not rise to the level of requiring NEPA analysis, the agency should still be required to provide public notice of permit applications and the opportunity to comment on them.

In order to allow both the *de minimis* and agency-permitted experiments to proceed without undue burden, Congress should consider preempting state or local laws requiring permission to conduct such experiments. At the same time, Congress should make it very clear that all other laws—state and federal, civil and criminal—apply to the experiment and the person(s) conducting it.

Lastly, in order to ensure public and international confidence in the limited and regulated nature of any such experiments, Congress should ensure that failure to abide by the agency's regulations would be subject to significant civil and administrative penalties, and that violation of the hard cap would also be subject to criminal penalties.

Congress might also consider whether to extend that criminal liability not only to such experiments originating within or over the United States, but also conducted outside of our borders that result in an impact on the United States commensurate with a domestic experiment over the hard cap. Such considerations would need the input of the diplomatic and international community.

Congress could either set the level of the *de minimis* threshold and the hard cap itself, or delegate that responsibility to agency rulemaking done in consultation with the scientific community.[21] To inform such

[21] There have been some suggestions for thresholds of radiative effect that would separate lightly regulated and off-limits experiments to which governments and science agencies could agree. For example: Parson and Keith, *End the Deadlock on Governance of Geoengineering Research*, Science 2013. http://science.sciencemag.org/content/339/6125/1278.

deliberation, Congress may want to request a study from the National Academy of Sciences or a blue ribbon commission to provide a set of recommendations on future governance of geoengineering research.

Conclusion

The case for further scientific inquiry into geoengineering is compelling. It is an idea that could help many people or it could be impossibly hazardous and politically unacceptable. We don't presently know. Giving the scientific community the charge of answering what questions it can seems prudent.

In the near term, this research—even small scale field experiments—probably doesn't need additional regulatory constraint in the United States. But while not immediately necessary for funding to flow or experiments to occur out-of-doors, it would be better for some regulatory structure to be in place earlier rather than later. The framework presented above is one proposal in that direction. The considerations of how to regulate such experiments to protect the public, without impeding scientific progress or creating political storms, will require negotiation and thought.

I would like to thank the Committee for the opportunity to testify on this matter, and look forward to your questions.

BIOGRAPHY OF JOSEPH MAJKUT

Dr. Joseph Majkut is director of climate policy at the Niskanen Center. He is an expert on climate science, the global carbon cycle, and risk and uncertainty analysis for decision-making. Before joining the Niskanen Center, he worked on climate change policy in Congress as a congressional science fellow, supported by the American Association for the Advancement of Science and the American Geoscience Institute. He holds degrees from Princeton University, the Delft University of Technology, and Harvey Mudd College.