DRAFT: Geoengineering Responses to Climate Change Require Enhanced Research, Consideration of Societal Impacts, and Policy Development

It is not currently possible to robustly assess the potential consequences of geoengineering (also known as "climate engineering"). Therefore, significant additional research, risk assessment, and consideration of difficult policy questions are required before the potential of geoengineering systems to offset climate change can be evaluated adequately.

It is well established that humans are responsible, primarily through the release of greenhouse gases, for most of the well-documented increase in global average temperatures over the last half century. Further emissions of these pollutants, particularly of carbon dioxide from the burning of fossil fuels, will almost certainly cause additional widespread changes in climate, with major negative consequences for most nations and natural ecosystems.[i]

The only way to slow and stop human impacts on climate is through mitigation of these emissions, which must therefore be central to any policy response to the dangers of climate change. Over the last three decades it has become apparent that there are many political and technological difficulties in achieving deep, global reductions, and many studies have shown that current mitigation efforts are not sufficient to limit global warming to widely discussed goals such as 1.5 to 2 degrees Celsius above pre-industrial levels. Mindful of this reality there has been more attention to climate adaptation: moderating climate impacts by increasing the capacity of societies to cope with them.

Insufficient mitigation and adaptation leaves humans and nature exposed to large, harmful changes in climate. That reality has led, in part, to growing interest in the option of *geoengineering*: "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change."[ii] In theory, geoengineering technologies could be deployed—in tandem with mitigation and adaptation—with a variety of goals, such as reducing peak levels and rates of climate change or responding to unforeseen and harmful shifts in climate.

Although the general term "geoengineering" is widely used, we find the concept unhelpful because it amalgamates many different technologies and strategies—each with distinct risks, opportunities, technological readiness, scenarios for deployment, and unknowns.

These proposals fall into two main categories. [iii] One involves techniques that remove CO2 directly from the air, also known as "carbon dioxide removal" (CDR). This approach would reduce the levels of atmospheric gasses through manipulations that remove greenhouse gases directly from the atmosphere.[iv] These include large-scale afforestation, combining energy crops with storage of CO_2 underground and machines that chemically remove carbon dioxide from the atmosphere. They would confer global benefits because this gas is mixed throughout the global atmosphere. A few private firms have emerged to test these technologies and research programs are underway in several countries. AGU recommends that governments evaluate whether there is adequate investment in this option from the private sector, or whether a public program is needed. Carbon dioxide removal from the atmosphere could prove highly valuable as a supplement to mitigation.

Since 2009, when AGU first issued a statement on geoengineering, there has been considerable research suggesting that the line between CDR options and mitigation of emissions is blurring. As reviewed in the latest assessment report of the Intergovernmental Panel on Climate Change, many scenarios that envision rapid and deep decarbonization of the world's energy system rely on massive deployment of energy crops with sequestration of CO_2 underground. AGU recommends that the ecological and economic impacts of such deployments must be examined in more detail, along with how those impacts vary with the scenario for deployment.

The other category of geoengineering proposals is called "solar radiation management" (SRM). It principally involves exerting a cooling influence on Earth by reflecting sunlight (e.g., putting reflective particles into the atmosphere, seeding clouds in the lower atmosphere to brighten them, increasing surface reflectivity, or putting mirrors in space). Radiation management might also be achieved by thinning cirrus clouds in the atmosphere, which could allow more longwave radiation to leave the planet. Solar Radiation Management could, in theory, cool the climate quickly and thus prove highly valuable should society at some point face rapid changes in climate that cause unacceptable damage.

SRM raises acute challenges for policy. The deployment of SRM systems would be highly premature, not least because the harms and benefits are currently highly uncertain. Reflecting sunlight would reduce Earth's average temperature but could, for example, 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—raising the spectre that some or all nations might not favor deployment of SRM systems while others proceed nonetheless. Because of these potentially acute ethical, legal, diplomatic, and national security concerns, decisions about SRM will require a large measure of international coordination.[v]

Research of various types is essential to improving scientific understanding of the potential consequences of different SRM systems. Such a research program, if conducted openly with introspection and self-scrutiny as befits the global scientific community, could help diffuse information widely and also help facilitate the development of appropriate international norms about testing and evaluation of SRM systems.

Since 2009 several groups have advocated SRM research programs.[vi] Those include the US National Research Council,[vii] whose findings on this topic AGU broadly endorses.

While much can be learned from laboratory and modeling research, AGU finds that an effective SRM research program must recognize that important advances in knowledge may also require field experiments. Field experiments that could pose substantial risks may require additional governance mechanisms, yet to be developed. In managing such a research program, AGU recommends that scientists recognize a tension that has already been revealed as the geoengineering topic becomes more politicized. The broader public, on the one hand, may be interested to regulate such research according to whether the "intent" of scientists is to use the information for geoengineering purposes. On the other hand, many systems for scrutinizing appropriate research already exist, including many international accords, and the concept of "intent" may be unworkable in practice. Much of the knowledge needed to understand SRM schemes overlaps heavily with the knowledge needed to understand the changing climate system. Making such a research program sustainable will require a large degree of openness and scrutiny.

AGU recommends that a research program include historical, ethical, legal, and social implications of SRM. It is necessary to integrate international, interdisciplinary, and intergenerational issues and perspectives and includes lessons from past efforts to modify weather and climate.

CDR and SRM will not substitute for aggressive mitigation nor the need for proactive adaptation, but they 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.

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[i] For example, impacts are expected to include further global warming, continued sea level rise, greater intensity of rainfall and severe storms, more serious and pervasive droughts, enhanced heat stress episodes, 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. In addition, the buildup of carbon dioxide in the atmosphere is causing ocean acidification, a problem in its own right that will also compound many of the effects of changing climate on ocean ecosystems. http://sciencepolicy.agu.org/files/2013/07/AGU-Climate-Change-Position-Statement_August-2013.pdf

[ii] Shepherd, J. G. S. et al., 2009: *Geoengineering the climate: Science, governance and uncertainty*, RS Policy Document 10/09, (London: The Royal Society). [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.]

[iii] We focus here on the two main types of interventions that are most associated with the concept of geoengineering. A third type of geoengineering might involve altering transport of heat in the oceans, such as through a network of vertical pipes, but we set that aside as impractical with current knowledge and likely cost.

[iv] National Research Council, 2015: *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration,* (Washington, DC: The National Academies Press) https://doi.org/10.17226/18805.

Smith et al., 2016: *Biophysical and economic limits to negative CO_2 emissions*, (Nature Climate Change, 6, 42–50) doi:10.1038/nclimate2870.

Wilcox et al., 2017: Assessment of reasonable opportunities for direct air capture, *Environmental Research Letters*, *12*(6), 065001

[v] We are mindful that some international accords on related topics already exist, although international governance is a patchwork of activities, few of which were conceived for the purpose of managing testing or deployment of SRM systems. Solar Radiation Management Governance Initiative (SRMGI), 2011: *Solar radiation management: the governance of research,* (SRMGI) http://www.srmgi.org/files/2016/02/SRMGI.pdf

[vi] Bipartisan Policy Center's Task Force on Climate Remediation Research, 2011: *Geoengineering: A national strategic plan for research on the potential effectiveness, feasibility, and consequences of climate remediation technologies, (*Washington, DC: Bipartisan Policy Center) https://bipartisanpolicy.org/wp-content/uploads/sites/default/files/BPC%20Climate%20Remediation%20Final%20Report.pdf.

Government Accountability Office (GAO), 2011: *Climate Engineering: Technical Status, Future Directions, and Potential Responses. Report GAO-11-71*, (Washington, DC: GAO) http://www.gao.gov/new.items/d1171.pdf.

Shepherd, J.G., Working Group on Geoengineering the Climate, 2009: *Geoengineering the climate: science, governance and uncertainty*, (London, GB Royal Society) https://royalsociety.org/~/media/Royal_Society_Content/policy/publications/2009/8693.pdf.

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