

White Paper of the American Geophysical Union:  
**Climate Intervention Requires Enhanced Research, Consideration of Societal Impacts, and Policy Development**

*It is not currently possible to assess robustly the potential consequences of climate intervention (also often called “geoengineering” or “climate engineering”). Significant additional research, risk assessment, and consideration of difficult policy questions are required to evaluate the potential of climate intervention systems to offset climate change.*

Humans are responsible, through the release of carbon dioxide (CO<sub>2</sub>) and other greenhouse pollutants, for most of the increase in global average temperatures over the past half century. Further emissions of these substances, particularly of CO<sub>2</sub> from the burning of fossil fuels, will cause additional widespread changes in climate and ocean acidification, with adverse consequences for human welfare and natural ecosystems.<sup>i</sup>

Deep reductions in emissions of CO<sub>2</sub> and other greenhouse pollutants must be central to any policy response to the dangers of climate change. Over the past 3 decades, it has become apparent that there are many barriers to achieving deep, global reductions, and many studies have shown that current efforts to control emissions are far from sufficient to limit global warming to “well below 2°C above pre-industrial levels,”<sup>ii</sup> as adopted in the 2015 Paris Agreement and endorsed in many other forums. Because of this, more attention has been paid to climate adaptation: moderating climate impacts by increasing the capacity of societies to cope with them.

Insufficient reductions in emissions and adaptation could leave humans and nature exposed to large, harmful changes in climate. That reality is part of what has led to growing interest in the option of climate intervention: “deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change.”<sup>iii</sup> Climate intervention technologies could be deployed as a complement to emissions reductions and adaptation. For example, climate intervention could attempt to slow the rate of climate change and reduce the peak rise in global average temperature, which could moderate the most severe impacts of climate change.

While there are many different options, and scientists will envision still more methods for climate intervention, the most plausible approaches fall into two distinct categories.<sup>iv</sup>

The first category, known as carbon dioxide removal (CDR), utilizes approaches and techniques that remove CO<sub>2</sub> directly from the atmosphere, thus reducing atmospheric concentration and the associated intensification of human-induced greenhouse warming.<sup>v</sup> CDR approaches include large-scale afforestation, which is already being done on the planet to some degree, along with enhanced mineralization or weathering, combining energy crops with storage of CO<sub>2</sub> in the soils or reservoirs deep underground, and machines that chemically capture carbon dioxide from the atmosphere.<sup>vi</sup> Each of these options has its own potential side effects and questions about the extent to which the intervention might work at scale, and research is needed to understand those limitations.

Since 2009, when AGU first issued a statement on climate intervention, the line between CDR options and efforts to control emissions has blurred. 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<sub>2</sub> underground. Since 2009, a few privately funded teams have begun to develop machines that chemically capture carbon dioxide from the air, but the overall level of research effort in CDR remains very small.

AGU recommends that the ecological and economic impacts of such deployments be examined in more detail. It endorses calls for substantial CDR research programs such as those outlined by the National Academies.<sup>vii</sup> Understanding the economic, environmental, and practical challenges in scaling these options is essential given the urgency of the climate problem and the potential roles for CDR in overall strategies for lowering the concentrations of warming pollutants in the atmosphere.

The second general category of climate intervention proposals is albedo modification (AM). It involves cooling Earth by reflecting sunlight away from the planet. Most AM research has focused on putting reflective particles into the upper atmosphere or seeding clouds in the lower atmosphere to brighten them.<sup>viii</sup> AM cannot substitute for reductions in greenhouse gas emissions, because its effects on the climate are not simply to reverse warming and because it would have no direct effect on ocean acidification caused by increasing carbon dioxide levels. However, in theory, it could reduce some harm done by climate change during the time it takes for societies to implement deep cuts in greenhouse gas emissions while potentially developing and deploying CDR systems. It could also, 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.

Many questions have been raised about potential impacts of AM schemes on global circulation patterns, storm tracks, and precipitation. Research is needed to understand those possible impacts and to inform policy decisions that have interconnected ethical, legal, diplomatic, and national security implications. As with the climate change caused by greenhouse gas emissions, the consequences of reflecting sunlight would not be the same for all nations and peoples; some nations might not favor deployment of AM systems while others might proceed nonetheless. Research and policy decisions on these will occur mainly within countries, but AM will require a large measure of international coordination and governance for which the needed institutions are not in place.<sup>ix</sup>

AGU urges national funding agencies to create substantial research programs on AM and to embed them, where appropriate, in existing larger programs on climate science because much of the knowledge needed to understand AM systems overlaps heavily with the

knowledge needed to understand the changing climate system. Since 2009, several groups have advocated AM research programs.<sup>x</sup> These include the U.S. National Academies,<sup>xi</sup> whose findings on this topic AGU endorses. Such research, 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 AM systems. AGU is concerned that scientific discussions around AM are taking place mainly in a small number of western countries. A proper and full evaluation of potential uses and impacts of AM will require a broader dialogue that engages more societies.<sup>xii</sup>

While much can be learned from laboratory and modeling research, AGU finds that robust AM research programs must recognize that important advances in knowledge may also require field experiments. Decisions about where and how to conduct field experiments are best left to competent authorities that already oversee such questions; where adequate national oversight does not exist, active efforts will be needed to build that capacity. This approach of relying on national regulatory oversight should be evaluated regularly with experience. Active engagement with the broader society on the goals and modes of AM research will be essential because the public, at present, knows little about climate intervention and must be part of an informed debate. In addition to consideration of the physical, technological, and practical aspects of the scientific research, inquiry and analysis are needed of the ethical, legal, diplomatic, national security, and governance aspects. Attention is needed, as well, to the historical context provided by past efforts, often steeped in hubris, to modify weather, climate, and other aspects of the Earth system.<sup>xiii</sup>

AGU is concerned that the debate over research funding for CDR and AM has been prone to paralysis. While legitimate concerns have been raised about scalability and the side effects of climate intervention schemes, those same concerns have been used to block funding of the research that could help understand and address them. Some observers also think that merely investigating climate intervention options might lessen political pressure to implement cuts in emissions. The reality is that climate change is happening, and it too creates risks; balancing those risks is essential to effective policy strategies. There are currently no large public research programs on climate intervention and only a few private sector efforts aimed at advancing particular technologies. Public sector research programs are essential to ensuring transparency and an adequate coverage and level of research support.

CDR and AM cannot substitute for deep cuts in emissions or the need for adaptation, but it is possible that they could contribute to a comprehensive risk-management strategy aimed at reducing the harms of climate change. The potential for climate intervention to help society cope with climate change and the risks of adverse consequences implies a need for adequate research, comprehensive ongoing review, appropriate regulation of outdoor research, and transparent deliberation.

---

<sup>i</sup> 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](http://sciencepolicy.agu.org/files/2013/07/AGU-Climate-Change-Position-Statement_August-2013.pdf)

- 
- ii United Nations, Conference of the Parties to the United Nations Framework Convention on Climate Change, 2015: *Paris Agreement* [https://unfccc.int/files/meetings/paris\\_nov\\_2015/application/pdf/paris\\_agreement\\_english.pdf](https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english.pdf)
- iii 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—mitigation (control of emissions), adaptation, and climate intervention—sometimes overlap, and some specific actions are difficult to classify uniquely. To the extent that a climate intervention 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. We avoid using the terms “geoengineering” and “climate engineering” to describe these options, because those terms imply too much control and certainty, and rather use “climate intervention,” as recommended by the National Research Council (footnotes v and xi).
- iv We focus here on the two main classes of actions that are most associated with the concept of climate intervention. A third type of climate intervention 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. We also emphasize CO<sub>2</sub> in this statement because of the long-lived nature of that particular greenhouse gas. While studies are being done on other greenhouse gases, they are still too preliminary to examine fully.
- v 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, P., et al., 2016: Biophysical and economic limits to negative CO<sub>2</sub> emissions (*Nature Climate Change*, 6, 42–50) doi:10.1038/nclimate2870
- Wilcox, J., et al., 2017: Assessment of reasonable opportunities for direct air capture (*Environmental Research Letters*, 12(6), 065001)
- vi In future, similar approaches might be developed for other greenhouse gases. However, direct air removal is likely to be most useful for gases that have higher concentrations in the atmosphere (and are thus easier to remove) and longer lifetimes (and are thus more valuable to remove from the air when compared with cutting emissions). CO<sub>2</sub> fits those criteria well.
- vii National Research Council, 2015: *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration* (Washington, DC: The National Academies Press) <https://doi.org/10.17226/18805>
- viii Other methods have been suggested but are currently even more speculative or difficult to scale, such as increasing surface reflectivity or putting refractive materials into space. Similar effects in altering the planet’s energy balance might also be achieved by thinning cirrus clouds in the atmosphere, which could allow more longwave radiation to leave the planet.
- ix 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 AM systems. See Appendix 3 of Solar Radiation Management Governance Initiative (SRMGI), 2011: *Solar radiation management: The governance of research* (SRMGI) <http://www.srmgi.org/files/2016/02/SRMGI.pdf>
- Oschlies, A., and G. Klepper, 2017: Research for assessment, not deployment of climate engineering: The German Research Foundation’s Priority Program SPP 1689 (*Earth’s Future*, 5, 128–134)
- x 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, The Royal Society) [https://royalsociety.org/~media/Royal\\_Society\\_Content/policy/publications/2009/8693.pdf](https://royalsociety.org/~media/Royal_Society_Content/policy/publications/2009/8693.pdf)
- xi National Research Council, 2015: *Climate Intervention: Reflecting Sunlight to Cool Earth* (Washington, DC: The National Academies Press) <https://doi.org/10.17226/18988>
- xii Oldham, P., B. Szerszynski, J. Stilgoe, C. Brown, B. Eacott, and A. Yuille, 2014: Mapping the landscape of climate engineering (*Philosophical Transactions of the Royal Society A*, 372, 20140065) doi:10.1098/rsta.2014.0065
- xiii Fleming, J., 2011: Iowa enters the space age: James Van Allen, Earth’s radiation belts, and experiments to disrupt them (*Annals of Iowa*, 70, 301–324) [https://www.academia.edu/6999031/Iowa\\_Enters\\_the\\_Space\\_Age\\_James\\_Van\\_Allen\\_Earth’s\\_Radiation\\_Belts\\_and\\_Experiments\\_to\\_Disrupt\\_Them](https://www.academia.edu/6999031/Iowa_Enters_the_Space_Age_James_Van_Allen_Earth’s_Radiation_Belts_and_Experiments_to_Disrupt_Them)