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## The Geoengineering Option

### A Last Resort Against Global Warming?

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Summary: As climate change accelerates, policymakers may have to consider "geoengineering" as an emergency strategy to cool the planet. Engineering the climate strikes most as a bad idea, but it is time to start taking it seriously.

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Each year, the effects of climate change are coming into sharper focus. Barely a month goes by without some fresh bad news: ice sheets and glaciers are melting faster than expected, sea levels are rising more rapidly than ever in recorded history, plants are blooming earlier in the spring, water supplies and habitats are in danger, birds are being forced to find new migratory patterns.

The odds that the global climate will reach a dangerous tipping point are increasing. Over the course of the twenty-first century, key ocean currents, such as the Gulf Stream, could shift radically, and thawing permafrost could release huge amounts of additional greenhouse gases into the atmosphere. Such scenarios, although still remote, would dramatically accelerate and compound the consequences of global warming. Scientists are taking these doomsday scenarios seriously because the steady accumulation of warming gases in the atmosphere is forcing change in the climate system at rates so rapid that the outcomes are extremely difficult to predict.

Eliminating all the risks of climate change is impossible because carbon dioxide emissions, the chief human contribution to global warming, are unlike conventional air pollutants, which stay in the atmosphere for only hours or days. Once carbon dioxide enters the atmosphere, much of it remains for over a hundred years. Emissions from anywhere on the planet contribute to the global problem, and once headed in the wrong direction, the climate system is slow to respond to attempts at reversal. As with a bathtub that has a large faucet and a small drain, the only practical way to lower the level is by dramatically cutting the inflow. Holding global warming steady at its current rate would require a worldwide 60-80 percent cut in emissions, and it would still take decades for the atmospheric concentration of carbon dioxide to stabilize.

Most human emissions of carbon dioxide come from burning fossil fuels, and most governments have been reluctant to force the radical changes necessary to reduce those emissions. Economic growth tends to trump vague and elusive global aspirations. The United States has yet to impose even a cap on its emissions, let alone a reduction. The European Union has adopted an emissions-trading scheme that, although promising in theory, has not yet had much real effect because carbon prices are still too low to cause any significant change in behavior. Even Norway, which in 1991 became one of the first nations to impose a stiff tax on emissions, has seen a net increase in its carbon dioxide emissions. Japan, too, has professed its commitment to taming global warming. Nevertheless, Tokyo is struggling to square the need for economic growth with continued dependence on an energy system powered mainly by conventional fossil fuels. And China's emissions recently surpassed those of the United States, thanks to coal-fueled industrialization and a staggering pace of economic growth. The global economic crisis is stanching emissions a bit, but it will not come close to shutting off the faucet.

The world's slow progress in cutting carbon dioxide emissions and the looming danger that the climate could take a sudden turn for the worse require policymakers to take a closer look at emergency strategies for curbing the effects of

global warming. These strategies, often called "geoengineering," envision deploying systems on a planetary scale, such as launching reflective particles into the atmosphere or positioning sunshades to cool the earth. These strategies could cool the planet, but they would not stop the buildup of carbon dioxide or lessen all its harmful impacts. For this reason, geoengineering has been widely shunned by those committed to reducing emissions.

Serious research on geoengineering is still in its infancy, and it has not received the attention it deserves from politicians. The time has come to take it seriously. Geoengineering could provide a useful defense for the planet -- an emergency shield that could be deployed if surprisingly nasty climatic shifts put vital ecosystems and billions of people at risk. Actually raising the shield, however, would be a political choice. One nation's emergency can be another's opportunity, and it is unlikely that all countries will have similar assessments of how to balance the ills of unchecked climate change with the risk that geoengineering could do more harm than good. Governments should immediately begin to undertake serious research on geoengineering and help create international norms governing its use.

## THE RAINMAKERS

Geoengineering is not a new idea. In 1965, when President Lyndon Johnson received the first-ever U.S. presidential briefing on the dangers of climate change, the only remedy prescribed to counter the effects of global warming was geoengineering. That advice reflected the scientific culture of the time, which imagined that engineering could fix almost any problem.

By the late 1940s, both the United States and the Soviet Union had begun exploring strategies for modifying the weather to gain battlefield advantage. Many schemes focused on "seeding" clouds with substances that would coax them to drop more rain. Despite offering no clear advantage to the military, "weather makers" were routinely employed (rarely with much effect) to squeeze more rain from clouds for thirsty crops. Starting in 1962, U.S. government researchers for Project Stormfury tried to make tropical hurricanes less intense through cloud seeding, but with no clear success. Military experts also dreamed of using nuclear explosions and other interventions to create a more advantageous climate. These applications were frightening enough that in 1976 the United Nations adopted the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques to bar such projects. By the 1970s, after a string of failures, the idea of weather modification for war and farming had largely faded away.

Today's proposals for geoengineering are more likely to have an impact because the interventions needed for global-scale geoengineering are much less subtle than those that sought to influence local weather patterns. The earth's climate is largely driven by the fine balance between the light energy with which the sun bathes the earth and the heat that the earth radiates back to space. On average, about 70 percent of the earth's incoming sunlight is absorbed by the atmosphere and the planet's surface; the remainder is reflected back into space. Increasing the reflectivity of the planet (known as the albedo) by about one percentage point could have an effect on the climate system large enough to offset the gross increase in warming that is likely over the next century as a result of a doubling of the amount of carbon dioxide in the atmosphere. Making such tweaks is much more straightforward than causing rain or fog at a particular location in the ways that the weather makers of the late 1940s and 1950s dreamed of doing.

In fact, every few decades, volcanoes validate the theory that it is possible to engineer the climate. When Mount Pinatubo, in the Philippines, erupted in 1991, it ejected plumes of sulfate and other fine particles into the atmosphere, which reflected a bit more sunlight and cooled the planet by about 0.5 degrees Celsius over the course of a year. Larger eruptions, such as the 1883 eruption of Krakatau, in Indonesia, have caused even greater cooling that lasted longer. Unlike efforts to control emissions of greenhouse gases, which will take many years to yield a noticeable effect, volcano-like strategies for cooling the planet would work relatively promptly.

Another lesson from volcanoes is that a geoengineering system would require frequent maintenance, since most particles lofted into the stratosphere would disappear after a year or two. Once a geoengineering project were under way, there would be strong incentives to continue it, since failure to keep the shield in place could allow particularly harmful changes in the earth's climate, such as warming so speedy that ecosystems would collapse because they had no time to adjust. By carefully measuring the climatic effects of the next major volcanic eruption with satellites and aircraft, geoengineers could design a number of climate-cooling technologies.

## ALBEDO ENHANCERS

Today, the term "geoengineering" refers to a variety of strategies designed to cool the climate. Some, for example, would slowly remove carbon dioxide from the atmosphere, either by manipulating the biosphere (such as by fertilizing the ocean with nutrients that would allow plankton to grow faster and thus absorb more carbon) or by directly scrubbing the air with devices that resemble big cooling towers. However, from what is known today, increasing the earth's albedo offers the most promising method for rapidly cooling the planet.

Most schemes that would alter the earth's albedo envision putting reflective particles into the upper atmosphere, much as volcanoes do already. Such schemes offer quick impacts with relatively little effort. For example, just one kilogram of sulfur well placed in the stratosphere would roughly offset the warming effect of several hundred thousand kilograms of carbon dioxide. Other schemes include seeding bright reflective clouds by blowing seawater or other substances into the lower atmosphere. Substantial reductions of global warming are also possible to achieve by converting dark places that absorb lots of sunlight to lighter shades -- for example, by replacing dark forests with more reflective grasslands. (Engineered plants might be designed for the task.) More ambitious projects could include launching a huge cloud of thin refracting discs into a special space orbit that parks the discs between the sun and the earth in order to bend just a bit of sunlight away before it hits the planet.

So far, launching reflective materials into the upper stratosphere seems to be the easiest and most cost-effective option. This could be accomplished by using high-flying aircraft, naval guns, or giant balloons. The appropriate materials could include sulfate aerosols (which would be created by releasing sulfur dioxide gas), aluminum oxide dust, or even self-levitating and self-orienting designer particles engineered to migrate to the Polar Regions and remain in place for long periods. If it can be done, concentrating sunshades over the poles would be a particularly interesting option, since those latitudes appear to be the most sensitive to global warming. Most cost estimates for such geoengineering strategies are preliminary and unreliable. However, there is general agreement that the strategies are cheap; the total expense of the most cost-effective options would amount to perhaps as little as a few billion dollars, just one percent (or less) of the cost of dramatically cutting emissions.

Cooling the planet through geoengineering will not, however, fix all of the problems related to climate change. Offsetting warming by reflecting more sunlight back into space will not stop the rising concentration of carbon dioxide in the atmosphere. Sooner or later, much of that carbon dioxide ends up in the oceans, where it forms carbonic acid. Ocean acidification is a catastrophe for marine ecosystems, for the 100 million people who depend on coral reefs for their livelihoods, and for the many more who depend on them for coastal protection from storms and for biological support of the greater ocean food web. Over the last century, the oceans have become markedly more acidic, and current projections suggest that without a serious effort to control emissions, the concentration of carbon dioxide will be so high by the end of the century that many organisms that make shells will disappear and most coral reef ecosystems will collapse, devastating the marine fishing industry. Recent studies have also suggested that ocean acidification will increase the size and depth of "dead zones," areas of the sea that are so oxygen depleted that larger marine life, such as squid, are unable to breathe properly.

Altering the albedo of the earth would also affect atmospheric circulation, rainfall, and other aspects of the hydrologic cycle. In the six to 18 months following the eruption of Mount Pinatubo, rainfall and river flows dropped, particularly in the tropics. Understanding these dangers better would help convince government leaders in rainfall-sensitive regions, such as parts of China and India (along with North Africa, the Middle East, and the desert regions of the southwestern United States), not to prematurely deploy poorly designed geoengineering schemes that could wreak havoc on agricultural productivity. Indeed, some climate models already suggest that negative outcomes -- decreased precipitation over land (especially in the tropics) and increased precipitation over the oceans -- would accompany a geoengineering scheme that sought to lower average temperatures by raising the planet's albedo. Such changes could increase the risk of major droughts in some regions and have a major impact on agriculture and the supply of fresh water. Complementary policies -- such as investing in better water-management schemes -- may be needed.

The highly uncertain but possibly disastrous side effects of geoengineering interventions are difficult to compare to the dangers of unchecked global climate change. Chances are that if countries begin deploying geoengineering systems, it will be because calamitous climate change is near at hand. Yet the assignment of blame after a geoengineering disaster would be very different from the current debates over who is responsible for climate change, which is the result of centuries of accumulated emissions from activities across the world. By contrast, the side effects of geoengineering projects could be readily pinned on the geoengineers themselves. That is one reason why nations must begin building useful international norms to govern geoengineering in order to assess its dangers and decide when to act in the event of an impending climatic disaster.

#### LONE RANGERS

An effective foreign policy strategy for managing geoengineering is difficult to formulate because the technology involved turns the normal debate over climate change on its head. The best way to reduce the danger of global warming is, of course, to cut emissions of carbon dioxide and other greenhouse gases. But success in that venture will require all the major emitting countries, with their divergent interests, to cooperate for several decades in a sustained effort to develop and deploy completely new energy systems with much lower emissions. Incentives to defect and avoid the high cost of emissions controls will be strong.

By contrast, geoengineering is an option at the disposal of any reasonably advanced nation. A single country could deploy geoengineering systems from its own territory without consulting the rest of the planet. Geoengineers keen to alter their own country's climate might not assess or even care about the dangers their actions could create for climates, ecosystems, and economies elsewhere. A unilateral geoengineering project could impose costs on other countries, such as changes in precipitation patterns and river flows or adverse impacts on agriculture, marine fishing, and tourism. And merely knowing that geoengineering exists as an option may take the pressure off governments to implement the policies needed to cut emissions.

At some point in the near future, it is conceivable that a nation that has not done enough to confront climate change will conclude that global warming has become so harmful to its interests that it should unilaterally engage in geoengineering. Although it is hardly wise to mess with a poorly understood global climate system using instruments whose effects are also unknown, politicians must take geoengineering seriously because it is cheap, easy, and takes only one government with sufficient hubris or desperation to set it in motion. Except in the most dire climatic emergency, universal agreement on the best approach is highly unlikely. Unilateral action would create a crisis of legitimacy that could make it especially difficult to manage geoengineering schemes once they are under way.

Although governments are the most likely actors, some geoengineering options are cheap enough to be deployed by wealthy and capable individuals or corporations. Although it may sound like the stuff of a future James Bond movie, private-sector geoengineers might very well attempt to deploy affordable geoengineering schemes on their own. And even if governments manage to keep freelance geoengineers in check, the private sector could emerge as a potent force by becoming an interest group that pushes for deployment or drives the direction of geoengineering research and assessment. Already, private companies are running experiments on ocean fertilization in the hope of sequestering carbon dioxide and earning credits that they could trade in carbon markets. Private developers of technology for albedo modification could obstruct an open and transparent research environment as they jockey for position in the potentially lucrative market for testing and deploying geoengineering systems. To prevent such scenarios and to establish the rules that should govern the use of geoengineering technology for the good of the entire planet, a cooperative, international research agenda is vital.

#### FROM SCIENCE FICTION TO FACTS

Despite years of speculation and vague talk, peer-reviewed research on geoengineering is remarkably scarce. Nearly the entire community of geoengineering scientists could fit comfortably in a single university seminar room, and the entire scientific literature on the subject could be read during the course of a transatlantic flight. Geoengineering continues to be considered a fringe topic.

Many scientists have been reluctant to raise the issue for fear that it might create a moral hazard: encouraging governments to deploy geoengineering rather than invest in cutting emissions. Indeed, geoengineering ventures will be viewed with particular suspicion if the nations funding geoengineering research are not also investing in dramatically reducing their emissions of carbon dioxide and other greenhouse gases. Many scientists also rightly fear that grants for geoengineering research would be subtracted from the existing funds for urgently needed climate-science research and carbon-abatement technologies. But there is a pressing need for a better understanding of geoengineering, rooted in theoretical studies and empirical field measurements. The subject also requires the talents of engineers, few of whom have joined the small group of scientists studying these techniques.

The scientific academies in the leading industrialized and emerging countries -- which often control the purse strings for major research grants -- must orchestrate a serious and transparent international research effort funded by their governments. Although some work is already under way, a more comprehensive understanding of geoengineering options and of risk-assessment procedures would make countries less trigger-happy and more inclined to consider deploying geoengineering systems in concert rather than on their own. (The International Council for Science, which has a long and successful history of coordinating scientific assessments of technical topics, could also lend a helping hand.) Eventually, a dedicated international entity overseen by the leading academies, provided with a large budget, and suffused with the norms of transparency and peer review will be necessary.

In time, international institutions such as the Intergovernmental Panel on Climate Change could be expected to synthesize the findings from the published research. The IPCC, which shared the Nobel Peace Prize in 2007 for its pivotal role in building a consensus around climate science, has not considered geoengineering so far because the topic is politically radioactive and there is a dearth of peer-reviewed research on it. The IPCC's fifth assessment report on climate change, which is being planned right now, should promise to take a closer look at geoengineering. Attention from the IPCC and the world's major scientific academies would help encourage new research.

A broad and solid foundation of research would help on three fronts. First, it would transform the discussion about

geoengineering from an abstract debate into one focused on real risk assessment. Second, a research program that was backed by the world's top scientific academies could secure funding and political cover for essential but controversial experiments. (Field trials of engineered aerosols, for example, could spark protests comparable to those that accompanied trials of genetically modified crops.) Such experiments will be seen as more acceptable if they are designed and overseen by the world's leading scientists and evaluated in a fully transparent fashion. Third, and what is crucial, a better understanding of the dangers of geoengineering would help nations craft the norms that should govern the testing and possible deployment of newly developed technologies. Scientists could be influential in creating these norms, just as nuclear scientists framed the options on nuclear testing and influenced pivotal governments during the Cold War.

If countries were actually to contemplate the deployment of geoengineering technologies, there would inevitably be questions raised about what triggers would compel the use of these systems. Today, nobody knows which climatic triggers are most important for geoengineering because research on the harmful effects of climate change has not been coupled tightly enough with research on whether and how geoengineering might offset those effects.

Although the international scientific community should take the lead in developing a research agenda, social scientists, international lawyers, and foreign policy experts will also have to play a role. Eventually, there will have to be international laws to ensure that globally credible and legitimate rules govern the deployment of geoengineering systems. But effective legal norms cannot be imperiously declared. They must be carefully developed by informed consensus in order to avoid encouraging the rogue forms of geoengineering they are intended to prevent.

Those who worry that such research will cause governments to abandon their efforts to control emissions, including much of the environmental community, are prone to seek a categorical prohibition against geoengineering. But a taboo would interfere with much-needed scientific research on an option that might be better for humanity and the world's ecosystems than allowing unchecked climate change or reckless unilateral geoengineering. Formal prohibition is unlikely to stop determined rogues, but a smart and scientifically sanctioned research program could gather data essential to understanding the risks of geoengineering strategies and to establishing responsible criteria for their testing and deployment.

#### BRAVE NEW WORLD

Fiddling with the climate to fix the climate strikes most people as a shockingly bad idea. Many worry that research on geoengineering will make governments less willing to regulate emissions. It is more likely, however, that serious study will reveal the many dangerous side effects of geoengineering, exposing it as a true option of last resort. But because the option exists, and might be used, it would be dangerous for scientists and policymakers to ignore it. Assessing and managing the risks of geoengineering may not require radically different approaches from those used for other seemingly risky endeavors, such as genetic engineering (research on which was paused in the 1970s as scientists worked out useful regulatory systems), the construction and use of high-energy particle accelerators (which a few physicists suggest could create black holes that might swallow the earth), and the development of nanotechnology (which some worry could unleash self-replicating nanomachines that could reduce the world to "gray goo"). The option of eliminating risk altogether does not exist. Countries have kept smallpox samples on hand, along with samples of many other diseases, such as the Ebola and Marburg viruses, despite the danger of their inadvertent release. All of these are potentially dangerous endeavors that governments, with scientific support, have been able to manage for the greater good.

Humans have already engaged in a dangerous geophysical experiment by pumping massive amounts of carbon dioxide and other greenhouse gases into the atmosphere. The best and safest strategy for reversing climate change is to halt this buildup of greenhouse gases, but this solution will take time, and it involves myriad practical and political difficulties. Meanwhile, the dangers are mounting. In a few decades, the option of geoengineering could look less ugly for some countries than unchecked changes in the climate. Nor is it impossible that later in the century the planet will experience a climatic disaster that puts ecosystems and human prosperity at risk. It is time to take geoengineering out of the closet -- to better control the risk of unilateral action and also to know the costs and consequences of its use so that the nations of the world can collectively decide whether to raise the shield if they think the planet needs it.

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