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## 20 reasons why geoengineering may be a bad idea

Carbon dioxide emissions are rising so fast that some scientists are seriously considering putting Earth on life support as a last resort. But is this cure worse than the disease?

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BY ALAN ROBOCK

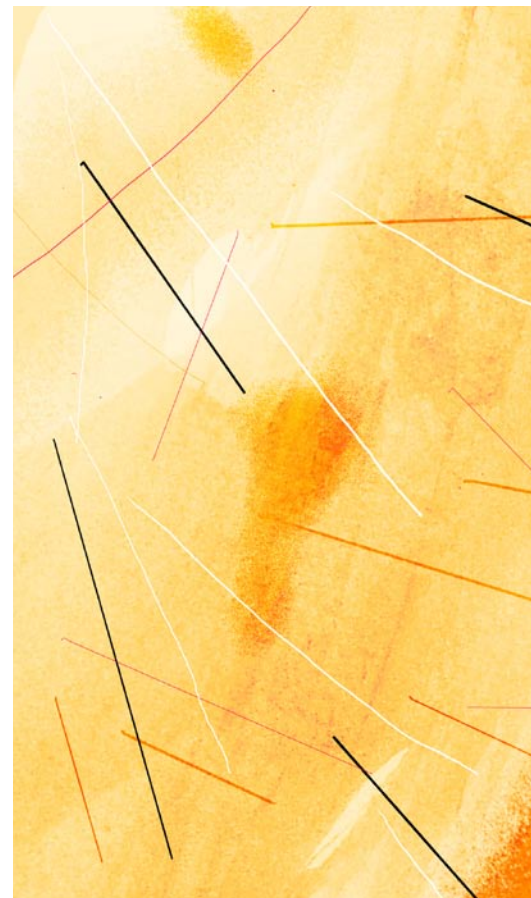
**T**HE STATED OBJECTIVE OF THE 1992 U.N. Framework Convention on Climate Change is to stabilize greenhouse gas concentrations in the atmosphere “at a level that would prevent dangerous anthropogenic interference with the climate system.” Though the framework convention did not define “dangerous,” that level is now generally considered to be about 450 parts per million (ppm) of carbon dioxide in the atmosphere; the current concentration is about 385 ppm, up from 280 ppm before the Industrial Revolution.

In light of society’s failure to act concertedly to deal with global warming in spite of the framework convention agreement, two prominent atmospheric scientists recently suggested that humans consider geoengineering—in this case, deliberate modification of the climate to achieve specific effects such as cooling—to address global warming. Nobel laureate Paul Crutzen, who is well regarded for his work on ozone damage and nuclear winter, spearheaded a special August 2006 issue of *Climatic Change* with a controversial editorial about injecting sulfate

aerosols into the stratosphere as a means to block sunlight and cool Earth. Another respected climate scientist, Tom Wigley, followed up with a feasibility study in *Science* that advocated the same approach in combination with emissions reduction.<sup>1</sup>

The idea of geoengineering traces its genesis to military strategy during the early years of the Cold War, when scientists in the United States and the Soviet Union devoted considerable funds and research efforts to controlling the weather. Some early geoengineering theories involved damming the Strait of Gibraltar and the Bering Strait as a way to *warm* the Arctic, making Siberia more habitable.<sup>2</sup> Since scientists became aware of rising concentrations of atmospheric carbon dioxide, however, some have proposed artificially altering climate and weather patterns to reverse or mask the effects of global warming.

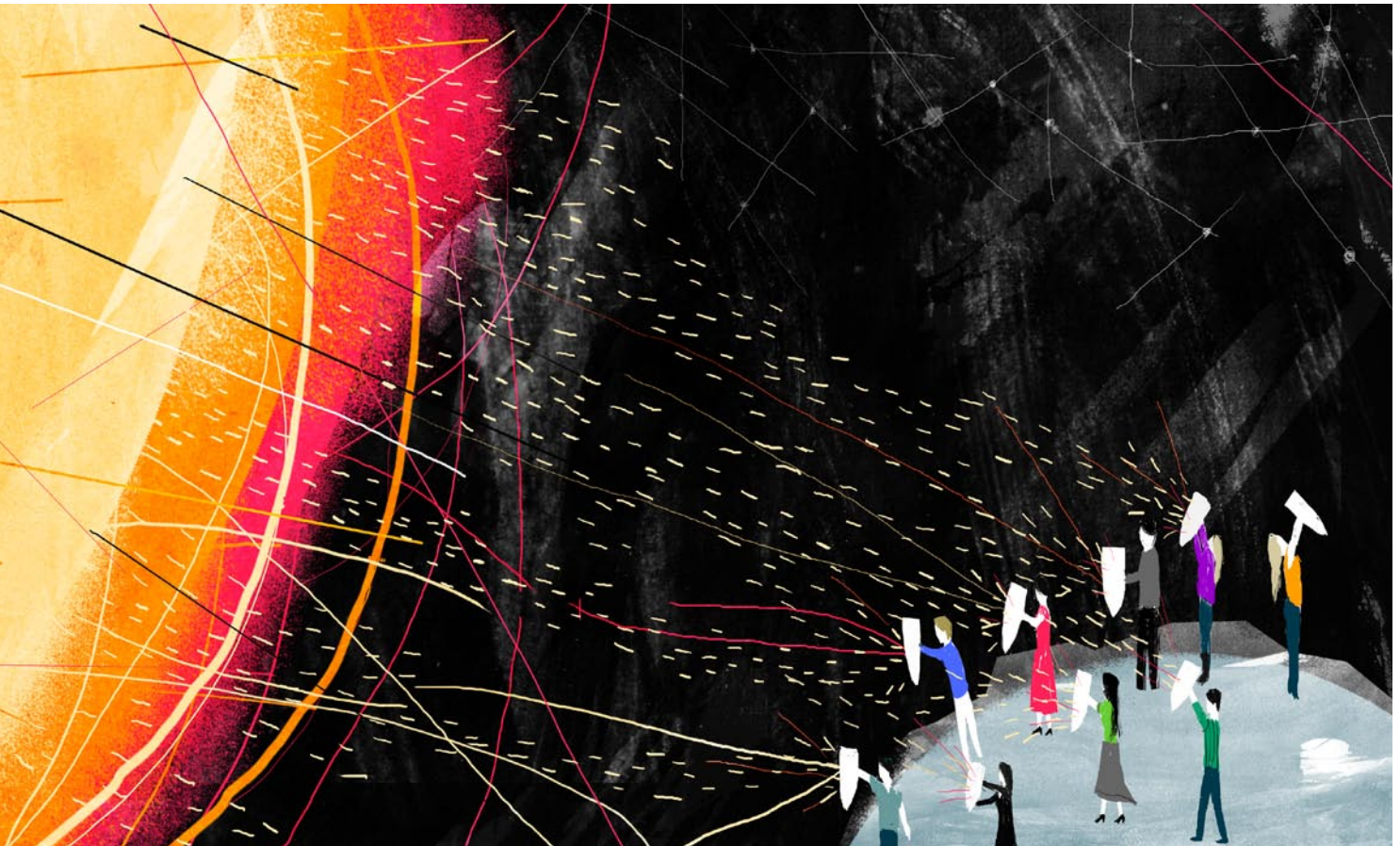
Some geoengineering schemes aim to remove carbon dioxide from the atmosphere, through natural or mechanical means. Ocean fertilization, where iron dust is dumped into the open ocean to



trigger algal blooms; genetic modification of crops to increase biotic carbon uptake; carbon capture and storage techniques such as those proposed to outfit coal plants; and planting forests are such examples. Other schemes involve blocking or reflecting incoming solar radiation, for example by spraying seawater hundreds of meters into the air to seed the formation of stratocumulus clouds over the subtropical ocean.<sup>3</sup>

Two strategies to reduce incoming solar radiation—stratospheric aerosol injection as proposed by Crutzen and space-based sun shields (i.e., mirrors or shades placed in orbit between the sun and Earth)—are among the most widely discussed geoengineering schemes in scientific circles. While these schemes (if they could be built) would cool Earth, they might also have adverse consequences. Several papers in the August 2006 *Climatic Change* discussed some of these issues, but here I present a fairly comprehensive list of reasons why geoengineering might be a bad idea, first written down during a two-day NASA-

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sponsored conference on Managing Solar Radiation (a rather audacious title) in November 2006.<sup>4</sup> These concerns address unknowns in climate system response; effects on human quality of life; and the political, ethical, and moral issues raised.

**1. Effects on regional climate.** Geoengineering proponents often suggest that volcanic eruptions are an innocuous natural analog for stratospheric injection of sulfate aerosols. The 1991 eruption of Mount Pinatubo on the Philippine island of Luzon, which injected 20 megatons of sulfur dioxide gas into the stratosphere, produced a sulfate aerosol cloud that is said to have caused global cooling for a couple of years without adverse effects. However, researchers at the National Center for Atmospheric Research showed in 2007 that the Pinatubo eruption caused large hydrological responses, including reduced precipitation, soil moisture, and river flow in many regions.<sup>5</sup> Simulations of the climate response to volcanic eruptions have also

shown large impacts on regional climate, but whether these are good analogs for the geoengineering response requires further investigation.

Scientists have also seen volcanic eruptions in the tropics produce changes in atmospheric circulation, causing winter warming over continents in the Northern Hemisphere, as well as eruptions at high latitudes weaken the Asian and African monsoons, causing reduced precipitation.<sup>6</sup> In fact, the eight-month-long eruption of the Laki fissure in Iceland in 1783–1784 contributed to famine in Africa, India, and Japan.

If scientists and engineers were able to inject smaller amounts of stratospheric aerosols than result from volcanic eruptions, how would they affect summer wind and precipitation patterns? Could attempts to geoengineer isolated regions (say, the Arctic) be confined there? Scientists need to investigate these scenarios. At the fall 2007 American Geophysical Union meeting, researchers presented preliminary findings from several different climate models that simulated

geoengineering schemes and found that they reduced precipitation over wide regions, condemning hundreds of millions of people to drought.

**2. Continued ocean acidification.** If humans adopted geoengineering as a solution to global warming, with no restriction on continued carbon emissions, the ocean would continue to become more acidic, because about half of all excess carbon dioxide in the atmosphere is removed by ocean uptake. The ocean is already 30 percent more acidic than it was before the Industrial Revolution, and continued acidification threatens the entire oceanic biological chain, from coral reefs right up to humans.<sup>7</sup>

**3. Ozone depletion.** Aerosol particles in the stratosphere serve as surfaces for chemical reactions that destroy ozone in the same way that water and nitric acid aerosols in polar stratospheric clouds produce the seasonal Antarctic ozone hole.<sup>8</sup> For the next four decades or so, when the concentration of anthropogenic ozone-depleting substances will still be large enough in the stratosphere

## CAPITALIZING ON CARBON

**W**ithout market incentives, geoengineering schemes to reflect solar heat are still largely confined to creative thought and artists' renderings. But a few ambitious entrepreneurs have begun to experiment with privatizing climate mitigation through carbon sequestration. Here are a few companies in the market to offset your carbon footprint:

California-based technology startups Planktos and Climos are perhaps the most prominent groups offering to sell carbon offsets in exchange for performing ocean iron fertilization, which induces blooms of carbon-eating phytoplankton. Funding for Planktos dried up in early 2008 as scientists grew increasingly skeptical about the technique, but Climos has managed to press on, securing \$3.5 million in funding from Braemar Energy Ventures as of February.

Also in the research and development phase is Sydney, Australia-based Ocean Nourishment Corporation, which similarly aims to induce oceanic photosynthesis, only it fertilizes with nitrogen-rich urea instead of iron. Atmocean, based in Santa Fe, New Mexico, takes a slightly different tack: It's developed a 200-meter deep, wave-powered pump that brings colder, more biota-rich water up to the surface where lifeforms such as tiny, tube-like salps sequester carbon as they feed on algae.

Related in mission if not in name, stationary carbon-capture technologies, which generally aren't considered geoengineering, are nonetheless equally inventive: Skyonic, a Texas-based startup, captures carbon dioxide at power plants (a relatively well-proven technology) and mixes it with sodium hydroxide to render high-grade baking soda. A pilot version of the system is operating at the Brown Stream Electric Station in Fairfield, Texas. To the west in Tucson, Arizona, Global Research Technologies, the only company in the world dedicated to carbon capture from ambient air, recently demonstrated a working "air extraction" prototype—a kind of carbon dioxide vacuum that stands upright and is about the size of a phone booth. Meanwhile, GreenFuel Technologies Corporation, in collaboration with Arizona Public Service Company, is recycling carbon dioxide emissions from power plants by using it to grow biofuel stock in the form of—what else?—algae.

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to produce this effect, additional aerosols from geoengineering would destroy even more ozone and increase damaging ultraviolet flux to Earth's surface.

**4. Effects on plants.** Sunlight scatters as it passes through stratospheric aerosols, reducing direct solar radiation and increasing diffuse radiation, with important biological consequences. Some studies, including one that measured this effect in trees following the Mount Pinatubo eruption, suggest that diffuse radiation allows plant canopies to photosynthesize more efficiently, thus increasing their capacity as a carbon sink.<sup>9</sup> At the same time, inserting aerosols or reflective disks into the atmosphere would reduce the total sunlight to reach Earth's surface. Scientists need to assess the impacts on crops and natural vegetation of reductions in total, diffuse, and direct solar radiation.

**5. More acid deposition.** If sulfate is injected regularly into the stratosphere, no matter where on Earth, acid deposition will increase as the material passes through the troposphere—the atmospheric layer closest to Earth's surface. In 1977, Russian climatologist Mikhail Budyko calculated that the additional acidity caused by sulfate injections would be negligibly greater than levels that resulted from air pollution.<sup>10</sup> But the relevant quantity is the *total* amount of acid that reaches the ground, including both wet (acid rain, snow, and fog) and dry deposition (acidic gases and particles). Any additional acid deposition would harm the ecosystem, and it will be important to understand the consequences of exceeding different biological thresholds. Furthermore, more acidic particles in the troposphere would affect public health. The effect may not be large compared to the

impact of pollution in urban areas, but in pristine areas it could be significant.

**6. Effects of cirrus clouds.** As aerosol particles injected into the stratosphere fall to Earth, they may seed cirrus cloud formations in the troposphere.<sup>11</sup> Cirrus clouds affect Earth's radiative balance of incoming and outgoing heat, although the amplitude and even direction of the effects are not well understood. While evidence exists that some volcanic aerosols form cirrus clouds, the global effect has not been quantified.<sup>12</sup>

**7. Whitening of the sky (but nice sunsets).** Atmospheric aerosols close to the size of the wavelength of light produce a white, cloudy appearance to the sky. They also contribute to colorful sunsets, similar to those that occur after volcanic eruptions. The red and yellow sky in *The Scream* by Edvard Munch was inspired by the brilliant sunsets he witnessed over Oslo in 1883, following the eruption of Krakatau in Indonesia.<sup>13</sup> Both the disappearance of blue skies and the appearance of red sunsets could have strong psychological impacts on humanity.

**8. Less sun for solar power.** Scientists estimate that as little as a 1.8 percent reduction in incoming solar radiation would compensate for a doubling of atmospheric carbon dioxide. Even this small reduction would significantly affect the radiation available for solar power systems—one of the prime alternate methods of generating clean energy—as the response of different solar power systems to total available sunlight is not linear. This is especially true for some of the most efficiently designed systems that reflect or focus direct solar radiation on one location for direct heating.<sup>14</sup> Following the Mount Pinatubo eruption and the 1982 eruption of El Chichón in Mexico, scientists observed a direct solar radiation decrease of 25–35 percent.<sup>15</sup>

**9. Environmental impacts of implementation.** Any system that could inject aerosols into the stratosphere, i.e., commercial jetliners with sulfur mixed into their fuel, 16-inch naval rifles firing 1-ton shells of dust vertically into the air, or hoses suspended from stratospheric balloons, would cause enormous environmental damage. The same could be said for systems that would deploy sun

shields. University of Arizona astronomer Roger P. Angel has proposed putting a fleet of 2-foot-wide reflective disks in a stable orbit between Earth and the sun that would bend sunlight away from Earth.<sup>16</sup> But to get the needed *trillions* of disks into space, engineers would need 20 electromagnetic launchers to fire missiles with stacks of 800,000 disks every five minutes for twenty years. What would be the atmospheric effects of the resulting sound and gravity waves? Who would want to live nearby?

**10. Rapid warming if deployment stops.** A technological, societal, or political crisis could halt a project of stratospheric aerosol injection in mid-deployment. Such an abrupt shift would result in rapid climate warming, which would produce much more stress on society and ecosystems than gradual global warming.<sup>17</sup>

**11. There's no going back.** We don't know how quickly scientists and engineers could shut down a geoengineering system—or stem its effects—in the event of excessive climate cooling from large volcanic eruptions or other causes. Once we put aerosols into the atmosphere, we cannot remove them.

**12. Human error.** Complex mechanical systems never work perfectly. Humans can make mistakes in the design, manufacturing, and operation of such systems. (Think of Chernobyl, the *Exxon Valdez*, airplane crashes, and friendly fire on the battlefield.) Should we stake the future of Earth on a much more complicated arrangement than these, built by the lowest bidder?

**13. Undermining emissions mitigation.** If humans perceive an easy technological fix to global warming that allows for “business as usual,” gathering the national (particularly in the United States and China) and international will to change consumption patterns and energy infrastructure will be even more difficult.<sup>18</sup> This is the oldest and most persistent argument against geoengineering.

**14. Cost.** Advocates casually claim that it would not be too expensive to implement geoengineering solutions, but there have been no definitive cost studies, and estimates of large-scale government projects are almost always too low.

(Boston's “Big Dig” to reroute an interstate highway under the coastal city, one of humankind's greatest engineering feats, is only one example that was years overdue and billions over budget.) Angel estimates that his scheme to launch reflective disks into orbit would cost “a few trillion dollars.” British economist Nicholas Stern's calculation of the cost of climate change as a percentage of global GDP (roughly \$9 trillion) is in the same ballpark; Angel's estimate is also orders of magnitude greater than current global investment in renewable energy technology. Wouldn't it be a safer and wiser investment for society to instead put that money in solar power, wind power, energy efficiency, and carbon sequestration?

**15. Commercial control of technology.** Who would end up controlling geoengineering systems? Governments? Private companies holding patents on proprietary technology? And whose benefit would they have at heart? These systems could pose issues analogous to those raised by pharmaceutical companies and energy conglomerates whose products ostensibly serve the public, but who often value shareholder profits over the public good.

**16. Military use of the technology.** The United States has a long history of trying to modify weather for military purposes, including inducing rain during the Vietnam War to swamp North Vietnamese supply lines and disrupt antiwar protests by Buddhist monks.<sup>19</sup> Eighty-five countries, including the United States, have signed the U.N. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD), but could techniques developed to control global climate forever be limited to peaceful uses?

**17. Conflicts with current treaties.** The terms of ENMOD explicitly prohibit “military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage, or injury to any other State Party.” Any geoengineering scheme that adversely affects regional climate, for example, producing warming or drought, would therefore violate ENMOD.

**18. Control of the thermostat.** Even if scientists could predict the behavior

and environmental effects of a given geoengineering project, and political leaders could muster the public support and funding to implement it, how would the world agree on the optimal climate? What if Russia wants it a couple of degrees warmer, and India a couple of degrees cooler? Should global climate be reset to preindustrial temperature or kept constant at today's reading? Would it be possible to tailor the climate of each region of the planet independently without affecting the others? If we proceed with geoengineering, will we provoke future climate wars?

**19. Questions of moral authority.** Ongoing global warming is the result of inadvertent climate modification. Humans emit carbon dioxide and other greenhouse gases to heat and cool their homes; to grow, transport, and cook their food; to run their factories; and to travel—not intentionally, but as a by-product of fossil fuel combustion. But now that humans are aware of their effect on climate, do they have a moral right to continue emitting greenhouse gases? Similarly, since scientists know that stratospheric aerosol injection, for example, might impact the ecosphere, do humans have a right to plow ahead regardless? There's no global agency to require an environmental impact statement for geoengineering. So, how should humans judge how much climate control they may try?

**20. Unexpected consequences.** Scientists cannot possibly account for all of the complex climate interactions or predict all of the impacts of geoengineering. Climate models are improving, but scientists are discovering that climate is changing more rapidly than they predicted, for example, the surprising and unprecedented extent to which Arctic sea ice melted during the summer of 2007. Scientists may never have enough confidence that their theories will predict how well geoengineering systems can work. With so much at stake, there is reason to worry about what we don't know.

THE REASONS WHY GEOENGINEERING may be a bad idea are manifold, though a moderate investment in *theoretical*

## AN ETHICAL ASSESSMENT OF GEOENGINEERING

**W**hile there are many questions about the feasibility, cost, and effectiveness of geoengineering plans, my colleague Alan Robock has been the most systematic and persistent of a number of scientists in raising ethical quandaries about the enterprise. But just how serious are these ethical quandaries?

Most science poses risks of unintended consequences, and lots of science raises issues of commercial and military control. At issue here is whether there is any reason to believe *ex ante* that these are special or unusually large risks. Merely asserting them does not ground an objection *per se*.

Not all of Robock's concerns involve ethics, but of those that do, some involve issues of procedural justice (such as who decides) while others involve matters of distributive justice (such as uneven benefit and harm). To simplify things, let's assume that injecting aerosols into the stratosphere successfully cooled Earth without any untoward effects and with evenly distributed benefits. One might still object that there are issues of procedural justice involved—who decides and who controls. But such concerns don't get much traction when everyone benefits.

Let's pull back from this idealization to imagine an outcome that involves untoward consequences and an uneven distribution of benefits. We deal with consequences by balancing them against the benefits of our interventions. The issue is whether or not we can obtain reliable estimates of both risks and benefits without full-scale implementation of the planned intervention. We already know from modeling that the impact of any such intervention will be uneven, but again, without knowing what the distribution of benefit and harm would be, it's hard to estimate how much this matters. Let's differentiate two circumstances under which going ahead with the intervention might be judged: One is where everyone benefits, while the other is a circumstance in which something less is the case. A conservative conclusion would be to say that beyond modeling and controlled, low-level tests (if the modeling justifies it), we shouldn't sanction any large-scale interventions unless they are in everyone's interest. A slightly eased condition, proposed by the philosopher Dale Jamieson, would be that at least nobody is worse off. That may not be as farfetched a condition as one might think, since, in the end, we are considering this intervention as a means to balance a risk we all face—global warming.

But suppose there are isolated livelihoods that only suffer negative effects of geoengineering. Then numbers begin to matter. In the case that a geoengineering scheme were to harm the few, we should have the foresight to be able to compensate, even if doing so requires something as drastic as relocating populations. I don't mean to oversimplify a complicated issue, but objection to any negative consequences whatsoever isn't a strong enough argument to end discussion.

More trenchant is the worry that the mere possibility of geoengineering would undermine other efforts to decrease our carbon output. Such moral hazard is a familiar worry, and we don't let it stop us in other areas: Antilock braking systems and airbags may cause some to drive more recklessly, but few would let that argument outweigh the overwhelming benefits of such safety features.

As Robock correctly asserts, the crux of addressing global warming may be a political—not a scientific—problem, but it doesn't follow that we may not need geoengineering to solve it. If it is a political problem, it is a *global* political problem, and getting global agreement to curb greenhouse gases is easier said than done.

With geoengineering, in principle, one nation or agent could act, but a challenge arises if the intervention is certain to have uneven impacts among nations. At this early stage, there is no cost associated with improving our ability to quantify and describe what those inequalities would look like. Once we have those answers in hand, then we can engage in serious ethical consideration over whether or not to act.

MARTIN BUNZL

*Martin Bunzl is a professor of philosophy at Rutgers University.*

geoengineering research might help scientists to determine whether or not it is a bad idea. Still, it's a slippery slope: I wouldn't advocate actual small-scale stratospheric experiments unless comprehensive climate modeling results could first show that we could avoid at least all of the potential consequences we *know* about. Due to the inherent natural variability of the climate system, this task is not trivial. After that there are still the unknowns, such as the long-term effects of short-term experiments—stratospheric aerosols have an atmospheric lifetime of a couple years.

Solving global warming is not a difficult technical problem. As Stephen Pacala and Robert Socolow detail with their popular wedge model, a combination of several specific actions can stabilize the world's greenhouse gas emissions—although I disagree with their proposal to use nuclear power as one of their “wedges.”<sup>20</sup> Instead, the crux of addressing global warming is political. The U.S. government gives multibillion-dollar subsidies to the coal, oil, gas, and nuclear industries, and gives little support to alternative energy sources like solar and wind power that could contribute to a solution. Similarly, the federal government is squashing attempts by states to mandate emissions reductions. If global warming is a political problem more than it is a technical problem, it follows that we don't need geoengineering to solve it.

The U.N. Framework Convention on Climate Change defines “dangerous anthropogenic interference” as *inadvertent* climate effects. However, states must also carefully consider geoengineering in their pledge to prevent dangerous anthropogenic interference with the climate system. ■

FOR NOTES, PLEASE SEE P. 59.

*Alan Robock is director of the meteorology undergraduate program and associate director of the Center for Environmental Prediction in the Department of Environmental Sciences at Rutgers University. This work is supported by the National Science Foundation.*

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a geoengineering research agenda.**

## 20 reasons why geoengineering may be a bad idea

CONTINUED FROM P. 18

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## Climate change and security

CONTINUED FROM P. 24

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