Buffering the Sun

David Keith and the question of climate engineering

by Erin O'Donnell

David Keith talks fast and takes stairs two steps at a time, as though impelled by a sense of urgency. The Harvard scholar is interested in both the scientific and the public policy questions that bear on climate change and has a hand in a surprising range of projects related to climate and energy. He co-manages the Fund for Innovative Energy and Climate Research (FICER), established by Microsoft founder Bill Gates '77, LL.D. '07, to support innovative climate-change research, and has founded Carbon Engineering, a company that appears on track to build the first industrial-scale plant to capture carbon dioxide from the air for possible commercial use. But Keith is best known for his work on solar geoengineering: strategies to counter rising global temperatures by reducing the amount of sunlight that reaches Earth and its atmosphere. Such work might someday save the planet.

As skeptics continue to question whether global warming is real, and worldwide efforts to cut greenhouse gases stall, a small but growing number of scientists believe that humans may need to consider a "Plan B" that takes control of our climate's future. Solar geoengineering encompasses multiple proposals to adjust the planet's thermostat, including deflecting sunlight away from the earth with massive space shields or with extra-bright low-altitude clouds over oceans. One suggestion, inspired by sulfur-spewing volcanoes, involves modifying a fleet of jets to spray sulfates into the stratosphere, where they would combine with water vapor to form aerosols. Dispersed by winds, these particles would cover the globe with a haze that would reflect roughly 1 percent of solar radiation away from Earth. (The 1991 eruption of Mount Pinatubo, which shot some 10 million metric tons of sulfur into the air, reduced global temperatures about 1 degree F for at least a year.)

David Keith

Scientists have discussed such strategies for decades, but (until recently) mostly behind closed doors, in part because they feared that speaking publicly about geoengineering would undermine efforts to cut greenhouse-gas emissions. Keith, who is McKay professor of applied physics in the School of Engineering and Applied Sciences (SEAS) and professor of public policy at Harvard Kennedy School, strongly advocates bringing discussion of geoengineering into the open. He says, "We don't make good decisions by sweeping things under the rug."

And even as he endeavors to publicize the geoengineering debate, Keith has also sought to move the science itself beyond computer models, toward the possibility of small-scale field-testing. "It is by no means clear what the right answer is, or how much, if any, geoengineering we should use," he says, "but the balance of evidence from the climate models used to date suggests that doing a little bit would reduce climate risks."

Photograph by Eliza Grinnell

Constructing Consensus

By keith's account, the topic of solar geoengineering has transitioned in the last five years from an obscure area, studied by only a handful of what he calls "geonerds," to a subject that draws increasing attention from both scientists and the general public. That lends Keith's own publicizing efforts some of their urgency; he not only sees a need to "broaden the scientific community to avoid the risk of groupthink," but also wants to help shape the conversation about these strategies and chart the course of related research.

He and fellow FICER administrator Ken Caldeira (of the Carnegie Institution for Science's department of global ecology, at Stanford), have used the fund for projects that assess the risks of a warming planet and the benefits and risks of advanced technologies to address the problem. They've also used a small portion of the money to jumpstart the development of new technologies to deal with climate change. Not only are good solutions to the problem currently lacking, Keith says, but there is nothing approaching "a social consensus that it's worth making serious efforts to solve the problem."

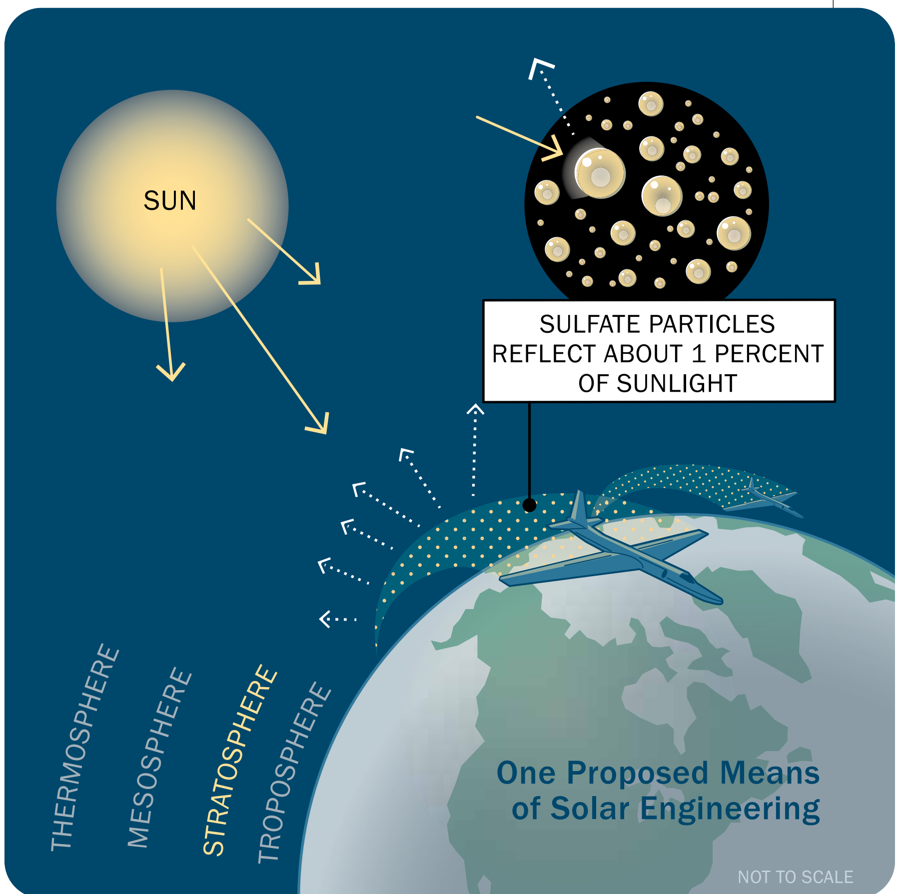
Meanwhile, the world's nations emitted an estimated 38.2 billion tons of carbon dioxide—the principal greenhouse gas, by volume—into the air in 2011, an increase of 3 percent over the previous year. This rate is expected to accelerate as developing nations such as China and India burn more coal and expand their vehicle fleets. In May, scientists reported that the average daily level of CO_2 in the atmosphere surpassed 400 parts per million, a level last seen two to four million years ago. Even if humans miraculously halted *all* carbon emissions next week—an impossibility, and an economic catastrophe—the problem of climate change would still loom ahead: most of the heat-trapping gas will linger for decades or centuries. One study found that 40 percent of the peak concentration of CO_2 would remain in the atmosphere for a thousand years after the peak is reached—and even then, inertia in the world's warmed oceans will prevent a quick return to cooler temperatures.

"We have already committed ourselves to a certain level of warming in the future, whatever we do about our emissions," says Andy Parker, a fellow in the science, technology, and policy program at the Kennedy School's Belfer Center. The most optimistic predictions for the rest of the century, cited by the Intergovernmental Panel on Climate Change in its 2007 assessment report, forecast a rise of 2.0 to 5.2 degrees by 2100, while the direst anticipate a rise of 4.3 to 11.5 degrees. Among the anticipated effects are rising sea levels, increasingly severe storms and droughts, and melting glaciers and permafrost.

Given these projected long-term consequences of global warming, certain geoengineering strategies that seem to offer relatively quick-acting countermeasures could become especially attractive.

In 1992, Keith and his mentor Hadi Dowlatabadi, a physicist and applied mathematician, both then at Carnegie Mellon, wrote one of the first papers assessing geoengineering strategies. Today, the term is often used to refer both to removing CO_2 from the air (for re-use or for storage in reservoirs such as the deep ocean—see "Capturing Carbon," page 26), and to limiting the amount of sunlight that reaches the earth in the first place (where it can be trapped in the atmosphere by greenhouse gases and contribute to warming).

Although these two strategies could work together to ease global warming, they have different costs and risks, and Keith argues against lumping them together. "We will have a better chance to craft sensible policy if we treat them separately," he told a congressional committee in 2010. The massive scale of the CO_2 problem means that carbon removal "will always be relatively slow and expensive," he added. It carries some local risks, but has no chance of harming the entire planet. Solar geoengineering, in contrast, could work quickly—and at surprisingly low cost. (By recent estimates, spreading sulfur in the atmosphere to reduce global temperatures could cost a few billion dollars annually, a fraction of the projected cost of reducing greenhouse gas emissions. One 2006 review by the British government estimated that cutting emissions by 25 percent by 2050 would cost about 1 percent of annual global GDP, or about $1 trillion in 2050.) Keith argues that costs for solar geoengineering are so low that "cost will not be a decisive issue." Instead, he says, scientists and policymakers will have to weigh risks: "the risk of doing it against the risk of not doing it."



Keith speaks candidly about the risks and uncertainties of solar geoengineering, acknowledging a range of possible outcomes. "The balance of evidence so far suggests that solar geoengineering could reduce climate risks, but early science might be wrong," he says. "We need experiments, which might show that it does not work."

Graphic by Funnel, Inc.

Additionally, some research suggests that sulfate aerosols may further damage the ozone layer, an issue that he says needs further study.

Alan Robock, professor of environmental sciences at Rutgers, is one critic who has raised other concerns, theorizing that sunlight-blocking strategies could not only reduce the amount of electricity produced through solar power but also alter weather patterns, which might trigger widespread droughts. Keith does not find these possibilities convincing. He believes solar energy would be affected only in "extreme scenarios" with very heavy use of solar geoengineering, and he says he has not seen serious analysis that supports the possibility of drought. Studies have found that crop yields could increase in some regions, because plants grow more efficiently in diffuse light, and excess CO_2 from the atmosphere could have a fertilizing effect. Yet one critical issue remains: solar geoengineering doesn't address the underlying danger of CO_2 emissions, which would continue to build up and create further problems, such as acidification of the oceans, which harms coral reefs and other marine life.

Above all, the techniques currently proposed would have to be applied gradually, to limit drastic climate changes. That presents knotty governance challenges—requiring diverse nations (and political groups within those nations) to agree on a joint course of action, something they have been largely unable to do when negotiating treaties to address greenhouse-gas emissions. "With solar geoengineering, at some level you've got just one knob," Keith says. "That demands collective global decisionmaking."

And yet solar geoengineering's relatively low cost raises the possibility that a single nation, or perhaps a group of island nations threatened by rising seas, could act unilaterally to initiate it. "One small group of people can have a lot of influence over the entire planet," Keith says. But he does not view this as an inexorable threat. "If some crazy group decides they're going to start flying airplanes and putting sulfur in unilaterally," he says, "it's not that hard to stop." Still, he's concerned. "I think the underlying brute reality"—that solar geoengineering "does seem to provide a significant way to reduce climate risk at very low cost—is going to be very powerful," Keith says, "and I think it's going to be hard to stop people from rushing to do it. I'm not eager to see things go faster."

In light of these caveats, Keith laments that some journalists and scholars depict him as a "techno-optimist" cheerleader for these technologies. The reality, he says, is that he's hopeful about technical innovation, "but deeply pessimistic about human be-

Governing Geoengineering Research

David Keith, McKay professor of applied physics in the School of Engineering and Applied Sciences (SEAS) and professor of public policy at the Harvard Kennedy School, is eager to establish governance structures so that small-scale field studies of geoengineering technology can move forward. He also acknowledges the need for some government oversight, in part to limit rogue projects by individuals or countries acting unilaterally.

But the field is too young to expect a treaty that provides governance. "It's not something that they're going to spend an hour on at the next G8 meeting," Keith says. In an article published in the journal *Science* last spring, he and coauthor Edward Parson of the UCLA School of Law suggest starting with an informal document, written by the main research bodies of the United States, Europe, and China, that would outline guiding principles for geoengineering studies, including ways to manage risk and promote transparency. "A document like that can have a lot of power," Keith says, "and you could do that next year if you wanted to."

Cox professor of law Jody Freeman, director of the Law School's environmental law and policy program, says it

Capturing Carbon

David Keith founded a company, Carbon Engineering, in 2009, while he held the Canada Research Chair in energy and the environment at the University of Calgary, to capture carbon and use it to develop low-carbon fuels, among other projects. (He launched it with $3.5 million from a group of angel investors that included Bill Gates.) The pilot plant, which he expects to be operational by next summer, should capture a modest 1,000 tons of carbon per year, roughly the amount generated by the activities of 50 average Americans in 12 months. Eventually the company expects to sell the CO_2 it captures for applications such as enhanced oil recovery (oil companies would use the gas to force oil out of the ground) and the production of algae-based biofuels. A commercial-scale plant built with this technology might capture up to 100,000 tons of CO_2 a year, but Keith stresses that his is a small company with a new technology. "Anyone who knows anything about carbon and energy knows that there isn't any one magic bullet," he says. "We're not trying to solve the world's climate problems."

He is careful to separate his efforts on behalf of his company from his academic work. Not only does he see carbon capture and solar geoengineering as technologies with very different risks and costs, he's also conscious of critics who have suggested that he aims to profit from his aerosol-reflector research. In fact, he has lobbied in Washington to outlaw patents on sun-blocking technologies. Because such global-scale climate solutions can have a dramatic effect on the planet, Keith says, "I think this is a bit like nuclear weapons, and there should be no for-profit work."

A rendering of Keith's proposed modular carbon-capture plant; he says such plants will not solve the carbon emissions problem.

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would also be important to address such questions in the United States. "We simply don't have a domestic legal infrastructure to regulate these kinds of experiments," she says. "None of our current laws really address it." Who would oversee the research and decide what's permissible? If there are risks to this research, who would be liable for the risks? These questions and more need to be considered carefully, Freeman says, but her sense is that the public is largely unaware of geoengineering, and other than a small elite group, most policymakers lack knowledge about it.

Freeman, who served in the White House Office of Energy and Climate Change from 2009 to 2010, says the Obama administration is focused on the pressing issues of greenhouse-gas mitigation and adaptation to global warming, so geoengineering "has not been at the top of the policy agenda." She continues, "Sometimes geoengineering pops up [in Washington], but it just hasn't broken through because it sounds so contingent and risky and unknown, and I think politicians are a little wary of it." Although she's noticed increased attention to the topic of geoengineering, "it's really not part of the mainstream dialogue yet, but it might be before long."

The dialogue may broaden through efforts undertaken through the Solar Radiation Management Governance Initiative (SRMGI), an NGO-driven project to encourage good governance of solar geoengineering, convened by the Royal Society, the Environmental Defense Fund, and the Third World Academy of Sciences, the academy of science for the developing world. One way to ensure responsible decisions around geoengineering is to engage more countries in the conversation, including developing nations, says Andy Parker, a research fellow in the science, technology, and policy program at Harvard Kennedy School's Belfer Center, who has been involved in multiple SRMGI efforts.

Parker helped organize a series of meetings about solar geoengineering in Senegal and South Africa in 2012, and Ethiopia in 2013. Held jointly with the African Academy of Sciences, the meetings were designed to introduce academics, NGO staff, policymakers, and the public to existing scientific and governance questions related to geoengineering, and to encourage critical discussion of these technologies. "It's extremely important to have a high degree of international cooperation over this research and its governance," Parker says. "I think this [initiative] gives us a chance of handling this issue responsibly as it develops and becomes more controversial or pressing."

SRMGI held similar meetings in India, Pakistan, and China in 2011. Its website (www.srmgi.org) states that the organization does not advocate for or against solar geoengineering because "it is impossible to tell at this stage whether the technology will be helpful or harmful."

havior when it comes to protecting the natural world. It's convenient for critics to pigeonhole me as a booster and cite some skeptical social scientist on the risks," he says, but he and fellow researchers in the field "have usually been the first to voice concerns about risk and governance challenges."

Difficult Conversations

In 2007, Keith, then at the University of Calgary, and Daniel Schrag—professor of environmental science and engineering, and director of the Harvard Center for the Environment—invited a group of environmental scientists and policymakers to Cambridge for a daylong workshop on geoengineering. The meeting was held off-campus and closed to the public.

Keith and Schrag also invited three science journalists, who were permitted to write about the discussion, but couldn't quote participants without their consent. Keith believes this is a useful way to run early meetings on new and controversial topics. "People need time to figure out what their opinion is, and to say things that they're not sure about," he explains. "If everything's public, you don't have the freedom to say 'Maybe it's a nutty idea, but maybe we should do X, or maybe we should do Y.' For a thing like this, if it's all out in public, you shut people down, and they're not free to engage in a give-and-take."

Although this wasn't the first major meeting about geoengineering, it was among the first to include social scientists and policymakers. "There was an excitement about confronting all these mind-blowing issues," remembers professor of economics Martin Weitzman, an attendee who believes the meeting changed some minds. He recalls a range of opinions: participants who believed geoengineering technologies should be used as a first line of defense against global warming, others who felt strongly that scientists shouldn't even discuss such strategies, and most people "arrayed between those extremes." Weitzman says the meeting crystallized his sense that initial research should proceed to prepare for emergencies, such as unilateral action by a rogue nation. He calls geoengineering "a scary proposition," but adds, "It's better to be informed than to be…caught unaware."

Keith himself was particularly struck by a point made at that 2007 conference by Eliot University Professor Lawrence Summers, who warned against withholding information about global-warming solutions, or prejudging how the public might react to these ideas. "I don't think scientists by virtue of being scientists have deeper political insight or more moral weight," Keith says. "The idea that we as a scientific class should decide what the rest of society is able to handle is really obscene, and I think that Larry was very clear about that."

But even as Keith considers public participation essential to a geoengineering conversation, he recognizes the need for public education beforehand. That brings the issue of small-scale field-testing into play. Experimentation is necessary to determine whether an aerosol solution is even viable. He's currently working with Weld professor of atmospheric chemistry James Anderson to develop a test that would send a helium balloon bearing small quantities of sulfur and water into the stratosphere, to monitor how they affect ozone; previous research has shown that sulfur and water vapor react with atmospheric chlorine, changing it to a form that damages ozone. The experiment would likely use just a couple of kilograms of sulfate particles and would have no effect on the climate, Keith says. Its impact "will likely be much less than a single commercial airline flight."

But the study may be a long time coming, in part because such research is so controversial. Some *(please turn to page 75)*

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critics say field tests should be banned because they are the first step down a slippery slope toward full-scale solar geoengineering. Keith emphasizes that he and Anderson will not move forward without public assent: "We will not do [our study] unless we have some formal governmental approval and public funding."

Indeed, he hopes that the study, beyond its scientific aims, will also help establish a structure to govern similar small-scale research in the future. This spring, he and Edward Parson of the UCLA School of Law called for government oversight of geoengineering research; they say that self-regulation isn't sufficient to manage the risks. But in place of a treaty, they suggest a nonbinding set of norms issued jointly by scientific bodies in the United States, Europe, and China: "sensible principles about how to manage risk, and about transparency and openness," Keith says (see "Governing Geoengineering Research," page 26). He would also like to see an international moratorium on large-scale deployment. Without broadly accepted governance, Keith says, field research will remain deadlocked. Funding agencies won't support experiments that lack a system of oversight, but such systems won't be created unless scientists are ready to conduct experiments.

Climate-Change Costs

Keith admires a quote on the Albert Einstein Memorial at the National Academy of Sciences in Washington, D.C.: "The right to search for truth implies also a duty; one must not conceal any part of what one has recognized to be true."

As a leader in his field, Keith's conclusions have at times run counter to accepted wisdom. For example, many scientists who investigate and think about solar geoengineering stress that the emphasis on cutting global greenhouse gas emissions must not change, even if research reveals that geoengineering strategies are worth pursuing.

Keith disagrees. He points out that many policymakers and scholars weigh climate-change solutions in terms of risks and costs, comparing, for example, the cost of climate damages to the cost of cutting emissions. "The money we spend cutting emissions will save money in climate damages," Keith says, and he believes we should spend much more on current emissions-slashing efforts. But he points out, "If you reduce the risk even a little bit with solar geoengineering, then in a perfect world you should be able to put a little less money into cutting emissions," thereby alleviating some of the daunting trillions in costs anticipated for future greenhouse-gas mitigation efforts.

Some researchers say they hope solar geoengineering technologies are never deployed, but Keith objects to this automatic discomfort about manipulating the planet. He hopes to foster a more nuanced debate. "I think there are lots of things that are scary about this prospect, but I just don't see how finding a potentially life-saving technology that helps to reduce climate risk a lot is awful," he says. "I just don't see that."

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