Sun blocker. Serious geoengineering research is long past due, says physicist David Keith.

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CLIMATE CHANGE

Dr. Cool

David Keith has helped usher geoengineering into the mainstream. Actually testing a way to cool the planet is his next big challenge

David Keith was a 26-year-old graduate student in experimental physics when he first heard of geoengineering, the concept of intentionally tinkering with Earth's climate system in order to counteract global warming. It was 1989, and some of his colleagues at the Massachusetts Institute of Technology (MIT) in Cambridge considered the idea distasteful, Keith recalls. Discussing possible experiments was "a de facto taboo" in the field.

That didn't deter Keith, who saw the dearth of interest as a professional opportunity. Three years later, he published his first paper on the topic. Geoengineering needed a "systematic research program," Keith and a co-author concluded after analyzing the few existing studies of possible approaches, including sucking carbon dioxide out of the atmosphere with machines and releasing particles into the sky to block sunlight. Such exotic technologies, they argued, had the "potential to mitigate catastrophic climate change."

Few others, however, paid much attention. And for the next 15 years, discussions of geoengineering drifted between the fringe of academic research and science fiction. Still, as Keith built a career as a specialist on energy and climate issues, he periodically published papers suggesting that scientists needed to take geoengineering seriously.

In the past 5 years, they have. As carbon dioxide continues to build up in the atmosphere, the U.S. National Academies, the United Kingdom's Royal Society, and the American Geophysical Union have all issued calls to explore expanding research into technological fixes. The number of scientists publishing on geoengineering is growing, as are citations of their work by influential groups, such as the Intergovernmental Panel on Climate Change (IPCC).

Keith has ridden geoengineering's shift from the fringe toward the mainstream—and has helped catalyze it. In addition to publishing influential academic papers, the Canadian scientist has become geoengineering's public face, delivering sold-out lectures and vivid quotes to the media. He's also become something of a power broker, advising one of the world's richest men on climate issues and doling out some $6 million of Bill Gates's money to convene meetings and spur new research. And 2 years ago, Keith gained a high-profile perch for promoting his views, moving from the University of Calgary in Canada to Harvard University.

Now, Keith wants to bring geoengineering out of the ivory tower and into the stratosphere. He and a partner at Harvard are proposing one of the world's first geoengineering field experiments, using a high-altitude balloon to release sun-blocking vapors into the atmosphere. And this month, Keith is releasing a book, *A Case for Climate Engineering*, in which he argues that "the potential upsides of geoengineering" demand greater research. Such studies "may show that these technologies will not work," he writes. "Yet the sooner we find this out the better."

It's an audacious agenda for a scientist colleagues describe as equal parts thoughtful, unorthodox, and headstrong. And he faces a myriad of obstacles, including a lack of organized government support and fierce opposition from critics—one of whom calls Keith's sun-blocking ideas "barking mad." He's even gotten death threats.

Further complicating matters is Keith's ownership stake in a company that is pursuing a different flavor of geoengineering—sucking carbon dioxide out of the air. That has raised questions about financial conflicts. And some wonder whether Keith has the diplomatic savvy to win over opponents. "David does not suffer fools gladly," says David Layzell, Keith's former boss at the University of Calgary. "Everybody respects him—or is a little terrified of him."

A polymath

Keith grew up in Ottawa, where his father and stepmother, both wildlife biologists, taught him how to stuff birds, enjoy the outdoors, and work with his hands. After earning a physics degree at the University of Toronto, Keith headed to MIT, where "he was an incredible hot shot," recalls Harvard's William Clark, an early mentor.

But Keith was troubled by the military applications of his physics research and instead drifted toward the burgeoning field of climate and energy research. After he earned

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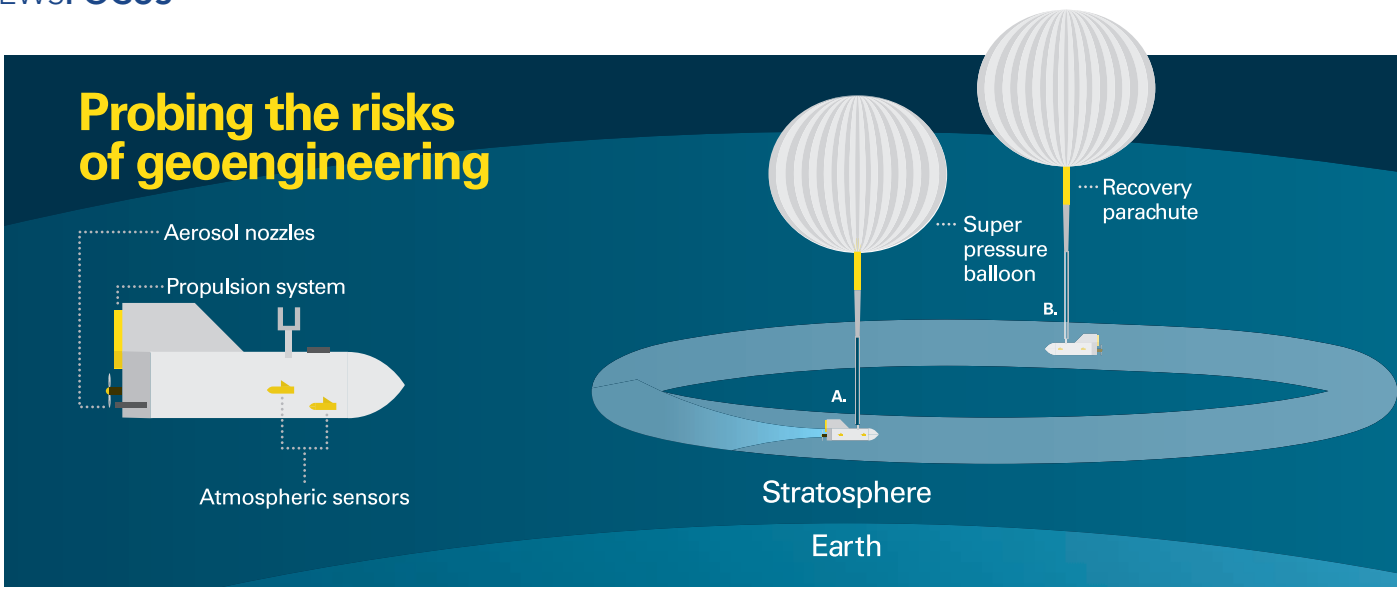

Aiming high. A proposed experiment would use a balloon to release sulfuric acid vapor (A) and then measure its effect on ozone chemistry in successive passes (B).

his doctorate in 1991, his eclectic interests led to an array of jobs over the next decade: policy analysis at Carnegie Mellon University in Pittsburgh, Pennsylvania; climate modeling at the National Center for Atmospheric Research in Boulder, Colorado; building atmospheric instruments at Harvard; and even a stint in environmental ethics at the University of Montana in Missoula. "A lot of rock climbing, too," Keith says.

Along the way, he published a number of provocative papers, including a 2001 *Science* publication that questioned the potential of wind power to replace fossil fuels, and analyses of hydrogen fuel, natural gas, and the then-controversial concept of carbon capture and storage (CCS): capturing carbon dioxide from industrial smokestacks and pumping it underground.

Geoengineering continued to fascinate him, Keith says, because it provided a new look at humanity's relationship with nature, which he valued personally as an outdoorsman. Geoengineering "encourages us to rethink some of our root assumptions about the means and ends of climate policy," he writes in his book.

By 2004, when the University of Calgary recruited Keith from Carnegie Mellon, he was considered a go-to voice on geoengineering, and he began building bridges with business. In 2007, he joined with four top executives in Alberta's powerful energy industry to write a report touting the potential of CCS to curb carbon emissions. It drew darts from environmentalists, but led to a pledge to invest $3 billion in CCS technology by the Alberta and Canadian governments, which had requested the study. "I've had a deputy minister stop me and say it was amazing what David did on that report," Layzell says.

Keith's persuasiveness came with a confidence that could be alienating, however. "David is usually right, and he has a high degree of confidence that he's right," says geochemist Ken Caldeira of the Carnegie Institution for Science in Palo Alto, California. And that can be "off-putting to some people," says Jane Long, an energy scientist at the University of California, Berkeley, who nonetheless commends Keith's "strong ability to get people to see his point of view, while seeing multiple conflicting points of view."

In Calgary, Keith's willingness to speak his mind sometimes complicated his relationships with industry. A few firms refused to partner with the university after Keith challenged Alberta's efforts to mine its oil sands, for instance. But Keith was becoming an entrepreneur himself, launching Carbon Engineering, a startup aiming to build machines to remove carbon dioxide from the atmosphere, in 2009. One of its investors is Microsoft cofounder Bill Gates, for whom Keith has served as an informal energy adviser since 2006.

The amount of Gates's investment in the company is undisclosed, but the mogul has also provided roughly $6 million to the informal Fund for Innovative Climate and Energy Research, managed by Keith and Caldeira. Since 2007, the fund has supported more than a dozen research projects, most on geoengineering. It also helps fund a weeklong summer school on the topic, now in its fifth year, which brings together physical and social scientists. The networking opportunity "shows David's great value" as a scientist and organizer, says Benjamin Kravitz, a climate modeler at Pacific Northwest National Laboratory in Richland, Washington, whose work is supported by the fund.

Keith's 2011 move to Harvard, where he holds appointments in the schools of engineering and government, has brought him close to science and policy heavyweights—and students who go on to become powerful policymakers around the world. It's also an opportunity to team with some of the nation's top atmospheric scientists, and ramp up efforts on one of Keith's priorities, developing rules for governing geoengineering research. And Cambridge offers a bully pulpit for injecting the topic into international discussions. Or, as Keith put it in a 2007 TED talk: "We need a broader debate … not just a few oddballs like me."

A low-dose supplement

Keith hopes to jump-start that debate with *A Case for Climate Engineering*. In 112 pages of authoritative prose, he largely eschews figures and technical terms in a bid to reach a lay audience. He begins by casting the climate challenge in stark terms: Past emissions have already committed Earth to substantial warming, he warns; even aggressive emissions cuts—if they ever materialize—can only partly reduce climate risks. But geoengineering techniques could relatively quickly "cut the average rate of global warming in half for the next half-century," he argues.

In particular, Keith focuses on one technique: releasing sulfuric acid vapor high in the stratosphere, where it would scatter sunlight away from Earth's surface. The approach mimics the global cooling effect of large volcanic eruptions, which spew sulfates into the stratosphere. But Keith envisions a "slow ramp scenario," gradually adding sulfur over decades to counteract about one-half the yearly climate change caused by humans. That would allow "ample time" to alter or halt the procedure if there are surprises, he

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notes. And the method could be relatively cheap: A 2010 study he arranged suggested that the cost of starting the plan with aircraft would be, incredibly, a few hundred million dollars—"the price of a Hollywood blockbuster," Keith writes.

Keith highlights the risks. The particles could catalyze chemical destruction of the protective ozone layer, or—at high doses—rob the climate system of crucial energy required to drive precipitation. And even discussing the idea might undermine efforts to transition away from fossil fuels, he concedes, or even prompt international tensions. But some modeling studies, he writes, suggest sun-blocking methods could reduce the harm caused by warming, including heat stress on crops "in the hottest and poorest parts of the world."

Still, many are skeptical. Last month, the IPCC warned that solar geoengineering could "modify the global water cycle," although it didn't specify how much sulfur it might take to cause concern. Other critics are more direct: Efforts to manipulate climate with light-scattering particles are "barking mad," says climate modeler Raymond Pierrehumbert of the University of Chicago in Illinois. One problem, he says, is sun-blocking may do little to reduce overall peak global temperature increases under many scenarios. And it could even lead to a relatively sudden global temperature spike, he warns, if the effort is interrupted by a war or calamity.

To clarify and quantify such risks, Keith says researchers need to move beyond theoretical debate to actual field experiments. First up, he argues, should be "process studies" that would be too small to have any appreciable impact on climate—studies like the one he and chemist James Anderson of Harvard have now proposed (see graphic, p. 308). The idea is to use a balloon release less than a kilogram of sulfuric acid vapor about 20 kilometers above Earth's surface during the fall or spring, when the stratosphere is very still. Chemical sensors aboard the balloon would then measure possible effects on stratospheric ozone. The craft would also repeat the experiment with water vapor, fingered recently by Anderson as a possibly underestimated threat to ozone.

A hazy outlook

Gates, among other tycoons, could fund such an experiment. But Keith is adamant that governments should lead on solar geoengineering research. International oversight agreements and government funding can make "the development of solar geoengineering technologies … as public and transparent as possible," he writes. Government leadership could also prevent potential conflicts of interest, he argues, by preventing companies from winning monopolies on new technologies and keeping them in the public domain. Keith and Anderson say they will ask the U.S. government to fund their experiment.

So far, however, U.S. agencies have held back from funding geoengineering research, and prospects overseas are dim as well. In 2010, the 197 nations that are members of the Convention on Biological Diversity adopted a resolution that asks governments to oppose "geo-engineering activities that may affect biodiversity." And one U.K.-funded effort, the Stratospheric Particle Injection for Climate Engineering project, had to cancel a 2011 field experiment after it became mired in controversy. Critics complained that researchers hadn't adequately vetted the test, which involved spreading a small quantity of water vapor from a tethered balloon, or worked out how ownership of any new technology might be handled.

Geoengineering Milestones

1908	Swedish chemist Svante Arrhenius proposes burning fossil fuels to release CO_2 into the atmosphere to warm the planet.
1965	In a report to President Lyndon Johnson, scientists suggest spreading particles on the sea surface to reflect sunlight to counteract "deleterious" CO_2 levels in the future.
1974	Russian climate modeler Mikhail Budyko proposes burning sulfur in the stratosphere to create a cooling haze.
1991	Mount Pinatubo in the Philippines erupts, creating a global layer of sulfuric acid haze that reduces global temperature by about 0.5°C
2006	Nobelist Paul Crutzen calls cuts in CO_2 emissions "a pious wish," says geoengineering research is required.
2009	The United Kingdom's Royal Society and the American Geophysical Union call for geoengineering research.

A public perch

A publicly funded experiment subject to customary environmental review could avoid such pitfalls, Keith says. But he faces obstacles of his own. One is his stake as president of Carbon Engineering, which some observers say poses a potential conflict of interest because his call for greater investment in geoengineering research could ultimately benefit his own company. Such concerns, in fact, blocked Keith from serving on a current National Research Council panel on geoengineering. "With David straddling this academic-business divide, his company is going to hold him back," Caldeira predicts. "It's impacting his academic career."

Keith sees "a sharp distinction in the role of private enterprise" in the two flavors of geoengineering. Because sun-blocking technologies hold global risks as well as benefits, they are no place for private enterprise, he says. His work in that area involves "open publications and no patenting." In contrast, he argues that firms serve a crucial function in developing air capture methods, which he says pose "local risks" akin to other industry.

Such nuances are often lost in public debate. After one article criticized his proposed experiment, Harvard alumni were "writing to the [university] president … asking why these maniacs are on your faculty," Anderson says. And then there are the two death threats, apparently from people who believe Keith is part of a government conspiracy. One caller last year was "verbally abusive and drunk," says Keith's assistant Hollie Roberts, prompting a report to the police.

Colleagues, however, appreciate Keith's increasingly public role as advocate. "It's important to have good spokespeople on geoengineering, and Keith is an independent and hyperarticulate one," says Caldeira, of Carnegie. "He's a very deep thinker," Long says. "You may not always agree with him, but you have to hear him out."

For his part, Keith says he's learned from his time in the limelight and is taking greater care in what he says and writes. "It gets under my skin when I am made out to be the rank advocate" for geoengineering, he says. "It hurts." So now he's "trying to be more disciplined about weaving caveats in," so that others can't take his words out of context. And his book tempers boldness with humility. "I myself have concluded that it makes sense to move with deliberate haste towards deployment of geoengineering," Keith writes. "You may well reach a different conclusion. My goal is simply to convince you that it's a hard choice."

–ELI KINTISCH