What is geoengineering—and why should you care?

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It's becoming clear that we won't cut carbon emissions soon enough to prevent catastrophic climate change. But there may be ways to cool the planet more quickly and buy us a little more time to shift away from fossil fuels.

They're known collectively as geoengineering, and though it was once a scientific taboo, a growing number of researchers are running computer simulations and proposing small-scale outdoor experiments. Even some legislators have begun discussing what role these technologies could play (see "The growing case for geoengineering").

But what is geoengineering exactly?

Traditionally, geoengineering has encompassed two very different things: sucking carbon dioxide out of the sky so the atmosphere will trap less heat, and reflecting more sunlight away from the planet so less heat is absorbed in the first place.

The first of these, known as "carbon removal" or "negative emissions technologies," is something that scholars now largely agree we'll need to do in order to avoid dangerous levels of warming (see "One man's two-decade quest to suck greenhouse gas out of the

sky"). Most no longer call it "geoengineering"—to avoid associating it with the second, more contentious branch, known as solar geoengineering.

This is a blanket term that includes ideas like setting up sun shields in space or dispersing microscopic particles in the air in various ways to make coastal clouds more reflective, dissipate heat-trapping cirrus clouds, or scatter sunlight in the stratosphere.

The word geoengineering suggests a planetary-scale technology. But some researchers have looked at the possibility of conducting it in localized ways as well, exploring various methods that might protect coral reefs, coastal redwoods, and ice sheets.

Where did the idea come from?

It's not a particularly new idea. In 1965, President Lyndon Johnson's Science Advisory Committee warned it might be necessary to increase the reflectivity of the Earth to offset rising greenhouse-gas emissions. The committee went so far as to suggest sprinkling reflective particles across the oceans. (It's revealing that in this, the first ever presidential report on the threat of climate change, the idea of cutting emissions didn't seem worth mentioning, as author Jeff Goodell notes in *How to Cool the Planet*.)

But the best-known form of solar geoengineering involves spraying particles into the stratosphere, sometimes known as "stratospheric injection" or "stratospheric aerosol scattering." (Sorry, we don't come up with the names.) That's in part because nature has already demonstrated it's possible.

Evan Cohen

Most famously, the massive eruption of Mt. Pinatubo in the summer of 1991 spewed some 20 million tons of sulfur dioxide into the sky. By reflecting sunlight back into space, the particles in the stratosphere helped push global temperatures down about 0.5 °C over the next two years.

And while we don't have precise data, huge volcanic eruptions in the distant past had similar effects. The explosion of Mount Tambora in Indonesia in 1815 was famously followed by the "Year Without a Summer" in 1816, a gloomy period that may have helped inspire the creation of two of literature's most enduring horror creatures, vampires and Frankenstein's monster.

Soviet climatologist Mikhail Budyko is generally credited as the first to suggest we could counteract climate change by mimicking this volcanic phenomenon. He raised the possibility of burning sulfur in the stratosphere in a 1974 book.

In the following decades, the concept occasionally popped up in research papers and at scientific conferences, but it didn't gain much attention until the late summer of 2006, when Paul Crutzen, a Nobel Prize–winning atmospheric chemist, called for geoengineering research in an article in Climatic Change. That was particularly significant because Crutzen had won his Nobel for research on the dangers of the growing ozone hole, and one of the known effects of sulfur dioxide is ozone depletion.

In other words, he thought climate change was such a threat that it was worth exploring a remedy he knew could pose other serious dangers.

So could geoengineering be the solution to climate change, relieving us of the hassle of cutting back on fossil fuels?

No—although the idea that it does is surely why some energy executives and Republican legislators have taken an interest. But even if it works (on which more below), it's at best a temporary stay of execution.

It does little to address other climate dangers, notably including ocean acidification, or the considerable environmental damage from extracting and burning finite fossil fuels. And greater levels of geoengineering may increase other disruptions in the climate system, so we can't just keep doing more and more of it to offset ever rising emissions.

How is geoengineering being researched?

In the years since Crutzen's paper, more researchers have studied geoengineering, mainly using computer simulations or small lab experiments to explore whether it would really work, how it might be done, what sorts of particles could be used, and what environmental side effects it might produce.

The computer modeling consistently shows it would reduce global temperatures, sea-level rise, and certain other climate impacts. But some studies have found that high doses of certain particles might also damage the protective ozone layer, alter global precipitation patterns, and reduce crop growth in certain areas.

Others researchers have found that these risks can be reduced, if not eliminated, by using particles other than sulfur dioxide and by limiting the extent of geoengineering.

But no one would suggest we've arrived at the final answer on most of these questions. Researchers in the field believe we need to do a lot more modeling work to explore these issues in greater detail. And it's also clear that simulations can only tell us so much, which

is why some are proposing small outdoor experiments.

Has anybody conducted real-world geoengineering experiments?

In 2009, Russian scientists conducted what is believed the be the first outdoor geoengineering experiment. They mounted aerosol generators on a helicopter and car and sprayed particles as high as 200 meters (660 feet). The scientists claimed, in a paper published in *Russian Meteorology and Hydrology, that* the experiment had reduced the amount of sunlight that reached the surface. (It's worth noting that Yuri Izrael, a climate skeptic and scientific advisor to Vladimir Putin, was the lead author of the study as well as the editor of the journal.)

One of the first attempts to conduct an experiment that was openly advertised in advance as geoengineering-related, known as the SPICE project, was ultimately scrapped. The idea was to pump particles up a pipe to a high-altitude balloon that would scatter them in the stratosphere. But the proposal prompted a public backlash, particularly after it emerged that some of the researchers had already applied for patents on the technology.

Scientists at Harvard have proposed what could be the next and most formal geoengineering experiment to date. They hope to launch a balloon equipped with propellers and sensors that would spray a tiny amount of calcium carbonate in the stratosphere. The aircraft would then fly through the plume and attempt to measure things like how broadly the particles disperse, how they interact with other gases, and how reflective they are. The team has already raised the funds, put an advisory committee in place, contracted with a balloon company, and begun development work on the necessary hardware. (See "Geoengineering is very controversial. How can you do experiments? Harvard has some ideas.")

Meanwhile, researchers at the University of Washington—in partnership with Xerox's Palo Alto Research Center and other groups—have proposed small-scale experiments as part of a larger research program to learn more about the potential of "marine cloud brightening." The idea, first floated by the British physicist John Latham in 1990, is that spraying tiny salt particles from seawater toward low-lying clouds above the sea could form additional droplets, increasing the surface area—and thus reflectivity—of the clouds. The team is currently raising funds to develop a "cloud-physics research instrument" and test it by spraying a small amount of sea-salt mist somewhere off the US Pacific Coast.

There have also been some early efforts in other areas of geoengineering, including more than a dozen so-called iron-fertilization experiments in the open ocean, according to Nature. The concept there is that dumping iron into the water would stimulate the growth of phytoplankton, which would pull carbon dioxide out of the air. But scientists have

questioned how well it really works, and what sorts of side effects it could have on ocean ecosystems. Environmental groups and others also criticized early efforts in this area, arguing that they went ahead without proper permission or scientific oversight.

Is anybody actually doing geoengineering?

Researchers stress that these experiments aren't actual geoengineering: the amounts of material involved are far too small to alter global temperatures. Indeed, despite a vast and varied array of online conspiracy theories to the contrary, feverishly spread by chemtrails truthers, nobody is conducting planetary-scale geoengineering today.

At least, nobody is on purpose. You could argue that burning massive amounts of fossil fuels is a form of geoengineering, just an inadvertent and very dumb one. And we also know that sulfur pollution from coal plants and ships has likely reduced global temperatures. Indeed, new UN rules requiring ships to emit less sulfur might actually raise temperatures slightly (see "We're about to kill a massive, accidental experiment in reducing global warming").

There's also a long and rich history of efforts in the US and China, among other places, to seed clouds with particles to increase snow or rainfall (see "Weather engineering in China"). But the results are mixed, and local weather modification is a far cry from attempting to twist the knob on the entire climate system.

Isn't geoengineering controversial?

Very.

There are real concerns about conducting, researching, or even discussing geoengineering.

Critics argue that openly talking about the possibility of a technological "solution" to climate change (it's not a solution, as explained above) will ease pressure to address the root cause of the problem: rising greenhouse-gas emissions. And some believe that moving forward with outdoor experiments is a slippery slope. It could create incentives to conduct ever bigger experiments, until we're effectively doing geoengineering without having collectively determined to.

A technology that knows no national bounds also poses complex, if not insurmountable, geopolitical questions. Who should decide, and who should have a say in, whether we proceed with such an effort? How do you settle on a single global average temperature to aim for, since it will affect different nations in very different ways? And if we can't settle on one, or come to a consensus on whether to deploy the technology at all, will some nation or individual do it anyway as climate catastrophes multiply? If so, could that spark conflicts, even wars?

Some argue it's playing God to tinker with a system as complex as the climate. Or that it's simply foolish to counteract one pollutant with another, or to try to fix a technocratic failure with a technocratic solution.

A final concern, and an indisputable one, is that modeling and experiments will only tell us so much. We can't really know how well geoengineering will work and what the consequences will be until we actually try it—and at that point, we're all stuck with the results.

Then why on earth is anyone considering it?

Few serious people would describe themselves as geoengineering advocates.

Scientists who study it profess ambivalence and openly acknowledge it's not the best solution to climate change. But they worry that society is locking in dangerous levels of warming and extreme weather by continuing to build power plants, vehicles, and cities that will pump out greenhouse gases for decades to come. So a growing number of academics say it would be irresponsible not to explore something that could potentially save many, many lives, as well as species and ecosystems—as long as it's used alongside serious efforts to slash emissions.

Yes, it's dangerous, they say—but compared to what? More dangerous than the climate-change-driven famine, flooding, fires, extinctions, and migration that we're already beginning to see? As those effects worsen, the public and politicians may come to think that tinkering with the entire planet's atmosphere is a risk worth taking.