


# Geoengineering

by Chris Woodford. Last updated: September 29, 2017.

Things aren't looking good for the climate. Every day brings a new story of melting glaciers or disappearing species, rising temperatures and a bleak future. It's a good 20 years since world leaders first began to contemplate the thorny issue of global warming and, in that time, they've made precious little headway in solving the problem. There's been some progress, for sure: businesses now talk about carbon trading and well-meaning people buy recycled goods and "offset" their flights—but still humankind seems locked on collision course with a rapidly changing climate. That's why some scientists are talking about the need for more radical action to stop a planetary catastrophe. It's known as geoengineering—and the basic idea is to make compensatory changes to Earth's climate to reverse the damage people have already done. What do they have in mind? Does it have any hope of working? And what if it goes wrong?

*Photo: Can humans put right the damage they've done to the planet? Or will geoengineering cause more problems than it solves. Composite image by Explainthatstuff.com, including a photo of Earth from NASA on the Commons.*

## What is geoengineering?

Most of the world's scientists now agree: climate change is real and happening fast. Over the last century, Earth's surface air temperature has risen by close to 1°C (1.4°F) and the current best-guess prediction is that, by 2100, temperatures will rise by another 1.4–5.8°C (2.5–10.4°F). Earth itself is under no threat from global warming: the planet will continue to exist whatever we do to it. What is in danger is life on Earth—human life and that of millions of other species—which is finely tuned to the climate. The risk is that Earth's climate will be knocked out of balance to such an extent that life, as we know it, becomes impossible to sustain.

Geoengineering (literally "Earth-engineering") is the currently fashionable term for making large-scale interventions in how the planet works to slow down or reverse the effects of climate change. In theory, the word "geoengineering" could be used to describe almost any large-scale scheme for tackling climate change. For example, if millions of people in China all planted a tree on the same day to capture carbon dioxide (CO2) from the atmosphere, that might alter the planet enough to be considered geoengineering. If everyone switched to using recycled paper simultaneously, that could (indirectly) be construed as geoengineering too—since it would drastically reduce the number of trees being felled. And building thousands of new wind farms (or even nuclear power plants) could also be described as geoengineering of a kind.

Generally, though, it's clearer to define geoengineering in a more specific way. In this article, we'll say that geoengineering means any attempt to rebalance Earth's climate through direct, large-scale, human change to the planet's land, oceans, or atmosphere.

Climate change is being caused by the greenhouse effect (a buildup of carbon dioxide and other gases in the atmosphere leading to increased temperatures on Earth, similar to what happens in a greenhouse), so there are broadly two different kinds of geoengineering solution. The first is to try to cool the planet by reducing the amount of incoming solar energy. The second is to remove some of the atmospheric carbon dioxide and lock it away where (we hope) it won't cause problems. Let's consider each of these in turn.

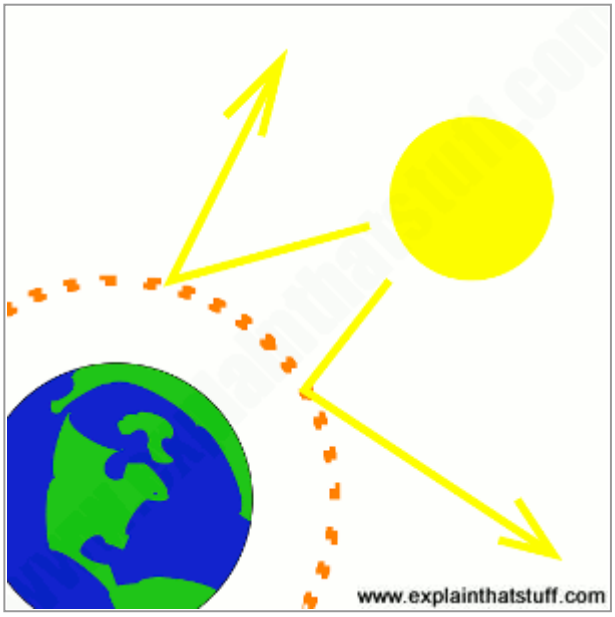
## Reducing solar radiation

We're all familiar with the way the Sun powers our lives: the weather and seasons change the amount of sunlight we receive from day to day and month to month. If Earth's problem is that it's receiving too much solar radiation, could the solution simply be to block out a fraction of the sunlight, just as greenhouse owners do with whitewash and blinds—just as we all do with sunscreens and sunblocks? Various schemes have been proposed for doing this.

### Sulfur suncreens

*Artwork: Could a thin blanket of sulfur dioxide (orange) reflect unwanted solar radiation back into space?*

Spectacular volcanic eruptions (such as those from Mount St Helens in 1980 and Mount Pinatubo in 1991) can significantly reduce how much sunlight reaches Earth. Eruptions reduce incoming solar radiation by firing sulfur dioxide gas into the atmosphere. Once there, it reacts with water vapor to make droplets of sulfuric acid that scatter sunlight back into space like billions of tiny mirrors.



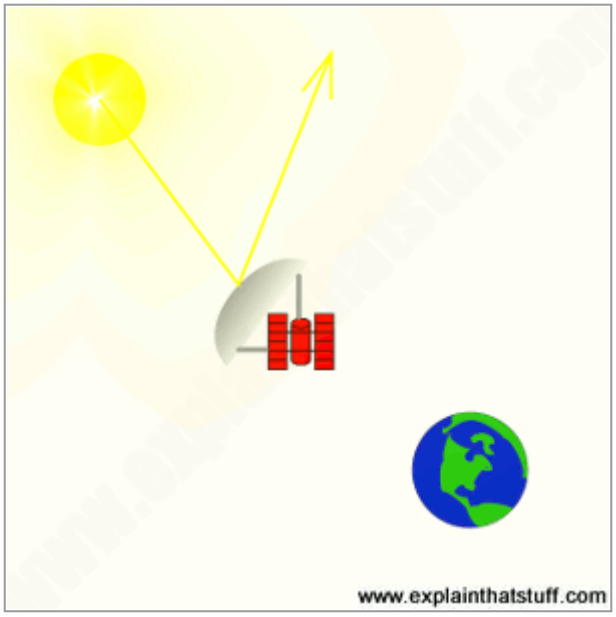

Could people tackle climate change by attempting something similar? We wouldn't need to explode volcanoes—just pump sulfur dioxide high into the atmosphere. One of the first people to propose this was Soviet climatologist Mikhail Budyko. American Earth scientist and oceanographer Wallace Broecker took up the idea in the 1980s when he suggested a fleet of about 700 Jumbo Jets could be hired to release roughly as much sulfur dioxide into the atmosphere each year as the Mount Pinatubo explosion. The sulfur-screen idea was revived once again in 2006 by Nobel-Prize-winning scientist Paul Crutzen.

Would it work? Some have suggested it would be hugely expensive—tens of billions of dollars have been mentioned. Ken Caldeira of the Carnegie Institution Department of Global Ecology at Stanford University, California has crunched the numbers and suggests enough sulfur could be added to the atmosphere "with a single fire hose," suspended from balloons, for a relatively modest outlay of $100 million per year. But he's quick to point out that the cost is less of an issue than the risk of other problems like massive air pollution or destroying the ozone layer—effectively swapping one catastrophic problem for another. For some, those problems could turn out as bad as climate change: in the last few years, some scientists have suggested that the great droughts that plagued Africa in the 1970s and 1980s may have been caused by sulfate pollution produced in Europe and the United States.

## Mirrors in space

Nothing says we have to use sulfur-based chemicals in Earth's atmosphere to reduce the incoming solar radiation. Why not do the same job with some kind of mirror—a giant, metal sun-bloc—further out in space? It's a breathtaking suggestion, but how realistic is it? Considering how taxing space scientists have found it to construct the International Space Station (ISS), you might wonder how they could possibly contemplate an engineering project vastly bigger in scale. And that's no exaggeration. Rough figures mentioned by some geoengineers suggest we'd need a mirror the size of Greenland!

*Artwork: Could a giant, distant mirror bounce precisely the right amount of sunlight away from Earth under remote, computer control?*




Perhaps enough light could be reflected without using a giant mirror? In the late 1990s, atomic scientist Edward Teller and his colleagues proposed fitting a kind of reflective mesh around Earth. More recently, Roger Angel of the University of Arizona has proposed using a trillion or so ultra-thin mirrors, roughly 60cm (2ft) across, to form an artificial space cloud about twice the width of Earth. Launched by some kind of space elevator or projectile system, they'd be held in place by a kind of gravitational tug-of-war between Earth and the Sun. Rough costings suggest the plan would be prohibitively expensive—anything from hundreds of billions to hundreds of trillions of dollars. Then again, how much is climate change going to cost us over the coming centuries, in dollars or human life? No-one knows whether hundreds of trillions of dollars could be a cheap alternative.

## Cloud seeding

Clouds naturally reflect sunlight back into space, so why not simply try to increase Earth's cloud cover? There have been many attempts to engineer the weather with so-called "cloud-seeding" experiments since the 1940s, a few decades after the invention of airplanes made such things feasible. But geoengineering would need cloud-seeding on a far bigger scale than planes could manage.

Stephen Salter and John Latham have proposed launching a huge flotilla of cloudseeders: around 1500 remote-controlled boats that would automatically pipe water up from the oceans and spray it into the atmosphere. Quite what effect this would have, no-one knows. Being Earth-based, a system like this would be relatively easy to set up and control and much cheaper than space mirrors. But how long would the clouds last? And could we cause as much damage in the short-term as we try to offset in the long-term if all those extra clouds bring about sudden disastrous floods or droughts?

## More research?

Many people would consider ideas like this beyond the realms of practicality; at the very least, much more research is clearly needed. A 2015 National Research Council report into the various sunlight blocking ("albedo modification") technologies concluded that they "would not require major technological innovation to be implemented and are relatively inexpensive," but they could not address damage to Earth caused by climate change, such as acidification

of the oceans or desertification, and would need to be "sustained indefinitely." Without emissions reductions, it said any such plans would be "irrational and irresponsible."

## Removing carbon dioxide

If all the carbon dioxide we're adding to the atmosphere is the problem, could the solution simply be to "suck" some of that pesky gas back down to Earth and store it underground or in the very deep ocean where it'll do less damage? A whole other set of geoengineering schemes have been proposed that start from this assumption.

### Carbon capture and storage (CCS)

Those who want us to carry on using fossil fuels have proposed power plants that don't pump carbon dioxide into the air. Instead, they'd have modified smokestacks (chimneys) with built-in "scrubbers," which would trap the waste carbon dioxide gas and turn it into a highly compressed liquid that could be stored safely out of the way. You'll hear this idea referred to as carbon capture and storage (CCS) or sequestration. It sounds good in theory, but it doesn't solve our immediate problem: even if we drastically reduce Earth's carbon dioxide emissions, there's so much CO2 in the atmosphere already that global temperatures are likely to carry on rising for centuries, while sea-level rises could continue for millennia (see this graph from the IPCC—the scientific body that coordinates publication of world climate change research).


*Artwork: Carbon capture and storage plants would stop carbon dioxide entering the atmosphere from burned fuel. If we ran them on low- or zero- carbon biomass, they would effectively work like "emissions vacuums," removing some CO2 from the atmosphere. This technology is called bio-energy with carbon capture and storage (BECCS).*

So what we'd actually need to do is not merely stop further emissions but remove some of the carbon dioxide that's already there. Massive reforestation of Earth would be one option, but it would take time. One scientist, Klaus Lackner of Columbia University, has proposed creating artificial trees that would each capture a ton of carbon dioxide per day in an absorbent resin. The CO2 would then be removed with steam and turned into a liquid, which could either be used industrially or pumped deep underground for indefinite storage.

## Iron-seeding

Like other plants, phytoplankton (tiny plants that float near the ocean surface) absorb carbon dioxide from the atmosphere when they grow. In theory, fertilizing the oceans could massively increase the amount of phytoplankton and significantly reduce carbon dioxide emissions. That idea was originally proposed in 1989 by ocean scientist John Martin of Moss Landing Marine Laboratories. Martin's so-called "iron hypothesis" suggested adding iron to the oceans would stimulate plankton growth and carbon dioxide uptake. When the plankton died, they'd fall to the seabed taking with them the carbon they'd absorbed—effectively removing it from atmospheric circulation. Few studies have actually been carried out, but preliminary results suggest plankton would make much less impact on global warming than Martin supposed. Another problem is that blooms of plankton could massively increase the acidity of the oceans, drastically harming the marine ecosystem.

## Ocean pipes

The highly respected but maverick climate scientist James Lovelock has often turned his attention to geoengineering. Widely credited with helping to alert the world to the issue of climate change, Lovelock argues that current attempts to reduce carbon dioxide emissions are trivial compared to the scale of the cutbacks actually required. He's proposed a number of different geoengineering solutions to climate change including, in 2007, a system of giant vertical pipes that bob up and down in the ocean. Each pipe would be 100-200m (339-660ft) long and would have a valve either at the top or the bottom. As it moved downward, cold water would rush in at the bottom. When it bobbed back up again, the cold water would spill out at the top, so the pipes would work like a pump continuously conveying cold water from the deep ocean to the surface. Since cold water is biologically more productive than warm water, adding more cold water to the ocean surface would stimulate algal growth in a similar way to adding iron—but with the same potential drawback: considerable acidification of the oceans. Apart from this, no-one knows what effect such dramatic intervention would have on the huge ocean currents that play such a key part in the world's weather.

## Biochar

One of the simplest and currently most fashionable geoengineering proposals is based on a practice used by ancient Amazonian Indians. The basic idea is to cook waste agricultural products (plant stems, stalks, and roots) to make charcoal and then simply bury it, taking the carbon it contains out of circulation. James Lovelock has supported the idea in principle and Craig Sams, the founder of Green and Black's chocolate, is also working on the idea. But creating huge biochar plantations could prove even more disruptive than the current rush for biofuels, as British environmentalist George Monbiot has argued: "We would either have to replace all the world's crops with biomass plantations, causing instant global famine, or we

would have to double the cropped area of the planet, trashing most of its remaining natural habitats."

*Photo: The practice of slashing and burning rainforests has added hugely to global warming by destroying a major carbon "sink." Some people think making charcoal (wood burned with reduced oxygen) and then storing it underground will help to reverse the damage. Photo by courtesy of US Fish and Wildlife Service.*

### More research?

The 2015 National Research Council report into carbon dioxide removal and sequestration found present schemes completely unviable: both too puny to make a difference and more expensive than replacing fossil fuels with renewables or other forms of low-carbon energy. Although it supported proven ideas like reforestation and low-till agriculture, it highlighted the high risk and unpredictability of iron-seeding; the large land-take needed for schemes based on storing carbon dioxide as biomass (such as biochar); and the unproven nature of technologies for pulling carbon dioxide directly from the air. Nevertheless, it wisely called for much more research.

## Thinking the unthinkable?

Cost and scientific feasibility are certainly important when we contemplate whether geoengineering schemes are worth pursuing, but there are political, ethical, legal, and other dimensions to the debate as well.

### Unpredictable?

The biggest objection to geoengineering is that its vast effects could be impossible to predict. People already speak of climate change as a kind of giant experiment with the future. But what if we really did start tinkering with the climate? What if we corrected the immediate problem of global warming... but then over-corrected so much that we risked another Ice Age? James Lovelock warns that geoengineering could mean managing Earth's climate forever: "Are we sufficiently talented to take on what might become the onerous permanent task of keeping the Earth in homeostasis?" Permanent really is a long time. Once we started injecting aerosols into the atmosphere, we'd have to continue for hundreds of years to prevent global warming from recurring.

On the other hand, it's clear that some of our initial, tentative attempts at geoengineering have actually been successful. Take the Montreal Protocol, for example: cutting ozone-depleting chemicals seems likely to restore the ozone layer within decades. Everyone agrees

that geoengineering should be a last resort, but the time may well come for last resorts. The question of whether we try geoengineering may have to be reframed: can we afford not to undertake geoengineering if the climate nudges toward a point of no return?

*Photo: If climate change pushes hundreds of millions of people to the brink of survival, could geoengineering become morally unavoidable? Photo by Ernest Scott courtesy of US Navy.*

## Wise use of money?

But even if we could accept geoengineering in principle, the huge investment most of these schemes need is likely to put them well beyond contention, at least for the time being. For just a fraction of the outlay of a space mirror system, we could develop clean renewable energy on Earth. Why not spend the same money solving the energy crisis once and for all rather than trying to mitigate its effects? If we could wean ourselves off fossil fuels entirely in the next few decades, humankind could conceivably live sustainably on Earth for the rest of its history. Isn't that worth a shot first?

## Unethical?

That's certainly how most environmentalists would see the issue. With Earth's wellbeing at the center of their moral compass, they generally find geoengineering unethical and disturbing. They argue that geoengineering makes our wasteful, polluting, resource-depleting ways here on Earth seem perfectly acceptable. Earth's looming climate crisis offers the impetus to clean up our act once and for all. Environmentalists would question the morality of tinkering with the planet's climate when it could have drastic implications on billions of people's lives for decades, centuries, or even millennia. Then again, one could argue that people have been geoengineering the climate since the start of the Industrial Revolution—that was what caused our problems in the first place. Does this mean direct climate engineering should be firmly embraced (because, in a sense we're doing it already) or avoided at all costs (because it got us into the mess to start with)?

## Politically impossible?

Political feasibility is another objection. Earth's 200-plus nations have found it remarkably difficult to agree on even modest cuts to their carbon dioxide emissions, so how could they possibly agree on geoengineering? Different schemes are bound to affect different countries and continents to different extents; cloud-seeding, for example, could lead to benefits in one country at the expense of floods or droughts elsewhere. How could countries hope to agree on schemes so huge and controversial? Could world wars break out over attempts by one or

more countries to impose geoengineering solutions on others? Or could the threat of imminent climate catastrophe finally bring the world together?

### Is there an alternative?

Only one thing seems certain about Earth's future: its absolute uncertainty. We may already have passed the "tipping point"—the point of no return, where Earth's climate becomes progressively hotter until we reach the point where life becomes impossible. Or maybe we do still have time to cut carbon dioxide emissions and revolutionize energy use to make human life truly sustainable. Arguably, we're already geoengineering the climate and we have a duty to reverse the damage we've done. Most scientists agree that we're a long way from needing to fire aerosols into the atmosphere or launch huge space mirrors. But while geoengineering was considered science fiction only a few years ago, it's now being talked about with increasing seriousness. Wallace Broecker calls it an "intelligent insurance policy" for if and when climate crisis heads towards planetary catastrophe. Prudent scientists are beginning to see we may have to start thinking the unthinkable to avoid the unavoidable.



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