Earth 2020

An Insider's Guide to a Rapidly Changing Planet

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Geoengineering

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When people think about responding to climate change, they typically think about reducing emissions of carbon dioxide (CO_2) and other heat-trapping greenhouse gases. Had we started on a path to reducing these emissions at the time of the first Earth Day — when the science was already indicating that our emissions would cause global warming — then climate change might be behind us today. Instead, fifty years later, our collective emissions are higher than they have ever been. Cutting emissions is absolutely essential, but it is no longer sufficient.[1] We must transform our entire global energy infrastructure, not just to reduce our emissions of greenhouse gases, but to eliminate them altogether. That won't happen overnight, and even if we succeed in that challenge over the next few decades (which we must), there will still be substantial global warming. This is our new reality in 2020.

Because CO_2 remains in the atmosphere for a long time, reaching zero emissions won't eliminate climate change, it will just stop making the problem worse.[2] Like a driver careening towards the car in front of us, the first thing we must do is to take our foot off the gas pedal. But that alone won't necessarily prevent the damage. The next step is to apply the brakes — and quickly — to lessen the impending impact. And even then, we might need airbags to avoid the worst possible consequences.

Over the past several decades, as our failure to limit greenhouse gas emissions has become ever more apparent, there has been increasing interest in applying the brakes on

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global warming by removing CO_2 from the atmosphere after it has been emitted. This set of ideas, known as carbon dioxide removal (CDR) or negative emissions technologies,[3] includes 'natural' methods such as planting trees, or changing agricultural practices to store more carbon in the soil; artificially fertilizing the oceans to encourage phytoplankton blooms that consume CO_2 and sequester some of it in the deep ocean; chemically capturing CO_2 from the air through reaction with various minerals; or enhancing the rate of weathering of rocks, the natural process that will ultimately remove atmospheric CO_2 over the coming millennia.[4] The challenge today is that while many CDR approaches have promise, none of them currently satisfies three essential criteria.

First, carbon removal needs to be scalable. Each tree planted, for example, will ultimately absorb something in the order of 1 ton of CO_2 over the next forty years. By comparison, we are currently emitting nearly 1300 metric tons of CO_2 *per second*. There is roughly a trillion more tons of CO_2 in the atmosphere than there was at the dawn of the industrial revolution, and, if we ramp down to zero emissions over the next twenty-five years, we will have emitted half that amount again. There simply isn't enough available land for tree planting alone to solve the problem we've created.[5] There are similar scaling limitations on other carbon removal approaches as well, in particular those that most closely mimic natural ecological processes.

Second, carbon removal needs to be reasonably economical. While planting trees might be relatively cheap, the current projected costs for more globally scalable approaches — such as direct capture of CO_2 from the air — are $100 or more per ton. At this price, removing just one year's worth of our current emissions would cost $4 trillion, about 20% of the United States GDP.

And third, carbon removal should not create local impacts that are potentially worse than climate change itself. The generation of bio-energy from plants would remove carbon from the atmosphere if the resulting CO_2 were captured from the flue gas and stored underground. But deploying this approach at the scale required to have a global impact would require either a large-scale transformation of natural ecosystems, or a massive diversion of land towards energy crops, resulting in competition for both food and water. In the case of ocean fertilization, the additional carbon transported into the deep ocean would stimulate oxygen consumption that could render some regions inhospitable to animal life.[6] Clearly, such unintended consequences must be factored into any future considerations.

With further research and development, there are carbon removal approaches that, when implemented together, might avoid all three of the challenges above. But at the same time, it would be foolhardy to assume that these approaches to CO_2 reduction can be relied on with certainty to avoid future climate change. And it would be even more unwise to continue to emit CO_2 today on the assumption that our children and grandchildren can figure out how to remove it.

We are thus left with no certain pathway to avoid serious climate change impacts. The most optimistic scenarios include both a rapid transformation of our entire global energy and agricultural systems, and a massive scale-up of 'negative' emissions using CDR technologies that currently do not exist. This is clearly a daunting task, both technically and politically, yet this is required if we are to have even reasonable odds of avoiding significant warming. The challenge is compounded by the fact that we don't know precisely how much the climate will continue to warm, or how bad the impacts of that warming will be. Most people carry fire insurance on their house, despite the odds of a fire being less than 1%. Yet, even the optimistic scenarios do not ensure that we can meet temperature targets and avoid the worst potential impacts of predicted climate change. We are, quite literally, gambling with the future of the planet.

In the face of this future uncertainty, there is another tactic — in addition to mitigation and carbon dioxide removal — that might provide a kind of planetary insurance. This approach, known as 'solar geoengineering', aims to reduce global warming by decreasing the amount of incoming energy from the Sun.[7] These ideas are not new, indeed they were discussed in the mid-1960s when US President Lyndon B. Johnson was briefed on climate change. But solar geoengineering remained mostly on the fringe until 2006, when Paul Crutzen, who was awarded a Nobel Laureate for his work in atmospheric chemistry, suggested that it be taken seriously.[8]

At its most basic level, solar geoengineering seeks to modify the radiation balance of Earth. When left to its own devices, the planet reaches an energy equilibrium state, with the amount of energy received from the sun closely balanced by the amount of energy sent back into space through reflected sunlight and emission of thermal radiation (heat). The reason the climate is warming today is that increased greenhouse gas concentrations in the atmosphere are making it harder for Earth's thermal energy to escape back to space. Since the Earth is now receiving more energy than it is emitting, it must warm up (increasing thermal losses) until the input and output are back in balance. Reducing atmospheric greenhouse gas concentrations deals with the imbalance directly, but reducing the amount of incoming energy could address the other side of the balance sheet. If we could deliberately reflect roughly 1% of the sunlight currently hitting Earth's surface back to space before it is absorbed, we would cool the planet enough to counteract all the warming from our past greenhouse gas emissions.

Just how difficult would it be to accomplish this? While 1% doesn't sound like a lot, consider, for perspective, that the entire continental US covers about 2% of Earth's surface. So, we cannot achieve this additional reflection by doing things like painting roofs white; there just aren't enough roofs. There are, however, at least two proposed approaches that could plausibly reflect enough sunlight to significantly influence global climate.

One such approach would mimic the cooling effect that occurs after large volcanic eruptions, such as the eruption of Mount Pinatubo in the Philippines. On June 15 of 1991, an explosive eruption from Pinatubo emitted large amounts of sulfur dioxide high into the atmosphere, where the gas underwent chemical reactions to produce reflective sulfate aerosols (small droplets or particles). If the gas had been released into the troposphere (the lower atmosphere), the resulting aerosols would have been rained out within weeks, with relatively little cooling effect. But higher up in the stratosphere — around 20 km above Earth's surface — the air is stable and dry, and the aerosols can persist for a year or more. These stratospheric aerosols, which were clearly visible in satellite imagery, reflected enough solar radiation back into space to decrease global temperatures by 0.3–0.5°C over the following year.

It is, in principle, possible to deliberately mimic this process of solar reflectance (without all of the ash and other negative impacts of a volcanic eruption). The stratospheric-aerosol approach would cool the planet, and would thus counteract many — but not all — of the impacts of climate change. We don't currently have aircraft that fly high enough with the capacity to deliver a useful payload, but these engineering challenges appear surmountable. In fact, one of the concerns with this idea is that the direct costs might be low enough to make the idea more enticing than it should be!

Another solar geoengineering idea is to enhance the formation of reflective low clouds over the ocean. Satellite imagery reveals that ships in some parts of the ocean leave behind 'cloud tracks' that can persist for up to a week. This phenomenon occurs when aerosol pollution from the ship enhances the formation of cloud droplets, either creating a cloud where none previously existed, or making more, smaller droplets that make existing clouds 'brighter'. In either case, the result is the same; more sunlight is reflected back to space. Achieving this effect does not necessarily require adding pollution; spraying salt water into the right type of clouds might be sufficient.

Spraying salt water into clouds may be more benign than adding sulfate to the stratosphere, but we don't understand the physics of cloud-aerosol interactions well enough to know how well this approach might work. Cloud brightening also comes with its own set of issues. While stratospheric aerosols spread roughly uniformly across the globe, marine clouds that can be brightened might only exist over about 10% of the Earth's surface. Achieving the same global cooling effect through cloud enhancement would require much larger changes over smaller areas, resulting in potentially significant impacts on regional weather patterns.

Beyond any technical challenges of solar geoengineering, there are other significant questions to be addressed, from the details of its physical impacts, to broader societal issues such as public acceptability, ethics and international relations. For example, both cloud-brightening and the introduction of stratospheric aerosols have the potential to change precipitation patterns. Climate models suggest that these precipitation changes will typically be smaller than those we would experience if we allowed climate change to grow without geoengineering. But that might not be true everywhere, and there is still considerable uncertainty in model predictions. In addition, stratospheric aerosols could delay the recovery of the ozone layer through their interactions with the long-lived chlorine compounds (CFCs) that were phased out by the 1987 Montreal Protocol.[9] And what goes up must come down — so there may be ecological impacts as sulfate aerosols are eventually returned to Earth's surface in the form of acid rain (though the amount of acid rain would likely be a small increment over today's background levels). We simply don't know enough today to adequately inform future decisions. More research might uncover reasons why geoengineering would always be a bad idea, or might conclude that the consequences of not deploying these approaches outweigh these concerns.

More challenging still are the societal and governance questions.[10] If deployed, solar geoengineering would affect everyone on the planet. Who would decide, and how? Whose voices would be heard; whose interests would matter?

If CO_2 emissions continue unabated, an increasing amount of geoengineering will be required to compensate. Future generations would be committed to maintaining the deployment practically indefinitely; if they ever stopped, the climate would rapidly warm to where it would have been without geoengineering. On top of that, some impacts of our anthropogenic emissions wouldn't be addressed at all by solar geoengineering, such as the ocean acidification driven by high atmospheric CO_2 concentrations. Despite these obvious concerns, there will be some who want to use a geoengineering option as a shortsighted excuse not to cut CO_2 emissions. How can we ensure that this approach is considered only as a supplement and not as a substitute? To answer this question, it is essential that scientific research into geoengineering goes hand in hand with the development of international governance capacity to make sound decisions.

Returning to the car-accident analogy, solar geoengineering is akin to air bags. It doesn't quite deal with the underlying problem of an impending impact — in our case, of having added greenhouse gases to the atmosphere. No-one would sit in their car and set off their air bag for fun, and, similarly, it only makes sense to consider the side-effects of solar geoengineering in the context of climate change. But it is possible that geoengineering could reduce some of the worst effects of climate change, and thus mitigate suffering, particularly for the world's most vulnerable inhabitants. For ecosystems without a capacity to adapt to rapidly changing conditions, a climate response plan that includes solar geoengineering may be the only way to avoid extinctions.

It wouldn't make sense to force society to choose between installing air bags in cars and enforcing speed limits. Similarly, we don't have to choose between cutting emissions, developing and deploying methods to remove CO_2 from the atmosphere, and conducting research to better understand solar geoengineering. Indeed, geoengineering approaches only make sense in conjunction with cutting greenhouse gas emissions. Had we been working diligently to reduce our CO_2 emissions over the last fifty years, perhaps we wouldn't need to think today about additional approaches to climate change response. Even if solar geoengineering is eventually deployed to help limit the impacts of climate change, we must strive for a future Earth Day when the excess atmospheric CO_2 will have been removed and solar geoengineering is no longer needed.

Endnotes

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