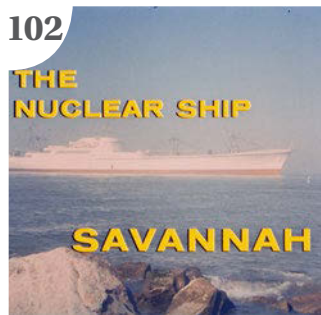
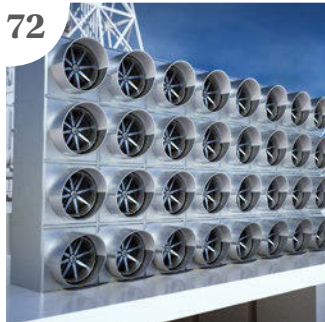


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**WASTE
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Insight & Opinion

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American Nuclear Society

On the cover: A workman checks waste canisters at the Savannah River Site's Defense Waste Processing Facility. See article starting on page 54. (Photo: Savannah River Site Photography)



If we don't decarbonize in time, do we have a Plan B?

By James Conca

We're failing. We're failing to decarbonize the world in any significant way. Global greenhouse gas emissions are still rising and appear on track to continue rising until at least 2040—the result of the energizing of the developing world.

It takes about 3,000 kilowatt-hours per person per year to lift someone out of poverty, and coal is the only energy source that can be built in a poor country that has little infrastructure. On top of that, oil is the only viable option for transportation in these same poor countries. So it's not surprising that coal and oil use are increasing globally right alongside carbon emissions. When faced with saving

the planet or saving your family, family wins every time.

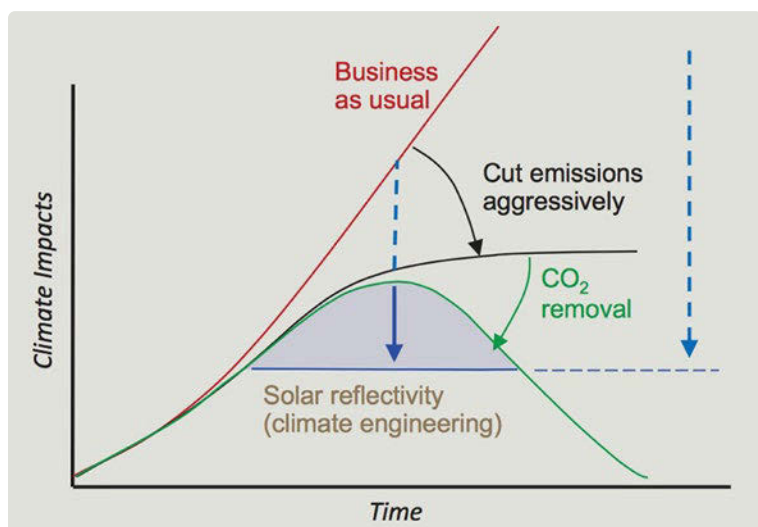
So what do we do? Do we have a Plan B? Yeah, but you're not going to like it!

It's called solar geoengineering, and it's a process by which we would deliberately reduce the effects of heat-trapping greenhouse gases by reflecting a small fraction of sunlight back into space. It sounds strange, but it isn't as odd—or as difficult—as it might seem. And we know that it works because it happens every time a huge volcano erupts. We've been studying those for over 100 years.

Some serious scientific mojo has been applied to this idea at universities around the world. The Solar Geoengineering Research Program, part of the Salata Institute for Climate and Sustainability at Harvard University, is a research initiative devoted entirely to the science, technology, and public policy of solar geoengineering.

There are several technologies that could be applied to this approach, but the most effective, cheapest, and quickest involves injecting aerosols (superfine droplets or particulates) into the stratosphere, where they would scatter some sunlight back to space, thus cooling the planet by reducing the amount of heat that enters the lower atmosphere and gets trapped by carbon dioxide. Because the impacts of climate change will hit the world's most vulnerable populations hardest, who lack the resources to move or adapt, there's actually a strong ethical case for research into solar geoengineering.

Besides, we've been geoengineering the atmosphere for over a century—in the wrong



There are three global strategies to decrease the impact of global warming: cutting greenhouse gas emissions, removing CO₂ from the atmosphere, or reflecting solar radiation back into space. We have not been aggressive enough with the first two in time to limit warming to 2°C or so, but we can utilize solar geoengineering during the next two decades, which will give us time to get—and stay—aggressive. (Image: Global Carbon Project)



Mount Pinatubo in the Philippines, as it began its cataclysmic eruption in 1991. Millions of tons of particulates were blown into the stratosphere, causing global cooling, similar to what solar geoengineering would do in a controlled way. (Photo: U.S. Geological Survey)

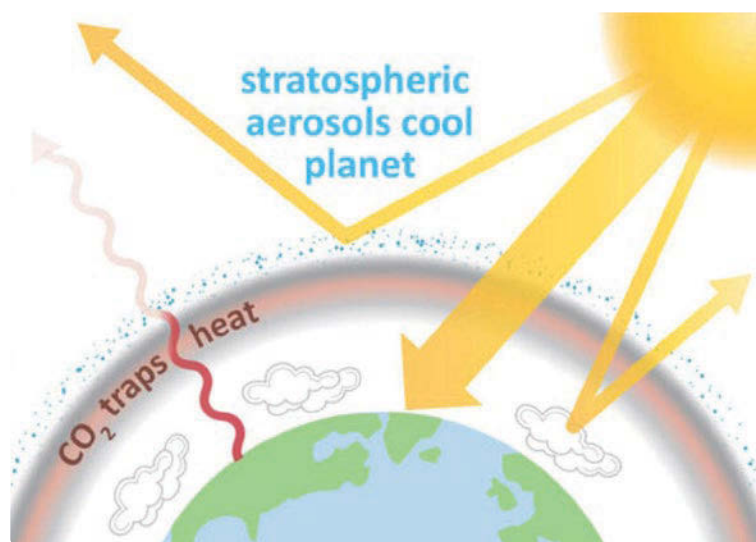
direction—by injecting huge amounts of CO₂ and other greenhouse gases into the atmosphere. All climate models show that the next 20-year period is critical. The best we can do is keep warming to around 2°C—and that is only if we get global emissions to zero by 2040. If we don't, temperatures rise by 3.3°C to 4.4°C. That's because CO₂ has a half-life in the atmosphere between 30 and 300 years, depending on the various chemical mechanisms that naturally remove CO₂ from the atmosphere. And that's just the half-life.

Let me state that clearly: there is no way to reduce carbon emissions in the next 20 years sufficiently to mitigate the worst effects of climate change.

Enter solar geoengineering.

Solar geoengineering should not replace reducing emissions (mitigation), coping with a changing climate (adaptation), or CO₂ removal and sequestration. Solar geoengineering does not change the CO₂ concentrations in the atmosphere. Rather, it treats a symptom—heat. It's like putting some serious sunblock on Planet Earth, giving us time to figure out how to lower our carbon emissions to near zero.

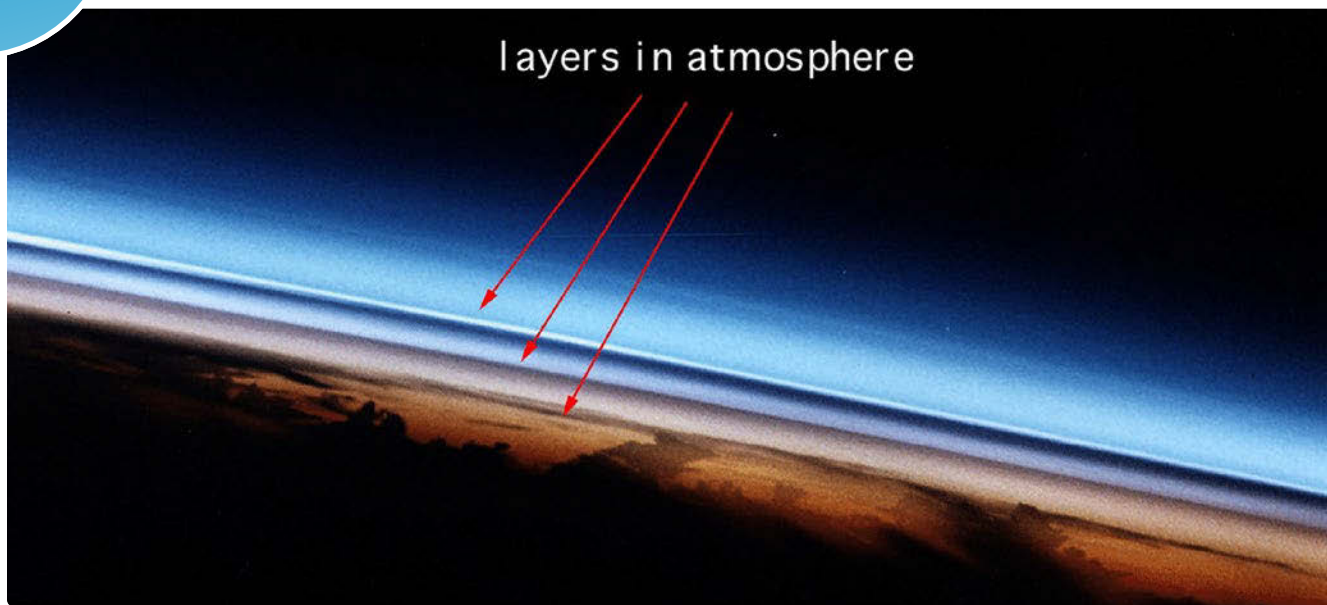
Geologists have seen the cooling effects



Solar geoengineering involves putting aerosols of fine particles, droplets, or gases into the stratosphere, where clouds are forming, to increase the amount of heat radiated back into space and help cool our warming world. It is well-known and well-studied, and it is probably the only short-term solution to global warming while we get our act together on cutting carbon emissions. (Image: David Keith)

of big fires and big volcanoes in the geologic record going back many millions of years, so we know it works, and how it works. When the huge volcano Krakatoa erupted in 1883, the billions of tons of particulates thrown

Continued



Shortly after the eruption of Mount Pinatubo, a NASA space shuttle photographed these layers of sulfate particles in the atmosphere. This effect is similar to how solar geoengineering would appear. (Photo: NASA)

into the stratosphere dropped global temperatures about two degrees. As the particulates came out of the atmosphere over the next few years, the effects went away.

These natural processes are uncontrolled and, in many cases, cause very big adverse environmental changes themselves. Of course, the particulates and gases that come out of a volcano are not the ones we would choose in solar geoengineering.

And that's the whole point of research. Because we have studied large volcanic eruptions like Krakatoa, Tambora, and Pinatubo, there aren't any real basic science unknowns. It's just figuring out how to do it effectively without causing other problems.

By choosing where to release the aerosols, a uniform global aerosol layer could be created. Its thickness could be varied as needed—thicker at high latitudes or in one hemisphere or the other—to craft a desired outcome. It would need to be done within certain limits, since stratospheric mixing is pretty fast.

David Keith, former director of Harvard's Solar Geoengineering Program (and now director of the Climate Systems Engineering Initiative at the University of Chicago), has described solar geoengineering as having three essential characteristics: it is cheap, it is fast, and it is imperfect. Long-established estimates show that solar geoengineering

is at least 100 times cheaper than cutting emissions in offsetting the expected global temperature rise through 2100.

A few grams of particles in the stratosphere can offset the radiative forcing of a metric ton of atmospheric CO₂. At about \$1,000 per metric ton for aerosol delivery, that adds up to maybe \$1 billion per year. Compare this to the approximate cost of \$10 trillion over 20 years for the United States alone to decarbonize. Without nuclear, that cost would escalate to \$20 trillion over 30 years. For the world, it will cost \$65 trillion—without nuclear, more than \$100 trillion. These are not trivial numbers and are unlikely to get spent in time to help.

On the other hand, all it would take to fund the necessary research in solar geoengineering is \$50–\$100 million per year for about 10 years. That's barely the cost of a single fighter jet—not much to ask for saving the planet and half the species on it.

Not funding this research would be akin to being too cheap to buy sunblock, knowing skin cancer runs in your family.

This research will answer a lot of questions, even those of the ethics on trying this approach at all. But if we don't do the research in the next 10 years, we may not be able to implement it correctly when we

Continued



Opinion

reach that critical moment. And others may do it anyway, without the care we might show. China has specifically said they will do exactly this if things get too out of hand with global warming. They already have a robust research program in place.

Let's be clear: solar geoengineering is not, nor should even be considered, a replacement for cutting carbon emissions. It simply buys us the several decades we need to actually cut emissions to near zero without frying the planet.

Solar geoengineering cannot eliminate all the damages caused by greenhouse gas-driven global warming, even if it tried to restore global average temperatures to preindustrial levels. Compared to the warming caused by greenhouse gases, which trap long-wave radiation, climate variables like temperature and precipitation respond differently to cooling caused by solar geoengineering, which reflects short-wave radiation. For example, if temperatures were restored to preindustrial levels by solar geoengineering, the water cycle might be weaker than it was in the 1700s.

An important point to remember is that solar geoengineering is inherently self-limiting. It must be done continuously until we get a handle on emissions. When it stops, so do its effects, in a year or two, as the aerosols come out of the atmosphere—just like happens in the years following a huge volcanic eruption.

But this is a good thing. Solar geoengineering can be adjusted easily and relatively quickly—even reversed—if the effects are not desired. As Keith put it, "Because the warming impact of carbon is more or less forever [on biological lifetimes], all that we can achieve this century by cutting emissions is to stop making the problem worse. Solar geoengineering allows a more optimistic

outcome. In combination with technologies to remove carbon that is already in the atmosphere, it would allow humanity to aim to restore the preindustrial climate over two human lifetimes."

And we do have technologies to remove and capture CO₂ from the atmosphere, the ocean, and the fossil fuels being burned. It just will take some time for there to be a global impact and for us to decide where to put the CO₂.

So what would we put into the atmosphere? Many materials have been considered, including alumina, diamond dust, and bismuth triiodide, all with a hope of decreasing unwanted side effects like ozone depletion (which might occur with sulfur). I like calcium carbonate particles—basically ground-up limestone or seashells. They are nontoxic, don't appear to harm the ozone layer, and may even help mitigate ocean acidification a bit as they fall into the ocean.

Peter Frumhoff of the Union of Concerned Scientists mused that solar engineering is the emergency room response to climate change. We need to have it ready, but we hope never to use it. Preventive medicine is always better, but we have failed at that as far as global warming goes. Standing next to a heart attack victim in the ER saying they need a better diet and exercise just isn't helpful.

Fossil fuel use is climbing as fast as ever worldwide, mainly in the developing world. And we in the developed world have failed at helping them access alternative energy sources like nuclear, just as we have failed to replace coal with nuclear in the developed world.

Like many epic choices about our future, it would be wise to do our due diligence before we are forced into radical actions.

A big question, of course, is whose hand would be on the thermostat?



James Conca is a scientist in the field of earth and environmental sciences specializing in geologic disposal of nuclear waste, energy-related research, planetary surface processes, radiobiology and shielding for space colonies, and subsurface transport and environmental cleanup of heavy metals.

