Connecticut Debate Association
February 24, 2018
Warde High School

Resolved: Geoengineering should be used to combat global warming.

What's the Deal With Geoengineering?

By Jacob Brogan, Slate, Jan. 6, 2016

Your 101 guide to the maybe-crazy, maybe-sane attempt fix climate change by tinkering with Earth's atmosphere.

Welcome to the first installment of Futurography, a new monthly course from Future Tense that aims to help you navigate discussions about the technologies that will define tomorrow. In January, we'll be discussing geoengineering. Can we stop climate change by tinkering with the atmosphere? Future Tense will help you understand the debates and the science behind geoengineering.

I keep hearing about this geoengineering thing. What is it, exactly?

At its simplest, "geoengineering" is the active transformation of our planet's climate through human intervention.

Am I crazy for thinking that sounds like something a Bond villain would propose?

Not entirely, but at least its proponents' intentions are altruistic: The field emerged in earnest in the last two-and-a-half decades as a response to global warming and other forms of environmental degradation. It's about using technology to solve crises created by other technologies, everything from filters that pull carbon dioxide out of the air to spraying chemicals that would lower the global temperature.

Though these efforts are relatively new, geoengineering as such has arguably been under way for much longer. As the science-fiction writer Kim Stanley Robinson puts it, "Our current technologies are already geoengineering the planet—albeit accidentally and negatively." Our cars, our factories, and our whole way of life are transforming our climate and everything that conditions it. Proponents of geoengineering hope to make that process more deliberate—and its effects more positive. Conversations about geoengineering have become increasingly urgent as the consequences of climate change grow unavoidable.

That sounds less terrifying than I expected. Why does it have so many people up in arms? Is it even doable?

Geoengineering is controversial precisely because it is surprisingly practicable. Its proponents and critics both point out that it is based in real, actionable science: If you inject sulfuric acid into the upper atmosphere or dump iron into the oceans, things will happen. But these and other proposed techniques are still poorly understood and highly experimental.

There are two primary approaches to geoengineering: The first, carbon dioxide reduction, would pull CO2 out of the air to prevent warming in the first place. The second, typically known as solar-radiation management, aspires to bring down ever-rising global temperatures by reflecting a portion of sunlight back into space. Both are promising, but even their most dedicated advocates insist that neither is a panacea. Geoengineering is a stopgap, not a solution.

Strictly speaking, both forms of geoengineering are possible without new innovations, though it might be necessary to advance and scale up existing technologies if we hope to make them truly effective. Indeed, some geoengineering practices are surprisingly low-tech. Painting rooftops white, for example, might help cool cities, and changing our forestry practices could reduce atmospheric CO2. Nevertheless, most discussions of geoengineering focus on more drastic approaches.

Carbon dioxide reduction sounds cool. Tell me more about that?

Sure. Researchers generally agree that artificial carbon dioxide reduction is both the most promising and the safest method of climate intervention. Even if we collectively switch to more environmentally friendly energy production methods, carbon dioxide reduction could be crucial. Without it, we'll be stuck with excessive atmospheric CO2, even if we stop adding more to the atmosphere, because without any intervention, it would take decades, maybe even centuries, for things to return to the way they were prior to the Industrial Revolution.

Two prominent carbon dioxide reduction methods are currently under discussion. The first, direct air separation, would filter CO2 out of the air, making it possible to safely contain the gas. The second, known as biological carbon dioxide reduction, would involve planting crops that naturally collect CO2. On reaching maturity, when they stop absorbing CO2, these plants would be burned, and the resultant gases passed through a filtration system, not entirely unlike that used in direct air separation. Whatever the method, once extracted this CO2 could be pumped underground or repurposed as an environmentally friendly fuel.

Great. Let's do it!

If only. While both of these reduction strategies are possible with current technology, they remain prohibitively expensive, making it difficult to implement them on a meaningful scale. A handful of small startups—including Global Thermostat and Carbon Engineering—are working to push the technologies forward in ways that may reduce their cost.

That sounds like tricky stuff. Is there a simpler way?

Another notable method of carbon dioxide reduction is ocean fertilization, which involves artificially stimulating the growth of plankton that naturally absorb CO2. Sometimes described as "biological pumps," these organisms ultimately sink into the ocean, removing pollutants from the air. But present methods may be dangerous to fish, sea birds, and other forms of marine life. It could also produce a variety of other harmful environmental effects in the process of removing CO2 from the air.

What if we want to do something more immediately?

In the short term, at least, solar radiation management seems to be the much more plausible approach to geoengineering, but it too presents a variety of serious risks. Instead of directly confronting the causes of climate change, solar radiation management seeks to ameliorate some of its effects, reducing temperatures by manipulating the albedo—

Hold up. Albedo?

That's a technical term for the reflection of sunlight into space. Changing it on a large scale could significantly reduce global temperatures, but it wouldn't do anything for the other effects of excessive atmospheric CO2, such as ocean acidification. We're talking about symptom management here, even more so than with those carbon dioxide reduction technologies.

So is this even a good idea?

It might not be. In fact, when you hear scientists worrying about geoengineering, they're typically talking about solar radiation management. But compared with carbon dioxide reduction, albedo modification would be relatively inexpensive. Arguing for this approach in his book A Case for Climate Engineering, Harvard University professor David Keith writes that "a well managed program could likely be ready to start by 2020 [for] a total budget of roughly a billion dollars." While that price tag would rise rapidly, this means that a moderately prosperous nation could, at least at first, attempt to modify the albedo on its own.

There's a Bond villain component here, too: Keith talks about flying custom-built Lear jets into clouds to inject them with chemicals. And Nathan Myhrvold has a plan that he calls the Stratoshield, which involves hoisting enormous acid spraying hoses into the upper atmosphere with balloons. It's just crazy enough that it might work. Really.

I feel a big "but" coming …

But not everyone thinks geoengineering is reasonable; climate scientist Raymond Pierrehumbert even described solar radiation management as "barking mad." As CO2 levels continue to rise, solar radiation management campaigns would have to escalate. If they should cease at any time, even for a period as short as a year, global temperatures would spike suddenly with likely catastrophic effects. Basically, any commitment to albedo modification would have to last for millennia. Other, more immediate, concerns include the possibility that it would negatively affect rainfall or damage the ozone.

Where does this leave us?

Even geoengineering's more cautious proponents tend to argue that the field requires further research and clearer international standards before any we deploy any version of it on a global scale. However, even if we are able to safely implement some of these strategies, the greatest risks may be social. As many have observed, ameliorating the effects of climate change may create the illusion that it's no longer necessary to fight its root causes. As the sci-fi writer Robinson has suggested, human engineering—transforming the ways that we live—may ultimately be the only truly effective form of geoengineering.

OK, so what's next?

Well, to some extent that's up to you! Future Tense will be exploring this topic for all of January, and we're eager to help you understand it better. What still puzzles you? What other questions can we answer? Most importantly, what do you think?

Your Geoengineering Cheat Sheet

By Jacob Brogan, Slate, Jan. 6, 2016

Geoengineering describes the active transformation of our planet's climate through human intervention. Here are some of the key players, major debates, and pop cultural landmarks shaping the ways that we understand this emerging field.

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Major Debates

Further environmental degradation: Though some geoengineering technologies may help cool the planet, it's possible that they may release additional greenhouse gasses, harm the ozone layer, or otherwise advance the damage they aim to prevent. Is geoengineering an environmental dead end?

Induced complacency: Even geoengineering's advocates acknowledge that it's not a true solution to climate change. But if it's successfully implemented, will it prevent us from doing more to save the planet? Will it simply give us permission to keep burning fossil fuels?

International cooperation: In the absence of treaties regulating geoengineering, there's a risk that companies or countries will pursue projects without taking proper precautions—and the climate doesn't respect national borders. Some commentators even worry that "rogue billionaires" might take matters into their own hands. Can we regulate geoengineering without restricting innovation?

Long-term commitment: Scientists such as Pierrehumbert argue that we'll have to stick with geoengineering some technologies for thousands of years once we embrace them, lest we cause even worse catastrophes. Will civilization stay stable for long enough to make a difference?

Price tag: At present, the most effective geoengineering technologies are prohibitively expensive, often less cost-effective than converting to environmentally safe energies. Can scientists bring down the expense? Or should we pursue these avenues regardless?

Unequal effects: Most geoengineering proposals would have different (and often unpredictable) effects on different regions of the planet. Even as some benefit, others would potentially suffer colder winters, decreased rainfall, or other problems. How can we assure that it helps all?

Unintended consequences: We lack the technological sophistication to accurately model most geoengineering proposals on a global scale, making it difficult to anticipate their effects. Should we continue researching these consequences or try to aggressively push the technology ahead?

Weaponization: Many geoengineering proposals originate in Cold War technologies. As the science advances, will we be able to prevent their renewed use as weapons? How can we prevent climatological conflicts?

Geoengineering's Moral Hazard Problem

By George Collins, Slate, Jan. 15, 2016

Would treating the symptoms of climate change give people permission to ignore the causes?

For more than a quarter-century, policymakers worldwide have puzzled over how to deal with climate change. If nothing else, these negotiations have served as a productive greenhouse environment for jargon. In particular, two modest-sounding words—mitigation and adaptation—have grown to occupy a special position, together including all possible responses to climate change. Mitigation attempts to reduce the atmospheric concentration of greenhouse gases by making humans emit less (via renewable energy, fuel-efficient cars, well-insulated houses, and so forth) and helping the Earth absorb as much or more (by, say, protecting or expanding forests and wetlands). Since we haven't mitigated enough already, we need adaptation as well, which softens the negative effects of higher temperatures, rising seas, and changing rainfall patterns by switching to drought-resistant crops, protecting coastal areas from floods, and trying, in hundreds of other ways, to make human and natural systems more resilient and robust. These two approaches are pretty comprehensive. Classically, the only other option is the default—proceeding as usual and hoping for the best—which is sometimes called "loss and damage" or, more candidly, "suffering."

Geoengineering—a diverse collection of extreme-sounding, planet-sized proposals for stopping or reversing climate change—is often presented as a disruptive (or simply destructive) alternative to these well-worn paradigms. But we need to look carefully at the various ways in which geoengineering might relate, for better or worse, to mitigation, adaptation, and suffering. Otherwise, we risk getting distracted by the novelty of the ideas involved and missing some deeper complexities and controversies.

Many geoengineering proposals involve poorly understood (or entirely theoretical) technologies intended to modify incredibly complex atmospheric, chemical, and biological dynamics. Determining the safety and efficacy of these technologies without just trying them out will be complicated, maybe even impossible. But imagine for the sake of argument that a particular geoengineering technology had somehow been indisputably proven "safe," with no chance of unwanted physical side effects such as sudden droughts or floods, biodiversity collapse, ozone depletion, or excessive cooling. There might still be reasons why we shouldn't seriously consider deploying or developing the technology. For example, certain geoengineering approaches could be fundamentally incompatible with democratic political processes, impossible to effectively govern or administrate, destined to create conflict between countries that might prefer different climates, or too tempting as an old-fashioned weapon of war. Or perhaps use of the technology would transgress a profound ethical boundary between humans and the Earth by bringing the entire planet under active management (rather than just subjecting it to reckless passive influence).

But even if all of these problems could be effectively and fairly resolved, what if geoengineering has a fundamentally antagonistic relationship with mitigation and adaptation? This concern is often (loosely) called the "moral hazard" problem, after the insurance industry's observation that people sometimes drive more recklessly if their cars have safety features. If politicians or their constituents inaccurately—but conveniently—believe that geoengineering could solve, will solve, or has solved climate change, why would they make any efforts to transition to renewable energy or help protect vulnerable people from climate effects? Will hope in an uncertain, far-off, deeply imperfect "solution" let humans off the hook at the time—now—when they most need to be on it?

Obviously, scientists, journalists, and others have been discussing geoengineering for quite a while, and it hasn't caused mitigation and adaptation to stop in their tracks. Some commentators suggest that geoengineering is a sufficiently scary prospect that merely mentioning it will increase public commitment to traditional climate solutions: "Don't make us have to use the sulfates." Then again, moral hazard concerns have not been helped by wildly overenthusiastic popular coverage of geoengineering (for example, the frankly ignorant treatment that it received in SuperFreakonomics). And moral hazard can be actively encouraged as well. The fossil fuel industry, say, might double down on geoengineering since it could, in principle, offer the industry a few more years with its existing business models.

It's best to think of moral hazard as a potentially serious social side effect of geoengineering—more complicated, but not necessarily less risky, than the physical side effects that people are worried about. But sometimes it's right to take risks, especially in extreme situations, and climate change, even with effective mitigation and adaptation, poses some big risks of its own. This point particularly relates to one set of geoengineering proposals—those known as solar radiation management, or SRM. Emissions reduction, although absolutely necessary, turns out to be a relatively slow way to bring the planet's temperature back down. (Some short-lived pollutants, such as black carbon, also contribute to global warming, and their removal could reduce temperatures quickly, but not necessarily by that much.) Adaptation—particularly ecosystem adaptation—takes significant time as well. Traditionally, only suffering happens fast.

Certain SRM technologies occupy a special place in the geoengineering conversation because they may be able to reduce global temperatures fairly quickly, albeit with suspected and possibly unsuspected side effects. In theory, the quick-acting nature of some SRM might be the only way to avoid an ecosystem-changing event like a catastrophic ice melt. This suggests the possibility of a relationship with healthy boundaries; mitigation and adaptation would continue on their own and SRM would be considered only in case of emergency, when no other approach we know of has a chance to work fast enough.

However, some recent commentary has cast shade on this proposal. Climate scientists point out that it is far from clear when a tipping point is about to be crossed; political theorists note that emergencies are often used to justify hasty and ill-advised choices and undemocratic decision-making; and international relations scholars anticipate great disagreement among countries about what an emergency sufficient to justify geoengineering would look like. Besides, the whole point of moral hazard is that people don't make objectively correct decisions when it comes to safety and risk. Even the feeling that emergency situations are covered by geoengineering could be enough to derail mitigation and adaptation.

As the emergencies-only viewpoint draws fire, another, sunnier position is getting more public attention. It views geoengineering less as Pandora's box and more as an extra toolbox. Some of the tools may be inappropriate, ineffective, or too dangerous to use, but proponents of this view take a self-consciously "rational" and often highly economic approach to the problem of integrating geoengineering, mitigation, and adaptation. As regards moral hazard, for example, a distractedly driven car with seat belts and airbags can be safer than a safely driven car without them (at least for the driver). And even if geoengineering made the world less safe, on the whole, at least it might be cheap, and a significant enough cost savings could justify, to an economist, an equivalent amount of additional risk.

Whether this viewpoint is promising or alarming depends, in large part, on whether economic ways of thinking such as cost-benefit analysis are useful in the face of problems this intricate. The need to rationally assign a price to everything may encourage irrationally simplified thinking. For example, even if moral hazard isn't created by informal discussions like this one, it could manifest unpredictably, once geoengineering had been deployed and therefore normalized. (Physics is filled with phenomena that change at a fundamental level when they become stronger or more widespread, and these phase changes or "scale effects" exist in human society as well.) An effect like this could throw a carefully constructed, well-intentioned, 50-year deployment proposal permanently off the rails in Year Five. The long-term planning, management, and commitment necessary to follow an effective strategy combining geoengineering, mitigation, and adaptation may be beyond the ability of our social systems. And just as with the fear that large-scale

SRM will cause crippling drought, it's not obvious how to find out whether this is true without trying it. But the costs of a failed experiment of this magnitude could be overwhelming.

Ultimately, it's important to ask whether separating geoengineering from mitigation and adaptation is even useful. The 1992 U.N. Framework Convention on Climate Change defines mitigation, in part, as "protecting and enhancing ... greenhouse gas sinks and reservoirs," which sounds a lot like many carbon dioxide removal proposals, and recent emissions scenarios—basically blueprints for keeping global temperatures within certain limits—actually depend upon negative emissions in the future. It's difficult to imagine how to achieve negative emissions without some amount of something that is often labeled geoengineering. Likewise, the definition of adaptation in the 2001 Intergovernmental Panel on Climate Change Third Assessment Report is "[a]djustment in natural or human systems in response to actual or expected climatic stimuli or their effects"—and putting sulfate aerosols in the stratosphere to reduce the amount of incoming sunlight seems like a pretty clear (if potentially drastic) adjustment of a natural system.

As the global climate change conversation heads into middle age, geoengineering proposals are likely to become more specific and differentiated. Perhaps this emerging familiarity will save us from both dismissing the field as a whole and from seeing it as a glittering new landscape filled with exciting solutions. Climate change of the speed and magnitude that we may experience in the coming century is entirely new territory, at least for human beings, and of the vast range of responses that have been proposed, only suffering is truly familiar.

The Two Questions You Should Ask Yourself About Climate Change

By Oliver Morton, Slate, Jan. 8, 2016

How you answer them determines the way you will feel about geoengineering.

In March 2012, in a large-windowed conference hall on the snowy campus of the University of Calgary, I heard two simple questions. The man asking them was trying to help his audience get the most out of their day by giving them a clear understanding of where they, and others, stood when it came to action on climate change. To that end he asked them:

Do you believe the risks of climate change merit serious action aimed at lessening them?

Do you think that reducing an industrial economy's carbon dioxide emissions to near zero is very hard?

The two questions posed that morning by Robert Socolow, a physicist from Princeton University, seem to me a particularly good way of defining your position on geoengineering. So take a moment to answer them, if you would.

Here's a bit of context.

There is no serious doubt that the atmosphere's greenhouse effect is a key determinant of the Earth's temperature. Nor is there any serious doubt that carbon dioxide is a greenhouse gas or that humans have been adding to the level of carbon dioxide in the atmosphere for the past few centuries by burning fossil fuels. In 1750, before the Industrial Revolution, the carbon dioxide level was 280 parts per million. In 1950, when the great global boom of the second half of the 20th century was taking off, it was about 310 parts per million. Today it is 400 parts per million. The bulk of that change has been due to the burning of fossil fuels. If you disbelieve any of those statements, you have been misled. I am not going to take the time to try and disabuse you, and you should read on in expectation of frustration.

There is, however, a lot of room for doubt about the level of climate change the planet will see over the next decades and centuries. The best current estimate is that if fossil-fuel use continues on anything like current trends, the Earth is likely to end up at least 2 degrees Celsius warmer than it was before the Industrial Revolution and possibly quite a lot warmer still. Change by 1 degree or 2 over a century or so may sound minimal, but it would be unprecedented in human history. Models of what happens to the climate in worlds in which fossil-fuel use is unconstrained point to severe, even cataclysmic, consequences in the form of damage to agriculture, greater harm done by extreme weather, the loss of biodiversity, and sea-level rise over timescales of decades to centuries.

That said, different models provide different possible climates at any given carbon dioxide level—some are more sensitive to the gas than others, in the language of modelers—and it is possible that the models on which warnings about climate change have mostly been based are, for some reason, skewed toward an unrealistically high sensitivity. It is also possible that humans and their natural world will be able to adapt to changed climates more easily and cheaply, and with less suffering, than most people concerned about climate change now believe. Thus it is possible that, even though carbon dioxide is unarguably a greenhouse gas and a lot of it is being added to the atmosphere, climate change due to human action will not in the end be a planet-changingly big deal.

The question, though, is not about the possibility of benign outcomes. It is about your willingness to do something about the risks of bad or even catastrophic ones. A catastrophe does not have to be certain for steps to avoid it to be worth taking.

Now here's some context for the second question. The International Energy Agency, which compiles such statistics for governments, says that when the industrial nations committed themselves to cutting their carbon-dioxide emissions at the Kyoto, Japan, climate-change conference in 1997, 80 percent of the world's energy demand was met with fossil fuels. Renewable energy sources furnished just 13 percent of the energy used; 10 of those 13 percentage points represented energy from biomass, including the wood burned on fires and in stoves by more than 1 billion people without other options. Wind, solar, and hydropower provided just three percentage points.

In 2012, after 15 years of post-Kyoto political action on climate, wind, solar, and hydro still provided 3 percent of the world's energy needs; fossil fuels provided 81 percent. Industrial carbon dioxide emissions in 2013 were more than half as high again as they were at the time of Kyoto.

So how do you answer the two questions?

I answer them Yes and Yes. Yes, the risks posed by climate change are serious enough to warrant large-scale action. And Yes, moving from a fossil-fuel economy to one that hardly uses fossil fuels at all will be very hard.

To judge by what they say and what policies they support, most people in favor of action on climate change are in the Yes/No camp: They want to act on the risks; they don't think that getting off fossil fuels is a terribly hard problem. Their way forward is to argue ever more strongly for emissions reductions; they believe these would be quite easily achieved were it not for a lack of political leadership willing to take on the vested interests of emitters.

Most of those against action on climate are in the No/Yes camp: They don't think climate is very much of a worry; but they do think that getting off fossil fuels is difficult, even impossible. Their leaders tend to focus on the weaknesses they see in the science and politics underlying the case for action on emissions and on the drawbacks of renewable-energy systems.

Neither of these approaches works for people like me in the Yes/Yes camp. Yes/Yes people need different responses: responses that seek to lessen the risks of climate change without impractically rapid cuts in fossil-fuel use; or responses which seek to change society so deeply that such reductions become feasible. I think that deliberate modification of the climate—climate geoengineering—could offer a response of the first sort. It is to outline the promise and attendant perils of that idea and to appreciate its antecedents and its implications that I have written The Planet Remade: How Geoengineering Could Change the World.

Our world has already changed in all sorts of ways that are not spoken of as clearly as they should be. It is a world in which the impact of the human is far greater than it used to be: a world in which the global economy has become something akin to a force of nature, in which the legacies of past generations and the aspirations of generations to come dwarf the impacts of hurricanes and volcanoes. Some people reject or denounce the implications of this change; others blithely accept them in a way that underplays their magnitude. I think those implications need to be opened up, inspected from different angles, interrogated, analyzed, appreciated. Only then will it be possible to make the necessary judgments and choices.

Thinking about geoengineering is a worthwhile end in itself. But it is also an exercise in building up the imaginative capacity needed to take on board these deep changes the world is going through and which it will continue to go through whether or not anyone ever actually attempts to re-engineer the climate. The planet has been remade, is being remade, will be remade.

What Experiments to Block Out the Sun Can't Tell Us

By Bina Venkataraman, Slate, Jan. 12, 2016

Using technology to fix climate change requires careful research—but that's easier said than done.

The historic agreement forged in Paris among 195 countries in December holds the promise of triggering a global shift to combat climate change—and harbors a hidden warning.

Regardless of what happens next, the Paris accord is a triumph of diplomacy among nations that have starkly disagreed in years past about who is responsible for cutting carbon dioxide emissions—and who should bear the cost. But success in heading off the worst climate disruptions hinges on whether countries fulfill the pledges each made leading up to the Paris talks and make bolder ones this decade. The teeth come in the form of sunshine and shame: The accord requires transparency and monitoring of emissions from each country. And it relies on countries to be motivated by the ignominy they would face if they reneged.

There is a danger that shame will not be enough. In the United States, Republican presidential candidates have already vowed to undo President Obama's climate change policies, including the pivotal Clean Power Plan that regulates emissions from the electricity sector. Senate Majority Leader Mitch McConnell warned that the Paris accord stands on shaky ground; he thinks, contrary to most credible legal experts, that the Obama power plant rules are illegal. It's unlikely the prospect of infamy would deter a climate change–denying president or Congress from shattering the U.S. pledge. That's the kind of consideration that pertains to the reasonable and rational.

What would happen if the U.S. failed to keep up its end of the agreement? The United States' actions greatly affect other countries', because the world sees us as responsible for the mess everyone's in. Leaders of developing countries and island nations hold industrialized countries responsible for the reckless carbon binges of past decades that have pushed low-lying territories to the brink of disaster. The Obama administration summoned all its leverage to persuade other countries to develop without emitting as much carbon as we did on our path to economic dominance. In Paris, the U.S. had to play the parents who say, "Do as I say, not as I do," while also promising a generous allowance.

The United States faces strong internal pressure to keep burning fossil fuels, reflected in our divisive politics; other nations—especially island nations like Tuvalu and Kiribati—face strong pressure to keep the planet cooler at any cost. The seas are already rising. The mood is ripe for private-sector companies or individual nations to seek drastic ways to change the climate, either to avoid the cuts agreed to in Paris or to hedge their bets in case of political failure. Yet absent from the Paris agreement and absent from U.S. political discourse is any robust discussion of what could be a growing threat, especially after the November presidential election: that countries, people, or businesses will take it upon themselves to directly cool the planet.

Experiments in geoengineering have already been tried. In 2012, a rogue scientist dumped 120 metric tons of iron into the Pacific Ocean to grow plankton blooms to remove carbon dioxide from the atmosphere. He violated no law. In 2015, China announced plans to seed clouds with chemicals to boost rainfall, building on its standing artificial weather program. Based on the cost and potential cooling effect of various geoengineering technologies, the most likely scenario today is that someone would attempt to change the atmosphere by pumping sulfate aerosols in the stratosphere—to reflect sunlight away from Earth. (This technology, dubbed solar radiation management, is being promoted and researched by a small but vocal group of scientists.)

Now is the time, with the wind from Paris at our backs, to set international norms for how geoengineering technologies are tested and deployed and to consider how the U.S. would navigate a global landscape in which different nations want to engineer the climate to different ends. Would Russia want to warm Earth beyond 2 degrees Celsius to turn Siberia into a fertile growing region? Will Vanuatu find a sympathetic billionaire to shield the planet from the sun so that sea levels do not rise so high?

More research on geoengineering could help us anticipate the possible ways the technologies could be used. But we should be clear about what each stage of research can actually show us. In order to prove that the technique of reflecting sunlight with sulfates can cool the planet consistently without terrible consequences, experiments must ultimately be large enough in geography and long enough in time frame. And those characteristics raise the possibility for widespread, unintended consequences. Rutgers climate scientist Alan Robock has argued that trials in the atmosphere won't show a significant climate response, "unless an experiment is so large as to actually be geoengineering" and lasts at least a decade. (Experimenters would need to confirm that any changes in climate were not just coincidental.)

Scientists have studied the effects of volcanoes that temporarily cooled the planet, such as the 1991 Mount Pinatubo eruption in the Philippines. But incidents in the past cannot simulate what it would really be like to try to cool the entire planet today with such technologies, over a time span of not years, but decades. Launching small experiments of limited duration—or gradual deployment, as has been advocated by Harvard geoengineering scientist David Keith—may also help advance our knowledge. But the world should be aware that this method cannot tell us whether the technology is safe enough or too dangerous to deploy—it can't give us the kind of insights that we have, for instance, when we test a drug for its side effects in a randomized controlled trial. (Even with that gold standard for assessing risk, we still have cases like Vioxx, where the dangerous side effects for large populations can be far worse than what appears in a limited clinical trial. In geoengineering, we have only one planet, not many patients, and the benefits and risks are collective, not individual.)

This conundrum of conducting large-scale solar geoengineering experiments poses an ethical dilemma that cannot be resolved by scientists alone. We need a robust public debate to ask when and to what extent it is ethical to experiment with the planet. We need global norms that take into account the uncertainty and serious risks that solar radiation management could pose, such as manipulation of weather patterns and damage to the food supply, air pollution deaths, depletion of the ozone layer, and other impacts we may not yet anticipate in the dynamic, complex system that is Earth's climate. If early experiments epically fail, will they be counterproductive to the technology over the long term, like the nuclear meltdown in Three Mile Island?

A recent global summit on gene editing technologies hosted by national scientific councils from the United States, the United Kingdom, and China could provide a model for how policymakers, ethicists, scientists, and the public can set boundaries on the use of technologies with unknown and intergenerational consequences. After the summit, the three councils published principles to guide when the use of gene editing is sound and ethical, and when it is too risky—

namely, when it poses unpredictable and irreversible impacts for future generations. While such norms won't stop rogue engineers, they at least keep the wise and the willing from unleashing unforeseen consequences. And they can help scientists navigate the fine line between expanding knowledge and deploying technologies in the absence of international support.

The chance of success in cutting climate change emissions has never seemed more palpable. But we should seize the goodwill generated in Paris to talk about the engineering elephant in the room. The United States can and should lead not just by making politically determinate commitments but by anticipating what could happen if we fail to keep up our end of the bargain.

The Good, Bad, and Ugly Approaches to Geoengineering

By Christophe Jospe, Slate, Jan. 25, 2016

It's not about the technologies themselves—it's about the way they are implemented.

Picture yourself driving a bus up a mountain. As you near the top, you can see the road on the downhill side—and you realize your brakes are broken. As the seriousness of the problem sinks in, you take your feet off the gas and swerve a bit to slow down. Had you slowed earlier in your climb, you might have been able to stop at the top, but now it is too late. You committed to going downhill. At least you are alive to make a last-ditch attempt to save yourself and the other passengers on board.

We find ourselves in a similar situation in the global efforts to address climate change. As manmade carbon dioxide emissions accumulate in the atmosphere, it is all but certain that concentrations will exceed safe limits, sending us over a tipping point without any brakes. Drastically reducing emissions will slow the speed of the bus, but that's insufficient. Indeed, the fifth assessment report by the Intergovernmental Panel on Climate Change stated that any success in stabilizing climate change will require prolonged periods of negative emissions. This means that to mitigate the most severe effects of climate change, a carbon-neutral future isn't enough—we need to pull back emissions from the past.

Geoengineering, or tinkering with the atmosphere to address problems we have caused, is an unfortunate term that includes very different technologies under a catchall umbrella for large-scale ways to not crash the bus and leave future generations with an unmanageable climate. In a 2015 publication, the National Academies of Science released two reports—using the synonymous but less controversial term "climate intervention"—on the topic, split into "carbon dioxide removal and reliable sequestration" and "reflecting sunlight into the earth." Broadly speaking, the former connects the problem to the solution: too much CO2 in the atmosphere causing climate change, therefore solutions involve methods to remove and sequester it. The latter considers addressing the symptoms of a warmer Earth: cooling the planet with modifications to divert sunlight.

But rather than dividing geoengineering approaches by type of technology, we should actually split the field into three different categories: the good, the bad, and the ugly. These categories are not based on the technologies that are used, but by their effects. Some technologies could be good, bad, or ugly, depending on how they are implemented and how they continue to be developed.

Good geoengineering motivates the bus driver to take his foot off the gas with the confidence that he can stop in time. It would be a "technological fix," which means that it 1) connects the problem (too much carbon dioxide in the air) to the solution; 2) creates measurable and unambiguous outcomes (for instance, we can measure the amount of carbon dioxide that the technology removes from the air, and we know how much CO2 needs to be removed to offset emissions); and 3) allows for future research and development that will lead to significant cost reductions. A technological fix would allow humanity to clean up after itself without causing an additional mess.

For instance, researchers are investigating technologies that would, for instance, allow us to remove CO2 from the atmosphere to be permanently stored. (I work at Arizona State University's Center for Negative Carbon Emissions; ASU is a partner with Slate and New America in Future Tense.) The logic is straightforward: If a ton of carbon dioxide is emitted, then a negative emission or offset is needed to put that ton away.

Good geoengineering would have the potential to scale, and scientists would fully understand the environmental effects and energy use. If the approach disrupts other systems or natural ecosystems, causes negative consequences, consumes land that might be needed for food production, or weakens support for reducing carbon emissions, it is not good and should not be undertaken. Good geoengineering would not be an easy fix, nor would it be expected to immediately reduce the pain that is felt from a warmer climate. It would be undertaken in conjunction with emissions reductions—it would not be a crutch.

The Bad

Bad geoengineering might seem more attractive once the bus is rolling and accelerating downhill. It is a quick and (usually) cheap fix and allows any individual actor, be it a country or a rogue billionaire, to operate independently. It also doesn't really solve the problem but rather tries to treat the symptom. For instance, solar geoengineering seeks to reduce the amount of sunlight that warms the Earth at the surface, troposphere, upper atmosphere, or even space level. The planet might cool, but this would require the continued treatment; it would be difficult to stop once started. Meanwhile, people would continue to freely dump CO2- into the atmosphere.

The Ugly

Ugly geoengineering might add brakes but could make the bus lose a wheel. Negative emissions could be ugly geoengineering if additional problems emerge when the technologies are brought to scale (or if they are unable to scale). An ugly approach to geoengineering would be masked in ambiguity and treat negative emissions as secondary to providing energy. For instance, consider bioenergy with carbon capture and storage, or BECCS. This approach burns biomass—like wood—at a centralized plant to make energy, and then the resulting carbon dioxide is captured and stored. The Intergovernmental Panel on Climate Change suggests it as an approach to negative emissions, but it's ugly because not all biomass is created equal, and if used as a form of geoengineering, it would require significant amounts of land and water. That might end up releasing more carbon dioxide in the air if it upsets existing biomass or ecosystems or take over arable land needed for food production. Likewise, iron fertilization might increase the uptake rate of carbon in the oceans but could cause massive algae blooms.

What shouldn't qualify:

Some of the things that people call "geoengineering" shouldn't really be considered such at all because they do more than just combat climate change. For instance, biochar—a technology, more than a century old, to create energy by burning wood and starving it of oxygen—is a great form of carbon-negative energy that can also have added benefits when applied to soils. Similarly, soil techniques that allow for negative carbon not only remove CO2 from the atmosphere, but also create a number of positive co-benefits for healthier crops.

Another approach that should not be considered geoengineering is removing carbon dioxide from the atmosphere with direct-air capture technologies for utilization—that is, technology that takes out the CO2 and then recycles it, whether for foods, fuels, or fibers. These direct-air capture techniques should consider the value of having a source of readily available carbon that is not fossil-based and can play a major role in accelerating a pathway to a carbon-neutral future.

* * *

As the world looks to make investments in technologies that might play a role in keeping the bus safe on the road, it is helpful to ask a few questions. Do we clearly understand the costs and benefits? Are we sure that it will not cause problems that weren't there before? Does it connect the problem to solution, rather than just offering a Band-Aid? If the answer to all of these is yes, then it's good—and we are probably better off just calling it a form of carbon management or negative emissions, not geoengineering. Let's leave that for the bad and ugly.

Panel Urges Research on Geoengineering as a Tool Against Climate Change

By HENRY FOUNTAIN, The New York Times, FEB. 10, 2015

With the planet facing potentially severe impacts from global warming in coming decades, a government-sponsored scientific panel on Tuesday called for more research on geoengineering — technologies to deliberately intervene in nature to counter climate change.

The panel said the research could include small-scale outdoor experiments, which many scientists say are necessary to better understand whether and how geoengineering would work.

Some environmental groups and others say that such projects could have unintended damaging effects, and could set society on an unstoppable path to full-scale deployment of the technologies.

But the National Academy of Sciences panel said that with proper governance, which it said needed to be developed, and other safeguards, such experiments should pose no significant risk.

In two widely anticipated reports, the panel — which was supported by NASA and other federal agencies, including what the reports described as the "U.S. intelligence community" — noted that drastically reducing emissions of carbon dioxide and other greenhouse gases was by far the best way to mitigate the effects of a warming planet.

But the panel, in making the case for more research into geoengineering, said, "It may be prudent to examine additional options for limiting the risks from climate change."

"The committee felt that the need for information at this point outweighs the need for shoving this topic under the rug," Marcia K. McNutt, chairwoman of the panel and the editor in chief of the journal Science, said at a news conference in Washington.

Geoengineering options generally fall into two categories: capturing and storing some of the carbon dioxide that has already been emitted so that the atmosphere traps less heat, or reflecting more sunlight away from the earth so there is less heat to start with. The panel issued separate reports on each.

The panel said that while the first option, called carbon dioxide removal, was relatively low risk, it was expensive, and that even if it was pursued on a planetwide scale, it would take many decades to have a significant impact on the climate. But the group said research was needed to develop efficient and effective methods to both remove the gas and store it so it remains out of the atmosphere indefinitely.

The second option, called solar radiation management, is far more controversial. Most discussions of the concept focus on the idea of dispersing sulfates or other chemicals high in the atmosphere, where they would reflect sunlight, in some ways mimicking the effect of a large volcanic eruption.

The process would be relatively inexpensive and should quickly lower temperatures, but it would have to be repeated indefinitely and would do nothing about another carbon dioxide-related problem: the acidification of oceans.

This approach might also have unintended effects on weather patterns around the world — bringing drought to once-fertile regions, for example. Or it might be used unilaterally as a weapon by governments or even extremely wealthy individuals.

Opponents of geoengineering have long argued that even conducting research on the subject presents a moral hazard that could distract society from the necessary task of reducing the emissions that are causing warming in the first place.

"A geoengineering 'technofix' would take us in the wrong direction," Lisa Archer, food and technology program director of the environmental group Friends of the Earth, said in a statement. "Real climate justice requires dealing with root causes of climate change, not launching risky, unproven and unjust schemes."

But the panel said that society had "reached a point where the severity of the potential risks from climate change appears to outweigh the potential risks from the moral hazard" of conducting research.

Ken Caldeira, a geoengineering researcher at the Carnegie Institution for Science and a member of the committee, said that while the panel felt that it was premature to deploy any sunlight-reflecting technologies today, "it's worth knowing more about them," including any problems that might make them unworkable.

"If there's a real showstopper, we should know about it now," Dr. Caldeira said, rather than discovering it later when society might be facing a climate emergency and desperate for a solution.

Dr. Caldeira is part of a small community of scientists who have researched solar radiation management concepts. Almost all of the research has been done on computers, simulating the effects of the technique on the climate. One attempt in Britain in 2011 to conduct an outdoor test of some of the engineering concepts provoked a public outcry. The experiment was eventually canceled.

David Keith, a researcher at Harvard University who reviewed the reports before they were released, said in an interview, "I think it's terrific that they made a stronger call than I expected for research, including field research." Along with other researchers, Dr. Keith has proposed a field experiment to test the effect of sulfate chemicals on atmospheric ozone.

Unlike some European countries, the United States has never had a separate geoengineering research program. Dr. Caldeira said establishing a separate program was unlikely, especially given the dysfunction in Congress. But he said that because many geoengineering research proposals might also help in general understanding of the climate, agencies that fund climate research might start to look favorably upon them.

Dr. Keith agreed, adding that he hoped the new reports would "break the logjam" and "give program managers the confidence they need to begin funding."

At the news conference, Waleed Abdalati, a member of the panel and a professor at the University of Colorado, said that geoengineering research would have to be subject to governance that took into account not just the science, "but the human ramifications, as well."

Dr. Abdalati said that, in general, the governance needed to precede the research. "A framework that addresses what kinds of activities would require governance is a necessary first step," he said.

Raymond Pierrehumbert, a geophysicist at the University of Chicago and a member of the panel, said in an interview that while he thought that a research program that allowed outdoor experiments was potentially dangerous, "the report allows for enough flexibility in the process to follow that it could be decided that we shouldn't have a program that goes beyond modeling."

Above all, he said, "it's really necessary to have some kind of discussion among broader stakeholders, including the public, to set guidelines for an allowable zone for experimentation."