

The Promises and Perils of Geoengineering

Simon Nicholson

Over the last handful of years, a set of radical ideas that have long been confined to the fringes of climate change discussions have begun to edge toward center stage. The ideas are known collectively as geoengineering proposals—sweeping technological schemes designed to counteract the effects of planetary warming. (See Box 29–1 for a full definition.)¹

Many of the best-known geoengineering proposals read like science fiction. One widely circulated idea is to launch giant mirror arrays or sunshades into near-earth orbit, in an attempt to reflect some amount of solar radiation. Other lines of research suggest that a similar effect could be achieved by depositing fine reflective particles of sulfur dioxide in the stratosphere or by deploying a host of ocean-going ships to spray cloud-whitening saltwater high into the sky. At the same time there are ongoing efforts to develop vast machines designed to suck carbon dioxide (CO₂) out of the air, to produce carbon-capturing cement, to lock carbon into soil, and to perfect the dropping of massive quantities of soluble iron into the oceans to encourage great carbon-inhaling blooms of plankton.²

Yet even while many geoengineering proposals sound fantastical, the field is beginning to receive sustained attention from serious people and groups. The Intergovernmental Panel on Climate Change (IPCC) has convened expert meetings to consider the topic. So too have other important scientific bodies around the world. In the United States, government agencies from the Pentagon through the Department of Energy have advocated that federal dollars be devoted to geoengineering research, and research teams in universities and the private sector in many countries are looking to move beyond theorizing about global climate control to technological development and deployment.³

Even as sober a scientific voice as President Obama's chief science advisor, John Holdren, who in 2007 had claimed that "belief in technological miracles is generally a mistake," seems to have come at least partly around.

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Box 29–1. Defining Geoengineering

A straightforward definition of geoengineering comes from an influential report issued by the United Kingdom's Royal Society in 2009. Geoengineering, suggests the report, is any “deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change.”

Building on this definition, there are—as physicist David Keith has noted—two key aspects that must delineate a geoengineering enterprise: scale and intent. By these criteria, sending giant mirrors into orbit is clearly a geoengineering activity. So would be the dropping of thousands of tons of iron into the oceans or the introduction of hundreds of tons of sulfate particles into the stratosphere.

Other activities fall in a gray zone. An individual installing a reflective white roof on a house gets a check mark for “intent,” but such an activity fails, by Keith's criteria, to qualify as a geoengineering effort because of limited “scale.” The same can likely be said of a single coal-fired power plant that attempts to capture and sequester some portion of its emitted carbon. On the other hand, if a coordinated nationwide or international effort was made to install white roofs or if a regulatory move required carbon sequestration from coal-fired power plants, then activity would be prompted at large enough a scale to constitute geoengineering.

Source: See endnote 1.

Holdren suggested in 2009, when asked about the geoengineering option, that “we don't have the luxury of taking any approach off the table.... We might get desperate enough to want to use it.”⁴

Dreams of weather and climate control are hardly new. Ancient traditions had a variety of rituals aimed at calling forth favorable weather. Since the beginning of the science age, numerous attempts have been made to create or dissipate rain, to still hurricanes, and to manage ice flows. This has not always been a venerable undertaking. Weather and climate manipulation has throughout history been a field replete with more than its share of tricksters and dreamers. Today a fresh cadre of would-be climate engineers is emerging. They have newly honed scientific understandings, increasing amounts of money, and strengthening political winds at their backs. So what, then, is to be made of geoengineering? Is it a new form of hucksterism? A dangerous folly? Or does geoengineering have some ultimately positive role to play in the transition to a sustainable future?⁵

Answering such questions is hardly straightforward. One important thing to keep in mind is that not all geoengineering proposals are alike. A catch-all category like this hides some very important distinctions. Some geoengineering ideas threaten to unleash extraordinarily high environmental or social costs or promise to concentrate political

power in a troubling fashion. Other proposals, if developed in sensible and sensitive ways, hold out some real hope for a world adjusting to a changing climate. Making sense of geoengineering demands a separation of the reality from the hype—and a separation of the ideas that are altogether too risky from those that appear a good deal more benign.

A Look at the Geoengineering Landscape

In November 2007, the U.S. National Aeronautics and Space Administration (NASA) hosted a meeting of handpicked scientists at the Ames Research Center in San Francisco, California. The meeting was called to look at the innocuous-sounding enterprise of “managing solar radiation.”⁶

The gathering brought together an array of geoengineering luminaries. While their main goal was development of a scientific research agenda for

this developing field, a central theme over the two days of conversation was impatience and frustration with the traditional suite of measures put forward to tackle climate change. United Nations–sponsored political negotiations, carbon trading schemes, attempts to promote alternative energies—all were seen by those in attendance as doomed to fail or to be progressing far too slowly to avert disaster.⁷

In this, the tone of the Ames meeting echoed a message from a particularly influential geoengineering paper in 2006 by Nobel prize–winning chemist Paul Crutzen. There, Crutzen had labeled attempts by policymakers to bring about reductions in greenhouse gas (GHG) emissions as “grossly unsuccessful.” He went on to call the hope that emissions could be brought under control rapidly enough to prevent widespread climate catastrophe a “pious wish.”⁸

Such views are the entry point into the world of geoengineering. By just about any available measure, the climate situation is worsening. As Arctic ice melts, sea levels rise, wildfires increase in frequency and severity, and storms worsen, there is a growing sense in influential quarters that political and social strategies aimed at reducing GHG emissions are proving hopelessly ineffective. The stage is set for a shift in focus to dramatic, technology-based climate stabilization measures.

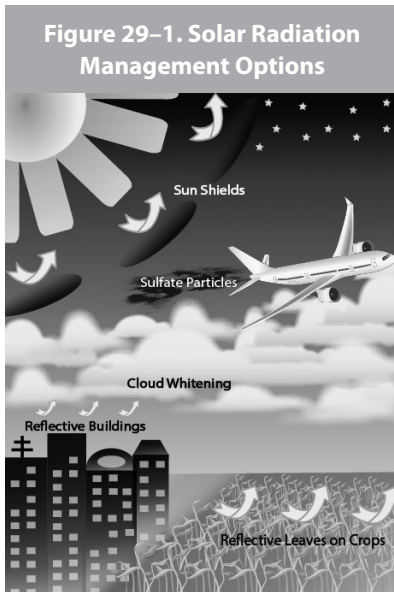
The technological strategies under consideration fall into two basic categories. The first are the kinds of solar radiation management (SRM) techniques that were under explicit consideration at the Ames meeting. SRM techniques are concerned with blocking or reflecting sunlight. Such a feat could, in theory, be achieved by boosting Earth’s surface albedo—its reflectivity—using any of a variety of methods or by preventing some portion of solar radiation from ever reaching the Earth’s surface. The second category is carbon dioxide removal (CDR). Strategies under this heading are concerned with drawing CO₂ out of the atmosphere and locking it into long-term storage.

Solar Radiation Management. The central notion underlying SRM efforts is straightforward, although in its implications SRM is a recipe for audacious action. Basic atmospheric science tells us that as greenhouse gas concentrations rise, so does the atmosphere’s ability to lock in heat from the sun. It is this simple fact, a brute product of chemistry and physics, that is pushing up global average temperatures. As human activity ups the planet’s levels of CO₂ and other greenhouse gases, the average temperature of the planet continues to rise.⁹

The most obvious way to prevent further warming is to stop putting excessive amounts of GHGs into the atmosphere. Failing that, the warming effect of these heat-trapping gases could, in theory, be counteracted by scattering or deflecting some percentage of incoming solar radiation. Models

of the climate system suggest that the heating associated with a doubling of CO₂ could be neutralized by deflecting about 1.5–2.0 percent of the sum total of the sun’s energy currently striking Earth. To achieve a feat of this magnitude—to, in effect, dim the sun—would be an extraordinary undertaking. On the other hand, the enterprise is far from unimaginable.¹⁰

There are, in fact, some well-established options for SRM. They start at ground level, with activities focused on the world’s lands, waterways, ice packs, and oceans, and extend all the way into the far reaches of space. (See Figure 29–1.)¹¹



Source: Graphic designed by Isabelle Rodas

At ground level, the basic strategy is to make some portion of the planet’s surface shinier. Some scientists are betting on the genetic engineering of crop varieties with more reflective leaves. If deployed on large enough a scale, such an innovation could reflect some measurable amount of solar radiation directly back into space. Other ideas include the creation of oceanic foams or the addition of reflective bubbles to expanses of the world’s seas or the placement of reflective materials in deserts, over areas of polar ice, or in the oceans. U.S. Secretary of Energy Steven Chu has called for home and business owners to whiten the roofs of their buildings. At large enough a scale, such an undertaking could have a small but discernible effect on the earth’s climate.¹²

Moving up to the lower atmosphere, the leading idea is to increase “oceanic cloud albedo”—that is, to make clouds whiter and more reflective. This was first proposed in the context of climate geoengineering by climatologist Jonathan Latham in 1999. It is Scottish engineer Stephen Salter, however, who has become cloud whitening’s poster child. Salter has envisaged a fleet of 1,500 computer-controlled “albedo yachts.” These wind-powered ocean-going vessels would draw water from the seas and deliver it in micron-sized droplets into the cloud layer. Developing precisely the right size for sprayed saltwater droplets is a big part of the engineering challenge for this scheme: too big a drop would simply rain back to earth; too small a drop would evaporate without a trace.¹³

While cloud whitening is an idea that has reportedly been getting some financial support from sources like the Gates Foundation, it is the upper atmosphere that has been receiving the most attention from SRM enthusiasts. Cooling the planet by introducing reflective material into the stratosphere is actually a geoengineering technique that has a direct analogy in nature. Erupting volcanoes can introduce vast quantities of material into the atmosphere, and the cooling effects of these natural events have long been noted and measured. Indeed, a real-world test of the “put sulfur in the stratosphere” idea happened relatively recently. When Mount Pinatubo in

the Philippines erupted in 1991, a gaseous plume containing an estimated 20 million tons of sulfur dioxide enveloped the planet. The Earth's average temperature fell by a remarkable 0.5 degrees Celsius for 18 months.¹⁴

The trick, for geoengineers, would be to reproduce something like the Pinatubo effect over a sustained period and in a controlled fashion. A steady supply of sulfate particles, or perhaps some other material with similar properties, could conceivably be introduced into the upper reaches of the atmosphere via ballistics—which is to say, as historian James Fleming has put it, by “declaring war on the stratosphere.” Other proposals involve streaming sulfate particles through giant hoses tethered to helium-filled balloons or adding sulfates to jet fuel. The required sulfur could itself be harvested in the needed quantities from coal-fired power plants, in effect rendering two of the main contributors to climate change—jet travel and the burning of coal—central components of the fix.¹⁵

Paul Crutzen, in his 2006 article, suggested that the stratospheric sulfur approach to climate stabilization could be developed and implemented for \$25–50 billion a year—a small fraction of the 5–20 percent of global gross domestic product that Nicholas Stern estimated, in his much-cited report for the U.K. government, climate change will cost the global economy if no remedial action is taken. One way to get more bang for these bucks would be to deploy stratospheric sulfate aerosols (or, perhaps, ground-level whitening) in a targeted fashion. Consider the Arctic. Shielding the Arctic from some percentage of solar radiation could, some suggest, rapidly reverse global warming–induced ice melt. Since melting Arctic ice sparks two very powerful and potentially dangerous feedback loops that affect the climate system—by releasing stored methane and exposing dark water that absorbs higher levels of solar radiation—arresting Arctic warming would be a logical priority for this sort of geoengineering approach.¹⁶

Finally, the most “way out” SRM strategy—way out in every sense—would involve launching sunshades into space. This would be by far the most technologically challenging of the options listed, but speculative accounts in support of the idea abound. A well-known proponent is astrophysicist Roger Angel. His plan is for a “cloud of many spacecraft,” with each small vessel consisting of a transparent material designed to reflect solar radiation, all launched into orbit using a system of ion propulsion. Angel has suggested that such a scheme could be in place in as few as 25 years, for a cost of a few trillion dollars.¹⁷

Carbon Dioxide Removal. While SRM options can potentially turn down the heat, they do nothing to clear the air of CO₂ and other greenhouse gases. This means that if an SRM project were to be successfully developed, it would have to be continued indefinitely. Otherwise, the full pent-up warming effect of rising atmospheric GHG concentrations would be sud-

denly unleashed. SRM also does nothing to curtail ocean acidification and the other disruptions that increases in CO₂ concentrations can cause. Here is where carbon dioxide removal enters the picture. With CDR, the idea is to draw significant amounts of carbon out of the atmosphere and then store it in some benign, long-term fashion.

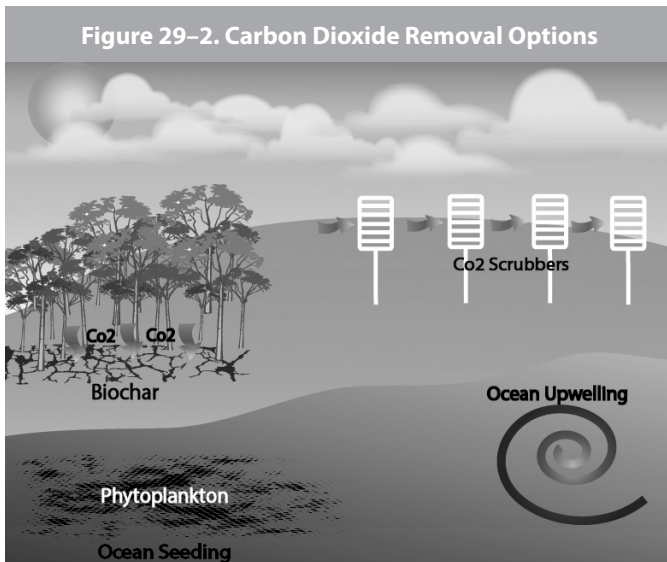
The United Kingdom's Royal Society, in an influential 2009 report, identified and analyzed a variety of CDR possibilities, dividing the schemes into land-based and ocean-based options. (See Figure 29–2.) One land-based idea that has captured a good deal of attention is development of a new generation of mechanical CO₂ “scrubbers.” The hope for these machines is that they could pull large quantities of CO₂ directly from the air. This is quite

different from most carbon capture and storage schemes currently under discussion, which aim to remove CO₂ from the flue gases that escape from fossil-fuel driven power plants. A company calling itself Carbon Engineering based in Alberta, Canada, and started by academic David Keith is a leading proponent of CO₂ scrubbers that operate apart from power stations, and it has developed a functioning prototype.¹⁸

An alternative land-based CDR approach involves sequestering carbon in biomass. The most obvious way to do this is to plant a whole bunch of trees or, on a large enough scale, to invest in tilling methods that encourage carbon to be taken into and stored in the soil.

Finding adequate land area for such schemes is the central limiting factor. Or perhaps biomass could be grown and then converted into liquid or hydrogen fuels, with the CO₂ from combustion of those fuels then captured and stored. Another idea in which a great deal of hope has been invested is the “biochar” option, which has captured the attention of figures like James Lovelock of Gaia hypothesis fame. Biochar involves growing biomass, combusting the living material to produce charcoal, and then burying the charcoal in the soil, which in turn serves both as carbon sink and soil enhancement.¹⁹

As for the oceans, the most talked-about CDR possibility is ocean seeding. Here the idea is to take advantage of the natural process whereby phytoplankton take in carbon from the atmosphere. When these plankton die, they sink to the ocean floor. Under certain conditions the carbon they con-



Source: Graphic designed by Isabelle Rodas

tain may remain under the ocean in a benign form for many centuries. Some would-be geoengineers hope to encourage blooms of carbon-hungry phytoplankton by introducing soluble iron into areas of the oceans in which iron is in relatively short supply. Though this idea makes sense in theory, the few field trials that have been undertaken have given mixed results. In one early trial, iron dumped into the South Atlantic did indeed trigger a plankton bloom. However, most of the additional plankton was eaten by a swarm of shrimp before it reached the bottom of the ocean. Ocean seeding, as with all the geoengineering proposals just described, has all kinds of challenges associated with its successful development, including any number of problems that cannot readily be anticipated in advance of full-scale deployment.²⁰

Suffice it to say, some CDR schemes on both land and water would depend on the willful augmentation and use of existing biological or chemical systems, while others would require the development of entirely new mechanical arrays. There is, ultimately, no shortage of schemes for drawing down the planet's surfeit of atmospheric carbon. The question then becomes where to put it and whether the carbon will stay where it is deposited. What was once thought to be the easy part of the "carbon capture and storage" puzzle is now turning out itself to be extraordinarily thorny.

The obvious place to put billions of tons of carbon is into the depleted oil wells from which much of it originally came or into porous rock formations deep underground. Carbon dioxide, once captured, can be transformed into a liquid and forced under pressure into such belowground formations. A handful of demonstration projects in Canada, Algeria, Norway, and the United States have shown the feasibility of this carbon storage approach.²¹

But feasibility does not mean practicality. Part of the problem is the sheer scale of the proposed undertaking. For instance, one estimate suggests that liquefying 60 percent of the CO₂ that U.S. coal-fired power plants produce annually in order for the CO₂ to be stored underground would amass about the same volume of liquid as the United States currently consumes in oil—that is, on the order of 20 million barrels a day. There is also the challenge associated with keeping the carbon in underground storage for, it is to be supposed, many thousands of years. Potential problems like groundwater contamination or the sudden release of vast quantities of CO₂ appear small but by no means negligible.²²

The bottom line is that research into these and many other ideas has already begun. There is much hope in the geoengineering community that a real, workable techno-fix can be developed. Still, very few are pretending that the task is an easy engineering puzzle. At the Ames meeting in 2007, for instance, hope for a technological breakthrough to tackle climate change was apparently tempered with a well-honed appreciation for the extraordinary nature of the challenge. We can just hope that there was also a strong

sense of irony present in the meeting room, given this anecdote related by James Fleming, who was present at the meeting: “Even as [conference participants] joked about a NASA staffer’s apology for her inability to control the temperature in the meeting room, others detailed their own schemes for manipulating the earth’s climate.”²³

Affixing a thermostat to the planet’s climate system should be considered no small task for a species that struggles to control the temperatures in its meeting spaces.

Parsing Geoengineering’s Costs

So, can human beings willfully use large-scale technologies to cool the planet? The answer is almost certainly yes. A different and altogether trickier question is, Should we? Is the geoengineering path really worth pursuing?

For some, the answer is a resounding “of course.” Richard Branson, for instance, chairman of Virgin Atlantic airlines and a host of other companies, is a well-known proponent of geoengineering: “If we could come up with a geoengineering answer to this problem, then [international climate change meetings like] Copenhagen wouldn’t be necessary. . . . We could carry on flying our planes and driving our cars.” Branson is investing more than words in pursuit of a solution that would leave his core business—flying people around the world—intact. In 2007 he kicked off the \$25 million Virgin Earth Challenge, an ongoing search for commercially viable ways to pull carbon out of the atmosphere.²⁴

Others, including the vast majority of scientists involved in geoengineering research, are far more circumspect. Hugh Hunt, a professor of engineering at Cambridge University, who is part of a team working on delivery systems to introduce reflective particles into the stratosphere, has summed up the general feeling among scientists working on geoengineering in this way: “I know this [talk of geoengineering] is all unpleasant. Nobody wants it, but nobody wants to put high doses of poisonous chemicals into their bodies, either. That is what chemotherapy is, though, and for people suffering from cancer those poisons are often their only hope. Every day, tens of thousands of people take them willingly—because they are very sick or dying. This is how I prefer to look at the possibility of engineering the climate. It isn’t a cure for anything. But it could very well turn out to be the least bad option we are going to have.”²⁵

This talk of cures suggests a critically important distinction that must be drawn, if it is not already clear. The only real way to tackle climate change is to stabilize and then work to dramatically reduce the atmospheric concentration of greenhouse gases. The surest way to achieve such a feat is to break the world’s addiction to fossil fuels. (See Chapter 14.) CO₂ removal schemes offer a back-end work-around—emit the carbon and then retrieve it—and

so can be seen as another way to resolve the central dynamic driving climate change. In other words, it is possible to imagine that CDR really does offer a kind of “cure” to the climate malady. But with current technologies, it is hard to see a CDR scheme coming online quickly enough or being deployed at large enough a scale to make a real dent in the atmospheric carbon load.

So it is SRM, rather than CDR, strategies that are receiving the bulk of the attention in geoengineering circles. And for SRM approaches, Hunt’s circumspection is absolutely warranted. Solar radiation management is not any kind of real answer to climate change. At best, SRM can reduce the planet’s fever for a period, perhaps allowing time for the real roots of climate change to be tackled.

Still, such distinctions are easily lost. Talk of geoengineering is gaining traction at least in part because of Richard Branson’s line of argument. That is, geoengineering has the appearance of an easy, sacrifice-free approach to tackling climate change. Finding ways to reduce the world’s dependence on fossil fuels is hard and messy. In contrast, developing some kind of geoengineering techno-fix looks easy and clean. Yet it is critically important to recognize that there are sacrifices, some obvious and some harder to spot, associated with the bulk of the geoengineering schemes under serious consideration—sacrifices that can be summarized as material, political, and existential.²⁶

Material Sacrifices. Perhaps the most obvious cause for concern is that geoengineering interventions could go catastrophically wrong. The great historian of technology Henry Petroski has argued in a series of books that failure is in the very nature of technological design. He once noted that while the object of engineering design is to reduce the possibility of failure, “the truly fail-proof design is chimerical.” In fact, Petroski has shown in a persuasive fashion that technological development has in a very basic sense depended on failure, since the lessons learned from failed design can often teach a great deal more than successful machines and structures.²⁷

Given the scope of the geoengineering endeavor, however, that calculus cannot apply. A problem with a new design for a television set or a new line of running shoes may provoke irritation. A problem with a space mirror or stratospheric sulfur deployment, on the other hand, could have truly devastating, irreparable consequences. With many of the geoengineering proposals on the table there is scant room for error. This is a worrying notion, particularly if influential elites become hell-bent on deploying geoengineering options, since as environmental studies professor Roger Pielke, Jr., has put it, “There is no practice planet Earth on which such technologies can be implemented, evaluated, and improved.”²⁸

The potential for catastrophe depends, of course, on the type and scale of the planned geoengineering scheme. As a group, SRM approaches offer the biggest potential for disaster, and computer modeling is our best cur-

rent tool for understanding the potential risks. Some forecasts based on computer modeling have looked anything but promising. For instance, one research team, during work for the IPCC, concluded that any large-scale attempt at SRM would likely have serious adverse climate effects, most notably a sharp decline in rainfall due to decreased evaporation at the tropics and a reduced ability of the climate system to transport wet tropical air to higher and lower latitudes.²⁹

Along with the danger of things going wrong, there are also massive challenges associated with things going exactly as planned. Even if executed without a hitch, certain geoengineering schemes would entail extraordinarily complex trade-offs. Under an SRM scenario, rainfall—even if it were not reduced—would almost certainly be redistributed by any radical intervention in the climate system. Some regions would see more rain, some would see less. The eruption of Mount Pinatubo has been linked to disruption of the Asian monsoon. To take two other examples, shooting sulfur into the

sky would cause acid rain and would promote stratospheric ozone depletion, while adding iron to the oceans would drive the overuse of important nutrients, potentially causing massive disruption of ocean ecosystems. These most promising of SRM techniques, in other words, would force those who seek to use them to choose among competing environmental disasters.³⁰

With this in mind, geoengineering is, it must be said, too grand a name for the enterprise. “Geo-tinkering” is closer to the mark. The climate system is incompletely understood. Any

intervention would be tentative at best, with catastrophic failures likely. And this is taking account just of the problems that are relatively easy to forecast. Complex technologies and technological systems have a habit of “biting back,” as historian Edward Tenner once put it, in ways hard to predict and sometimes hard to respond to.³¹

Given the stakes and challenges, 40 years ago British meteorologist H. H. Lamb suggested that before embarking down the geoengineering path, “an essential precaution [is] to wait until a scientific system for forecasting the behavior of the natural climate...has been devised and operated successfully for, perhaps, a hundred years.”³²

Political Sacrifices. Waiting 100 years for greater levels of scientific cer-



Courtesy/USGS

The 1991 eruption of Mount Pinatubo in the Philippines.

tainty is sage advice, but it is unlikely to be followed. This is because the political pressure to rapidly deploy geoengineering technologies may become overwhelming as the effects of climate change grow more pronounced. Mustering the political will to generate large-scale social change in response to climate change is proving, to state the obvious, difficult. However, should melting ice drive rapid sea level rise, or should climate-related food and water pressures cause great suffering in industrial countries (rather than just in developing ones, as at present), or should some other fast-moving climate calamity force the hand of rich-country elites, then swift technology-based action may suddenly be demanded.

Deploying geoengineering technologies under such circumstances would likely be met with more limited social and political resistance than might be expected, given that geoengineering fits into a broader narrative about using technologies to solve complex problems and that geoengineering approaches require little buy-in or behavior change by the public.

Scientists are eager to start with small-scale geoengineering experiments rather than be forced into large-scale development. If political pressure mounts, though, starting small would be hard. If geoengineering comes to be seen as a last-gasp option, the impetus will be toward rapid, full-scale deployment. There is no guarantee in such a situation that those who end up with their metaphoric hands on the planet's thermostat would act in the global interest rather than following some other calculus. Imagine for a moment that the U.S. government could deploy stratospheric sulfur for the direct short-term benefit of the North American continent. What if that deployment threatened African rainfall patterns? Or imagine a time when the United States is having a rotten summer while Europe is experiencing a heat wave: Who gets to adjust the mirror? What, to play this scenario out, of the legal costs to societies when every bad harvest or vacation spoiled by too much rain is thought to be the fault of distant geoengineers?

Space mirrors, stratospheric sulfur schemes, and the like—all require concentration of materials and political authority. By this measure, many geoengineering schemes have a distinctly anti-democratic flavor. Who, then, gets to call the shots in a geoengineered world? Who will receive the benefits? What of small countries with limited economic means and limited political voice? What of villages that happen to be situated on top of the perfect location for underground carbon storage? The questions that can be raised about such activities are endless.

The history of weather modification efforts and of technological development more generally suggests that tussles over mirror alignment might be the smallest of our problems. Militarization could be a far bigger challenge. The militaries of the world's great powers have long looked to weather modification as a potentially potent weapon of war. Given such a history,

James Fleming has suggested that “it is virtually impossible to imagine governments resisting the temptation to explore military uses of any climate-altering technology.”³³

Finally, there is a very real danger that a focus on geoengineering saps the political will for other forms of action. It is, tragically, in our collective nature to hope for a miracle. It is in the nature of our politicians and business leaders to promise one. This is the case despite repeated injunctions from scientists to continue work on traditional mitigation efforts even as research on geoengineering technologies advances.

Existential Sacrifices. This leads to a third category of geoengineering sacrifice—a category that we might call “existential.” The ability to control the weather was once the prerogative of a divine creator. Now it is a technique within the reach of the world’s governments, large corporations, and even wealthy individuals. The transgression of previously sacred and inviolable boundaries that is the product of such a development may seem abstract in the face of climate change, but it is actually profoundly important.

This is because more technology alone does not, despite narratives to the contrary, equal progress. Progress signals movement toward some goal. The large-scale development of geoengineering technologies would render some goals realistic and others unattainable. To imagine that geoengineering is some passive, neutral enterprise, forced on humanity by a changing climate, is to ignore the other options for response that are available and to ignore the role played by the blind worship of technology in creating the current ecological mess.

Now, there is no denying that, as Stewart Brand of the Long Now Foundation has put it, “humanity is stuck with a planet stewardship role.” The question is what to do with that role. The ultimate ecological question is a deceptively straightforward one: What kind of future will we craft? Because craft it we will. Does that crafting entail a kind of global biospheric management—the geoengineering path—or something else? A different vision of the future would privilege shared sacrifice, directed toward living well and meaningfully within ecological limits. Some geoengineering options close off or render unimaginable such a pathway. Why live differently if space mirrors will come to our rescue? A few geoengineering options, though, may be compatible with a world in which sufficiency rather than domination is the guiding ethic.³⁴

Political theorist Langdon Winner once coined a useful phrase that it is worth keeping in mind: “technological somnambulism.” Too often, he suggested, people tend to sleepwalk through the making of technological decisions. With geoengineering, the scope is too vast and the implications too all-encompassing for any kind of passive decisionmaking. The risks and impacts of geoengineering cannot be considered in isolation. They must be

compared with the risks of doing nothing in the face of climate change, certainly, but also the risks and benefits that inhere in other forms of response.³⁵

The Future of Planetary Engineering

Is geoengineering something to be avoided at all costs? Or is it, perhaps, “a bad idea whose time has come?” It is relatively easy to poke holes in the geoengineering enterprise. Humanity’s track record with large-scale technological deployment hardly gives one faith in the ability of geoengineers to completely and without harm manage the entire climate system. Scientific elites have too often had a misplaced faith in their abilities to cut through complex social problems. The horrors of the early years of the nuclear age and the ongoing blight of global hunger are just two obvious examples.³⁶

Still, at the same time as there is cause for real concern about the geoengineering push, doing nothing in the face of climate change is itself not an option. And the track record of recent international climate change meetings and of most efforts to wean individuals and communities from fossil fuel dependence hardly gives cause for optimism.

Perhaps the most dangerous of all future scenarios is that the climate situation becomes so bad so quickly that rogue actors try to implement some geoengineering option about which very little is understood. The specter of such a future was raised in a particularly stark way in October 2012. That month the public learned that Russ George, an American who for some time has dabbled in the world of geoengineering, had that summer taken a ship out into the Pacific Ocean and dumped something like 100 tons of iron sulfate into the water. George claimed that his actions represented “the most substantial ocean restoration project in history.” Given the many risks attached to such an enterprise, a different label, proposed by writer Michael Specter, is more apt. Russ George is now, officially, the world’s first “geovigilante.”³⁷

He is unlikely, though, to be the last. The genie of geoengineering is not going back into any bottle any time soon. Are there ways, then, that geoengineering’s development and deployment might be effectively governed? There is a difficult dance to choreograph here. Scientists need the freedom to propose and test geoengineering options without their work being used as an excuse to delay real mitigation actions. The public and the planet need to be protected from rogue geoengineering efforts and well-intentioned efforts run amok. There is a desperate need for transparency and openness in the development of geoengineering technologies, even as the deployment of those technologies is tightly managed.

With these sorts of challenges in mind, a team of scholars in the United Kingdom drafted in 2011 a short declaration that is now known as the Oxford Principles as a code of conduct for geoengineering research. (See Box

29–2.) In this way, scientists working on geoengineering are echoing the efforts of the 1975 Asilomar Conference on Recombinant DNA—trying to self-regulate by way of the establishment of clear guidelines for safe and ethical conduct. Such efforts are to be applauded and must receive further and widespread support. The straightforward and declarative nature of the Oxford proposal is as good a place as any to start the wide conversation that now must take place about the managed development of geoengineering options.³⁸

Box 29–2. The Oxford Principles: A Code of Conduct for Geoengineering Research

- Geoengineering to be regulated as a public good.
- Public participation in geoengineering decisionmaking.
- Disclosure of geoengineering research and open publication of results.
- Independent assessment of impacts.
- Governance before deployment.

Source: See endnote 38.

Box 29–3. Criteria for “Soft Geoengineering” Technologies

- Can be applied locally.
- Scalable to larger areas.
- Low or no anticipated negative impacts on ecosystems or society.
- Rapid reversibility if problems do arise.
- Has multiple benefits beyond impacts on climate.
- Analogous to natural processes.
- Effects are large enough soon enough to be worthwhile.
- Cost-effective with mature technologies deployed at moderate scale.

Source: See endnote 39.

Futurist Robert L. Olson has gone further to suggest a set of criteria that differentiate “soft geoengineering” technologies—those that can actually make a difference in the face of a changing climate but that have relatively few risks attached to their development—from their more dangerous cousins. (See Box 29–3.) Olson starts from the position that a sweeping dismissal of all geoengineering options may prove imprudent. Given the complexity of the climate challenge, he is almost certainly right. Far more useful than sweeping rejection is a clearheaded evaluation of the options before us. Are there really, as Olson believes, possibilities for geoengineering that entail “low or no significant negative impacts”? If so, then careful development of “soft geoengineering” options by credible actors should become a legitimate part of our efforts to tackle climate change.³⁹

Olson’s criteria focus on geoengineering’s technical elements. By his reckoning, options like brightening water through the infusion of “micro-bubbles,” blanketing vulnerable areas of ice and water in reflective fabrics, working to improve direct-air capture technologies for CO₂, and building up carbon in soil and vegetation are no-brainers,

since they offer real hope for slowing the destruction of vulnerable areas while limiting potential downsides. White roofs and other such efforts to make urban spaces more reflective should also receive attention, but whether a roof whitening scheme could ever be undertaken on a scale to make any real difference is an important consideration. On the other hand, some options—like stratospheric aerosols, space mirrors, and seeding the oceans with iron—have far too many associated risks and offer far too many technical hurdles to be taken seriously, at least at present.

Another criterion can usefully be added to Olson's list: local and democratic control. Forays into geoengineering could, conceivably, be part of the move to a more just and sustainable social order—but only if the technological development that geoengineering entails is tied to the cultivation of humanity's oldest political virtues, including humility and compassion. A moratorium on geoengineering is doomed to fail. At the same time, pushing ahead with the most outlandish geoengineering schemes is likely to result in catastrophic failure of a wholly different variety. The need is for a middle ground—not geoengineering as techno-fix but rather geoengineering as one small part of an effort to steer the world to a state of rightness and fitness in ecological and social terms.

Chapter 29. The Promises and Perils of Geoengineering

1. Box 29–1 based on The Royal Society, *Geoengineering the Climate: Science, Governance and Uncertainty* (London: 2009), and on D. Keith, “Geoengineering the Climate: History and Prospects,” *Annual Review of Energy and the Environment*, vol. 25 (2000), pp. 245–84.
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3. Intergovernmental Panel on Climate Change (IPCC) Expert Meeting on Geoengineering, Lima, Peru, 20–22 June 2011; U.S. government efforts from E. Kintisch, *Hack the Planet* (Hoboken, N.J.: John Wiley & Sons, 2010), p. 12.
4. Holdren quoted in A. Jha, “Obama Climate Adviser Open to Geo-engineering to Tackle Global Warming,” (London) *Guardian*, 8 April 2009.
5. J. Fleming, *Fixing the Sky: The Checkered History of Weather and Climate Control* (New York: Columbia University Press, 2010).
6. L. Lane et al., eds., *Workshop Report on Managing Solar Radiation*, Ames Research Center, 18–19 November 2006 (Washington, DC: National Aeronautics and Space Administration, 2007).
7. J. Fleming, “The Climate Engineers: Playing God to Save the Planet,” *Wilson Quarterly*, spring 2007, p. 46.
8. P. Crutzen, “Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?” (essay), *Climatic Change*, August 2006, pp. 212, 217.
9. Periodic assessments from the IPCC available at www.ipcc.ch; a useful popular primer is B. McKibben, “Global Warming’s Terrifying New Math,” *Rolling Stone*, 19 July 2012.
10. IPCC, *Third Assessment Report: Climate Change 2001—Working Group III: Mitigation*, section 4.7.
11. Figure 29–1 designed by Isabelle Rodas.
12. A. Ridgwell et al., “Tackling Regional Climate Change By Leaf Albedo Bio-geoengineering,” *Current Biology*, vol. 19, no. 2 (2009) pp. 146–50; “Secretary Chu Announces Steps to Implement Cool Roofs at DOE and Across the Federal Government,” press release (Washington, DC: U.S. Department of Energy), 19 July 2010.
13. See C. Mims, “‘Albedo Yachts’ and Marine Clouds: A Cure for Climate Change?” *Scientific American*, 21 October 2009.
14. Gates Foundation from O. Dorell, “Can Whiter Clouds Reduce Global Warming?” *USA Today*, 11 June 2010; for what Ken Caldeira calls the “Pinatubo option,” see Kintisch, op cit. note 3, p. 56.
15. A. Robock et al., “Benefits, Risks, and Costs of Stratospheric Geoengineering,” *Geophysical Research Letters*, vol. 36, L19,703 (2009); quote from Fleming, op. cit. note 7; helium-filled balloons from Crutzen, op. cit. note 8; J. Pierce et al., “Efficient Formation of Stratospheric Aerosol for Climate Engineering by Emission of Condensible Vapor from Aircraft,” *Geophysical Research Letters*, vol. 37, L18,805 (2010).
16. Crutzen, op. cit. note 8; N. Stern, *The Economics of Climate Change: The Stern Review* (Cambridge, U.K.: Cambridge University Press, 2007).
17. R. Angel, “Feasibility of Cooling the Earth with a Cloud of Small Spacecraft near the Inner Lagrange Point (L1),” *Proceedings of the National Academy of Sciences*, 14 November 2006, pp. 17,184–89.
18. The Royal Society, op. cit. note 1; Carbon Engineering, at www.carbonengineering.com; Figure 29–2 designed by Isabelle Rodas.
19. Kintisch., op cit. note 3; K. Roberts et al., “Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential,” *Environmental Science & Technology*, vol. 44, no. 2 (2010), pp. 827–33.
20. C. Bahric, “Hungry Shrimp Eat Climate Change Experiment,” *New Scientist*, 25 March 2009.

21. Intergovernmental Panel on Climate Change, “Carbon Dioxide Capture and Storage: Summary for Policymakers,” Geneva, September 2005; Global CCS Institute, “The Global Status of CCS: 2012,” (Canberra: 2012).
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23. Fleming, *op. cit.* note 7, p. 48.
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25. Quoted in M. Specter, “The Climate Fixers,” *New Yorker*, 14 May 2012.
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28. R. Pielke, Jr., *The Climate Fix* (New York: Basic Books, 2010), p. 132.
29. H. Schmidt et al., “Solar Irradiance Reduction to Counteract Radiative Forcing from a Quadrupling of CO₂: Climate Responses Simulated by Four Earth System Models,” *Earth System Dynamics*, vol. 3 (2012), pp. 63–78.
30. K. J. Anchukaitis et al., “Influence of Volcanic Eruptions on the Climate of the Asian Monsoon Region,” *Geophysical Research Letters*, vol. 37, L22703 (2010).
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33. Fleming, *op. cit.* 7, p. 60.
34. S. Brand, *Whole Earth Discipline: An Ecopragmatist Manifesto* (New York: Viking, 2009), p. 275; on the notion of sufficiency, see T. Princen, *The Logic of Sufficiency* (Cambridge, MA: The MIT Press, 2005).
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36. Quote from Kintisch, *op. cit.* note 3, p. 13.
37. M. Specter, “The First Geo-vigilante,” *New Yorker*, 18 October 2012.
38. Box 29–2 from “‘Oxford Principles’ Provide a Code of Conduct for Geoengineering Research,” press release (Oxford: Oxford Martin School, University of Oxford, 14 September 2011).
39. Box 29–3 from R. Olson, “Soft Geoengineering: A Gentler Approach to Addressing Climate Change,” *Environment*, September–October 2012, pp. 29–39.