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Committee on Environment and Public Works
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"Responses to Climate Change and their Implications on Preservation and Restoration of the Chesapeake Bay"

Presented by
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Good morning Madam Chairman and Members of the Committee. On behalf of the Thomas Jefferson Institute for Public Policy, we appreciate your invitation to attend this Hearing and thank you for the opportunity to participate in a discussion involving two issues on which the Institute has a continuing strong interest – Restoration of the Chesapeake Bay and the implications of alternative responses to global warming and climate change.

The greatest threat to restoration of the Chesapeake Bay comes not from the potential geophysical effects of climate change, but from the potential responses to climate change and, in particular, exclusive reliance on a strategy of reducing greenhouse gases. The scientific community has reached a consensus on this. As Nobel Laureate Paul Crutzen admits, efforts to forestall climate change exclusively through reductions in greenhouse gases is no more than "a pious wish". [2] [3] Public reports show nations have rejected this strategy[4], and without full, massive global cooperation, reliance on greenhouse gas reductions, alone, will fail.

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[2] P. J. Crutzen, "Albedo Enhancement By Stratospheric Sulfur Injections: A Contribution To Resolve A Policy Dilemma?" *Climate Change,* September 1, 2006; *see*: http://downloads.heartland.org/19632.pdf.

[3] *And see*: William B. Mills, "Geoengineering Techniques To Mitigate Climate Change: From Futuristic To Down-To-Earth Approaches", American Geophysical Union, Fall Meeting 2006, abstract #GC51A-0451, "Within the past several years, more and more scientists are questioning whether these techniques can be implemented on a global scale quickly enough to avoid dangerous anthropogenic climate change impacts. Further, some signatories to the Kyoto Protocol have already indicated they will not be able to meet their reductions of emissions by the agreed upon date of 2012, and in fact expect to increase their emissions. An important question becomes: Are there other mitigation techniques that could be used in a supplemental manner to help control anthropogenically-induced climate change should those techniques mentioned above fall short? In fact there are a variety of techniques that are commonly called geo-engineering methods" http://adsabs.harvard.edu/abs/2006AGUFMGC51A0451M .

In this light, how do we protect the Bay and otherwise address the potential effects of global warming? In his influential law review article, Jay Michaelson suggests, "We need an alternative to the policy myopia that sees emission reductions as the sole path to climate change abatement," and in particular we need to apply geo-engineering that can prevent global warming and reduce acidification of the oceans.[5] Others agree. Alan Carlin, Senior Economist with the U.S. Environmental Protection Agency argues that geo-engineering is "our best hope of coping with a changing world."[6] It is our best hope because we have firm evidence it will work and because the developing world can afford this approach. As Ken Caldeira, a professor of climate science at Stanford University, explains, reducing greenhouse gases will cost around 2 percent of the gross domestic product while geo-engineering (by putting reflective aerosols into the upper atmosphere) will cost about one-thousandth of that.[7]

Indeed, the IPCC[8] and William D. Nordhaus, Sterling Professor of Economics at Yale University, agree that the price tag for preventing the effects of global warming with geo-engineering is so small as to be considered virtually "costless".[9] More significantly, Professor Scott Barrett, Director of the Johns Hopkins University School of Advanced International Studies argues convincingly that because geo-engineering is the only practical means to mitigate catastrophic climate change, and is a virtually costless means of doing so, use of this technology is <u>inevitable</u> and our task is to ensure we do it in a sensible, incremental and reasoned manner.[10]

Thus, any investments in reducing greenhouse gases that would eat away at our existing investment in protecting and restoring the Bay would be the greatest threat to the Bay.

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[4] *See*, *e.g.*, International Herald Tribune at http://www.iht.com/articles/ap/2007/08/18/asia/AS-GEN-Australia-APEC-Emissions.php, documenting China's refusal to attempt an 80% reduction, *and see*, reports on the international agreement to go no further than adopting unenforceable "aspirational" goals at http://www.theage.com.au/news/national/move-to-lower-greenhouse-expectations/2007/08/17/1186857774683.html.
[5] Jay Michaelson (JD Yale), "Geoengineering: A Climate Change Manhattan Project" *Stanford Environmental Law Journal* January, 1998, *see*, http://www.metatronics.net/lit/geo2.html#three
[6] Alan Carlin, "Risky Gamble," *Environmental Forum*, 24(5): 42-7, (September/October, 2007), *see* http://carlineconomics.googlepages.com/CarlinEnvForum.pdf ; and see: "Global Climate Change Control: Is there a Better Strategy than Reducing Greenhouse Gas Emissions?" *University of Pennsylvania Law Review*, June 2007, *see* http://pennumbra.com/issues/articles/155-6/Carlin.pdf ; "Implementation & Utilization of Geoengineering for Global Climate Change Control," *Sustainable Development Law and Policy*, Winter 2007 *see* http://Carlineconomics.googlepages.com/CarlinSustainableDevelopment.pdf ; and "New Research Suggests that Emissions Reductions May Be a Risky and Very Expensive Way to Avoid Dangerous Global Climate Changes," http://yosemite.epa.gov/EE/epa/eed.nsf/WPNumberNew/2007-07
[7] Ken Caldeira, Standford University, quoted in the Christian Science Monitor, *see*, http://www.csmonitor.com/2007/0329/p13s02-sten.htm.
[8] IPCC Climate Change 2001: Report of Working Group III: Mitigation "It is unclear whether the cost of these novel scattering systems would be less than that of the older proposals, as is claimed by Teller *et al*. (1997), because although the system mass would be less, the scatterers may be much more costly to fabricate. However, it is unlikely that cost would play an important role in the decision to deploy such a system. Even if we accept the higher cost estimates of the NAS (1992) study, the cost may be very small compared to the cost of other mitigation options" (*citing to* Schelling, 1996). *See,* http://www.grida.no/climate/ipcc_tar/wg3/176.htm
[9] William D. Nordhaus, "The Challenge of Global Warming: Economic Models and Environmental Policy", Yale University, July 24, 2007; *see*: http://nordhaus.econ.yale.edu/dice_mss_072407_all.pdf .
[10] Scott Barrett, "The Incredible Economics Of Geoengineering" Johns Hopkins University School of Advanced International Studies, 18 March 2007, (in press, *Environmental and Resource Economics*).

Restoration of the Bay requires concerted efforts by local, state and federal governments, and funding from each. It also requires a vigorous, market-based application of advanced agricultural practices.[11] Any threat to that funding or the nascent nutrients market is a threat to restoration of the Bay. To date, private and governmental action has done no more than prevent further Bay degradation in the face of growing populations. To achieve full restoration, this local-state-federal-private coalition must expand its current commitments. It will need significant and continuing federal and state funding, as well as an expansion of the means to trade nutrient reduction credits. If it receives this support, we can look forward to restoration of the Bay within the next 20 years. If not, we simply cannot. Thus, the greatest threat to this restoration is not global warming or climate change. Rather, as explained below, barring an earthquake, and in light of the inevitability of geo-engineering, the strategy of relying exclusively on reduction of greenhouse gases stands as the single greatest threat to restoration of the Bay. If we rely exclusively on reduction of greenhouse gases, and prevent use of geo-engineering, advocates for the Bay will get a smaller slice of a smaller pie and the Bay will disappear in the impending ocean rise.

The remainder of this testimony first explains the timescale of climate change and the inevitable use of geo-engineering. Thereafter you will find a discussion of the Chesapeake Bay, its origin and how we are working to preserve and further restore its vitality. Finally, the testimony concludes with a recommendation that this Committee take a leadership role in building a two-pronged attack on climate change – one relying on geo-engineering as a first response and cost-effective greenhouse gas reduction as a final response.

Climate Change and Geo-Engineering

As the Committee knows, the international policy community defines the term climate change as human-caused changes in climate and geophysical processes. The current assumption is that, if we do nothing, greenhouse gases will cause further increases in global temperature that, in turn, will cause no less than seven irreversible geophysical events. Those events, in turn, will cause large increases in ocean levels and other undesirable outcomes.

The seven (preventable) irreversible events reach their first "tipping point" with melting of the Greenland ice sheet, an event that commences with a 1.2º to 2º C rise in global temperature and which, according to the IPCC(2007) may have already, albeit slowly begun. We must keep in mind, however, that complete melting of the ice sheet would cause a 7 meter ocean rise only after some 300 to 1,000 years. This long melting timescale assumes CO_2 rises to nearly three times the current level (four times the pre-industrial level) and stays that high for a millennium. Notably, science marches on, and in February of this year, a report on the assumptions underlying these estimates indicate that the IPCC estimate of the rate of sea-level rise is 29 percent higher than the actual value, while another analysis suggests the timescale is smaller than the IPCC estimate.[12] Thus, Greenland ice sheet melting may be more than 300

[11] *See*, David W. Schnare, "Only a Market Can Clean Up the Bay", PERC Reports (June 2007) http://www.perc.org/perc.php?subsection=5&id=887 .

[12] G. Wöppelmann, et al., "Geocentric sea-level trend estimates from GPS analyses at relevant tide gauges world-wide", *Global and Planetary Change* 57 (2007) 396–4. *But note*, while not a specialist in glaciers and ice sheets, Jim Hansen (NASA) argues that by 2100 we could expect a five meter rise in ocean levels due to melting of the

years off. [13] The other six events do not reach their tipping points until global temperatures increase by about 3º to 6º C and include: loss of the Amazon rainforest, melting of the West Antarctic Ice Sheet, loss of boreal forests, massive positive and negative rain and heat effects in the Sahara and Sahel, stoppage of the Atlantic ocean circulatory system, and increases in ENSO amplification, leading to large shifts in climate over important agricultural lands worldwide. [14] The only event necessary to destroy the Bay is complete melting of the Greenland ice sheet.

If permitted to occur, the land surrounding the Bay would eventually flood and the Bay itself would become no more than a part of the continental shelf. Under this assumption, as the watershed slowly submerges, the Bay environs would lose habitat, ecological integrity and commercial and recreational value. Notably, as part of a new coast line, we would also gain habitat, evolve a new ecological system and gain new commercial and recreational opportunities. According to the IPCC(2007), the loss of existing shoreline would begin very slowly and inundation would not occur for 300 to 1,000 years. As discussed below, natural processes may cause a similar degree of flooding at any time and are more likely to occur than the predicted climate change.

Increasing greenhouse gas levels may also cause a second undesirable effect, ocean acidification. Modeling of climate change acidification effects has not focused on the Bay or similar estuarial waters, particularly with regard to the types of organisms prevalent in or sought to be resurrected in the Bay and its freshwater tributaries. Geo-engineering can also address this problem, as seen in the liming activities long used in Scandinavia to prevent acidification of their fragile lakes.

We have every reason to believe that neither of these climate change-related geo-physical effects will ever harm the Bay because, as Professor Barrett explains, some party will apply geo-engineering techniques that will prevent the warming and protect the commercial activities in the Bay. What, then, is geo-engineering?

Geo-Engineering – The Inevitable Response

In general, geo-engineering is the deliberate modification of large scale geophysical processes and, in the context of this testimony, that means by processes other than by limiting the atmospheric concentration of greenhouse gases. The first of the two most common examples cited is placement of reflective aerosols into the upper atmosphere in order to reflect incoming sunlight and thus reduce global temperature. The second is injecting iron into parts of the ocean in order to speed the growth of phytoplankton and thus sequester carbon. Similar techniques can be used to inject lime into the ocean and reduce near-coast water acidity, and thereby protect coral reefs and shellfish.

Greenland ice sheet. As argued by Barrett, the timescale estimate is irrelevant as a mere one foot increase in sea level will occasion the inevitable use of geo-engineering.

[13] G. Wöppelmann, et al., "Geocentric sea-level trend estimates from GPS analyses at relevant tide gauges world-wide", *Global and Planetary Change* 57 (2007) 396–4.

[14] Timothy M. Lenton, "Tipping Points or Gradual Climate Change?", (t.lenton@uea.ac.uk) School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

You might think of geo-engineering as a human effort to replicate natural processes such as volcanic eruptions that inject large quantities of sulfates into the air and thereby shield the planet from sunlight. The eruption of Mount Pinatubo in the Philippines in 1991 injected a significant amount of sulfur dioxide into the stratosphere, lowering the Earth's surface temperature by about 0.5ºC the year following the eruption.[15]. Indeed, there have been many examples of intended and unintended geo-engineering, including some that have exacerbated warming. For example, when coal is burned, sulfate particles are thrown into the troposphere, thus limiting the amount that global temperatures rise due to carbon dioxide, something also produced when burning coal. But, the U.S. EPA has established regulations to limit the emission of sulfates into the atmosphere and by reducing emissions of these sulfate particles, U.S. EPA has inadvertently exacerbated global warming. In another example, jet aircraft routinely emit sun-blocking exhaust into the atmosphere.[16]

Scientists have been studying geo-engineering solutions for a considerable time. As early as 1996, the American Association for the Advancement of Science sponsored a symposium on the subject,[17] and recent contributions are reaching substantial numbers.[18] As discussed in the geo-engineering literature generally, because these techniques mimic natural phenomena, we know more about how quickly and well they work than we do about the efficacy of attempting to reduce greenhouse gases. We have measured the effects of the natural processes and can state with considerable certainty, bordering of complete certainty, that they will produce the result sought. Although the effects of greenhouse gas reduction would occur over a period of no less than decades and more likely centuries, the effects of geo-engineering can (and will) be manifest in a matter of weeks after application.[19]

The extremely low cost of geo-engineering allows many like Barrett to describe these techniques as economically "incredible." Table 1 shows that geo-engineering is not merely 200 to 2000 times less expensive, it prevents more damage than exclusive reliance on carbon control. Further, consider a risk not included in the $17 Billion worth of residual global warming damages shown in Table 1 – the $10 Billion a year cost to the United States from UV-caused cancer that would be avoided using geo-engineering.[20] In practical terms, the benefits to the United States, alone, and for UV-related cancer, alone, justify using geo-engineering – a gift to the world that would prevent some $5.2 Trillion in global warming-caused damages.[21]

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[15] Crutzen, P.J. (2006). "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" *Climatic Change* 77: 211-219. http://downloads.heartland.org/19632.pdf.

[16] Travis, D.J., A.M. Carleton, and R.G. Lauritsen (2002). "Contrails Reduce Daily Temperature Range." *Nature* 418: 601

[17] Six papers delivered at the AAAS symposium appear in *Clim. Change*, **33**(3), July 1996, edited by G. Marland. They cover scientific, legal, technical, political and ethical questions. *See*, http://www.gcrio.org/gccd/gcc-digest/1996/d96aug2.htm .

[18] *See, for example*, the citations in Crutzen (2006), Barrett (2007) and Carlin (2007b), cited in *supra* notes 14, 10 & 6, respectively.

[19] Wigley, T.M.L.. "A Combined Mitigation/Geoengineering Approach to Climate Stabilization." *Science* 314: 452-454. (2006)

[20] Teller, E., Hyde, R., Ishikawa, M., Nuckolls, J., and Wood, L. "Active stabilization of climate: inexpensive, low risk, near-term options for preventing global warming and ice ages via technologically varied solar radiative forcing," Lawrence Livermore National Library, 30 November, 2003.

[21] Nordhaus (2007) http://nordhaus.econ.yale.edu/dice_mss_072407_all.pdf.

Table 1

	Total Present Value Abatement Cost (2005 $Billions)	Residual (unprevented) Global Warming-Related Damages (2005 $Billions)
Exclusive Reliance on CO2 Emissions Reductions (Nordhaus "optimal", 2007)	$2,200.	$17,000.
Aerosol geo-engineering (Nordhaus, 1994) (Teller et al., 2003)	$10. $ 1.2	- 0 -

Notably, geo-engineering has gone commercial. Planktos, Inc., for example, is a for-profit ecorestoration company based in San Francisco with offices in the European Union and British Columbia. Their primary focus is to restore damaged habitats in the ocean and on land. They inject iron into iron-deficient waters to induce large blooms of plankton. This helps sequester carbon and Planktos sells carbon sequestration credits on the various carbon markets.[22] One must ask, if private geo-engineering to sequester carbon is already in play, can private geo-engineering to reduce global temperatures be far behind? Considering the potential harm from global warming, the potential regulatory costs associated with a greenhouse gas-based strategy and the relatively low cost of launching sunscreens, there is good reason to believe the inevitable use of geo-engineering to limit global temperature risk could occur in the private sector. This is a troubling concern many have discussed and on which this testimony touches in its final section.

The Chesapeake Bay and its Restoration

The Chesapeake Bay is a relatively recent geo-physical development. It exists because of a meteor impact occurring 35 million years ago. The impact fractured the earth's mantle and created a depression that forced rivers to reverse their flows and cut paths into what is now the Bay estuary. But the Bay formed long thereafter. As late as 18,000 years ago, the bay region was dry land; the last great ice sheet was at its maximum over North America, and sea level was about 200 meters lower than today. This sea level exposed the area that now is the bay bottom and the continental shelf. With sea level this low, the major east coast rivers had to cut narrow valleys across the region all the way to the shelf's edge. About 10,000 years ago, however, the ice sheets began to melt rapidly, causing sea level to rise and flood the shelf and the coastal river valleys. The flooded valleys became the Chesapeake Bay and the rivers of the Chesapeake region converged at a location directly over the buried crater.[23]

This ancient meteor created many faults that now cut through the sedimentary beds below the site of the impact, many of which lay no more than 10 meters below the bay floor. These faults are zones of crustal weakness and have the potential to suddenly collapse and thus flood

[22] *See*, http://www.planktos.com/About/About.html

[23] C. Wylie Poag, U.S. Geological Survey, "The Chesapeake Bay Bolide Impact: A New View of Coastal Plain Evolution", July, 1, 1998. *See*: http://marine.usgs.gov/fact-sheets/fs49-98/ .

large portions of land surrounding the Bay. In other words, we now confront natural and potentially cataclysmic coastal flooding we cannot prevent and in a timeframe we cannot predict.

Rather than permit this inevitability to limit our economic interests in the Bay, we instead accept the risk and seek to preserve this ecosystem for as long as nature allows. On the geological clock, our interests reflect mere ticks of the second hand.

We measure the timescale of Bay degradation and restoration in decades, not centuries or millennia. A mere 70 years ago, the Bay was the largest commercial fishing waters in the U.S. If restored, the Bay could produce $3 Billion in commercial fishery revenues per year. It now produces less than $100 million. Overall, some suggest the fishing and recreational value of a bay at full ecological competence (assuming the ecology of the past) at more than a trillion dollars.[24] Virginia, Maryland, Pennsylvania, the District of Columbia, the U.S. Environmental Protection Agency, and others, began their efforts to recover the ecological wealth of the Bay only 20 years ago. They have succeeded in preventing significant further deterioration despite large increases in population density and growth over the intervening years.

An entire array of local, state and federal regulatory programs now protect the Bay as an ecological, recreational and commercial resource. The size of the annual revenues generated within the private marketplace for Bay related activities from mere shore-side residence to recreational swimming and sailing and to commercial activities like fishing, all testify to our success in maintaining, and to some degree improving the quality of the Bay. Nevertheless, problems persist. The Bay suffers from two threats that the current regulatory programs have not resolved: the discharge of sediments and nutrients into the waters of the Bay's watershed. The sediments bury the life on the bottoms of rivers, deltas, and shorelines. These include the extremely important breeding grounds for mollusks and fish. As the name implies, nutrients, specifically nitrogen and phosphorus, provide essential "food" to algae and other small life forms that constitute the bottom of the food chain in the bay. Too many nutrients, however, and the algae can consume too much oxygen, thus forcing the top of the food chain (the fish) to other waters, and causing mollusks and fish hatchlings to fail to thrive and eventually die. Restoration will require reductions in both sediments and nutrients by two critical sectors on the watershed, municipalities and the agricultural community.

Figure 1, below, shows the significant sources of the threats to the Bay and each source's potential to reduce discharges. As these charts show, all sources will have to participate in reducing nutrient loadings into the Bay. In some cases, municipalities simply will not be able to do their share, in part because they simply will not have the funds needed to build advanced water treatment facilities. If response to climate change empties the state and federal environmental purse, as would happen with current legislative proposals, then we will not only lose the battle to restore the Bay but will lose ground due to continuing population growth. Even with current funding levels, municipalities will not have the capacity to do their share. Fortunately, in Virginia, the state legislature has authorized a state nutrients bank that allows municipalities to pay others to reduce nutrients when they can not. In the main, those "others" are our agricultural community.

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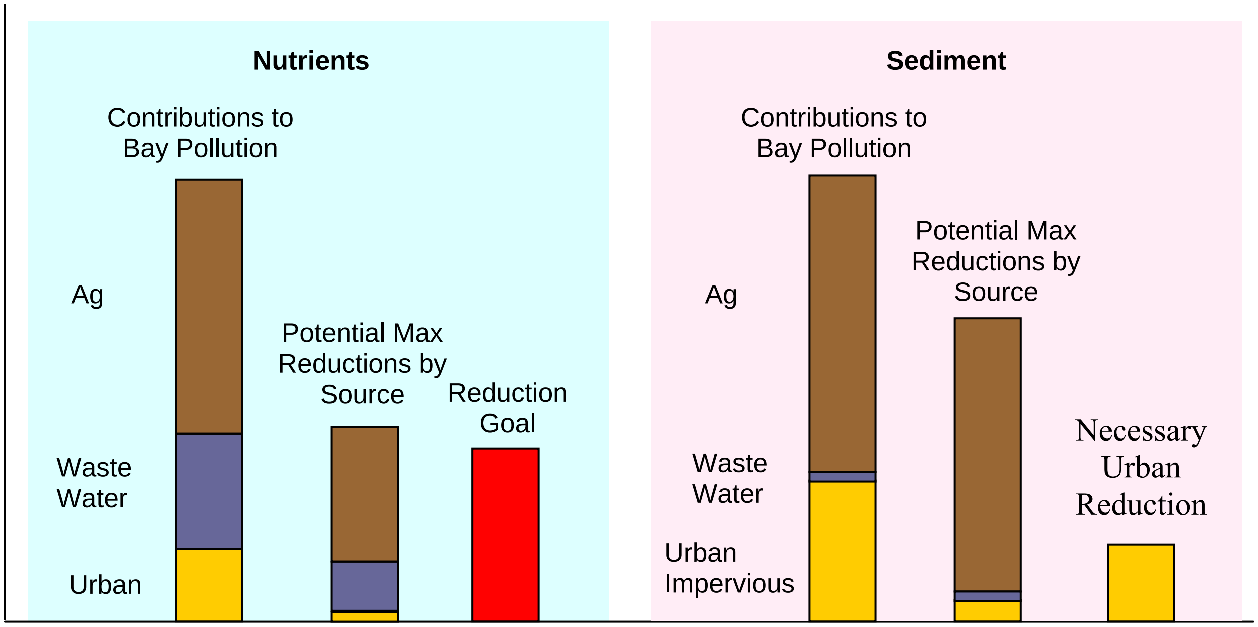
[24] Rebecca Hanmer, U.S. Environmental Protection Agency**, "**Chesapeake's value worth more than the sum of its parts", *see* http://www.bayjournal.com/article.cfm?article=2395 .

Figure 1



Reduction of nutrients from agricultural sources takes several forms, but controls on concentrated animal feeding operations (CAFOs) and "never-till" crop management seems the most promising. By leaving all but the harvestable grain in the field, by not tilling the field and by planting cover crops to hold nutrients and soil in place over the winter, this cropping technique has reduced nutrient and sediment runoff from those croplands by over 95 percent.[25] Ten years ago farmers used these conservation tillage practices in only rare occasions. In Virginia today, farmers have nearly 15 percent of small grains and corn cropland in never-till management. To expand this number significantly will require a more robust nutrient market, increased technical agricultural assistance and further funding of transition to conservation tillage. Like municipal wastewater treatment, we will succeed in solving this problem only if response to climate change does not empty the state and federal environmental purse.

With regard to sediment, again the agricultural community has the tools to resolve much of the problem. Conservation tillage holds sediments in the field, reducing sediment discharge by over 95%. Indeed, the nutrients adhere to the sediments and in particular the carbonaceous elements within the soil. Further, conservation tillage sequesters carbon in the soil. And, the farming community has already recognized the potential to reap carbon sequestration dollars through never-till farming.[26]

At present, Iowa's Farm Bureau is currently providing services to allow farmers to participate in the carbon sequestration market.[27] Notably, for every ten pounds of carbon

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[25] *See*: http://www.charlescity.org/2rivers.php . There is a wealth of technical science on no-till and never-till cropping, as a browse through an internet search will access.
[26] *See*, http://www.ppionline.org/ppi_ci.cfm?knlgAreaID=116&subsecID=900039&contentID=252026 .
[27] *See*, http://www.iowafarmbureau.com/special/carbon/default.aspx .

sequestered through never-till practices, a pound of nitrogen (and an equivalent weight of phosphorus) is also sequestered in the soil.[28]

In light of the financial interest the farming community has in carbon sequestration and the potential for large scale positive effects of conservation tillage on the water quality of the Bay, we believe Bay restoration should be considered an element of climate change mitigation, but recognize this opportunity will disappear if funding for both municipal and agricultural Bay restoration efforts evaporate.

We further suggest that the timescale of Bay restoration stands in stark contrast to the timescale of climate change and the timescale of a response to climate change that relies exclusively on reduction of greenhouse gases.

We recommend something else.

Global Leadership on Geo-Engineering – An Unmet National Duty

In light of the inevitable use of geo-engineering to prevent further global warming, this Committee may be well advised to follow Professor Sunstein's admonition to avoid the twin dangers of over-reaction and apathy.[29] So too would groups that have decided to bypass Congress and attempt to convince State governments to commit to policies relying exclusively on regulatory reduction of greenhouse gases.[30] Sunstein recommends that Congress try to ameliorate, if not avoid, future catastrophes, by looking at the widest possible solution set, by rejecting preconceived notions and emotion-based argument, thus retaining our sanity as well as scarce financial resources that can be devoted to more constructive ends.

Sunstein makes an important point on the need to remember we have goals other than carbon reduction. In this hearing you cannot fail to recognize that commitment to a remedy based exclusively on reduction of greenhouse gases would sacrifice our current commitment to restoration of the Bay. Having served on the staff of the Senate appropriates committee, I thoroughly understand the level of competition for federal dollars. I know you do too. As you consider how to respond to global warming, I ask that you keep in mind what programs you will cut in order to pay for what you propose. And keep in mind that use of geo-engineering will pay

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[28] Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis, *see*, http://cdiac.ornl.gov/programs/CSEQ/terrestrial/westpost2002/westpost2002.pdf .

[29] Cass R. Sunstein, Karl N. Llewellyn Distinguished Service Professor of Jurisprudence, University of Chicago, *Worst-Case Scenarios*", Harvard University Press (2007).

[30] The worst example of this narrow-minded approach was recently used in North Carolina and is on the hunt in many other states. One group (Center for Climate Strategies), funded by foundations committed to raising alarm about global warming, has used non-transparent, highly subjective and openly coercive methods to exclude discussions on alternatives to their preferred carbon-reduction strategy. Notably, this group has failed to provide your testifier the basis for their analysis or the assumptions they used in their analysis. They have failed to consider a policy of limiting action only to those efforts likely to reduce global warming. And, they refuse to estimate the effects their proposals on global warming. Groups such as CCS offer a false promise in light of the international rejection of greenhouse gas proposals required to prevent significant warming. *See*: http://www.carolinajournal.com/exclusives/display_exclusive.html?id=4087

for itself, while exclusive reliance on greenhouse reduction will not only fail to pay for itself, it will fail to prevent global warming.

In light of Professor Sunstein's admonition, and the economic and fiscal realities of global warming, geo-engineering and alternatives thereto, the most sensible approach would be a mixed strategy of geo-engineering to prevent further global warming and the effects of ocean acidification over the next century or two and vigorously developing a transition from carbon-based energy, to include research on scrubbing greenhouse gases from the atmosphere. Lacking this two-pronged attack, current legislative proposals must be considered what Sunstein calls "over-reaction" or panic.

We can make no more eloquent argument than that of Professor Barrett regarding what next this nation should do with regard to climate change, so this testimony ends by quoting his recommendation:

> Mitigating, forestalling, or averting global climate change is a global public good. Supplying it by means of reducing emissions is vulnerable to free riding. Too few countries are likely to participate in such an effort, those that do participate are likely to reduce their emissions by too little, and even their efforts may be overwhelmed by trade leakage (Barrett 2005). Geoengineering presents a very different set of incentives. A single country can deploy a geoengineering project on its own—and the economics of geoengineering are so attractive that it seems likely that a country, or perhaps a small group of countries, may want to try to do so at some point in the future, especially should the worst fears about climate change ever unfold.
>
> The challenge posed by geoengineering is not how to get countries to do it. It is to address the fundamental question of who should decide whether and how geoengineering should be attempted—a problem of governance (Barrett 2007). Failure to acknowledge the possibility of geoengineering may or may not spur countries to reduce their emissions, but it will mean that countries will be unrestrained should the day come when they would want to experiment with this technology. This, to my mind, is the greater danger.

Madam Chairman, as this Committee demonstrates leadership in protecting the Chesapeake Bay while meeting its duty to help prevent catastrophic climate change, it should champion sensible, incremental, international geo-engineering, in addition to reasoned, cost-effective efforts to limit greenhouse gases.

Because the Barrett and Carlin messages are of such paramount importance, I have attached hereto copies of their seminal papers.

- End -

THE INCREDIBLE ECONOMICS OF GEOENGINEERING[*]

Scott Barrett
Johns Hopkins University School of Advanced International Studies
18 March 2007

Geoengineering—which I shall take to be the deliberate modification of the climate by means other than by changing the atmospheric concentration of greenhouse gases—sounds like an idea conceived in Hollywood.1 To most people, the suggestion seems crazy if not dangerous (Schelling 1996). For better or worse, however, it is a concept that needs to be taken seriously. As I shall explain in this paper, its future application seems more likely than not. This is partly because the incentives for countries to experiment with geoengineering, especially should climate change prove abrupt or catastrophic, are very strong. It is also because the incentives for countries to reduce their emissions are weaker. Geoengineering and mitigation are substitutes.

Indeed, it is mainly because geoengineering and emission reductions are substitutes that the concept lacks "broad support from scientists" (Cicerone 2006: 221).[2] Not all scientists welcomed the recent publication of a paper by Paul Crutzen, a Nobel-prize-winning chemist, on geoengineering.3 To acknowledge the feasibility of controlling the climate deliberately, these scientists fear, undercuts "human resolve to deal with the cause of the original problem, greenhouse gases in the case of climate change" (Cicerone 2006: 224). Crutzen understands this view; he only wrote about the subject reluctantly. He would prefer that emissions of greenhouse gases be cut to an extent that geoenegineering would not be needed. He has only recognized the possible utility of geoengineering now because he despairs about the prospect of emissions being reduced enough, and quickly enough, to avoid dangerous climate change.

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[*] In my lecture to the British Association for the Advancement of Science, I gave an overview of my new book on global public goods (Barrett 2007), of which the topic of this paper is but one example. I have used the opportunity of this special issue to expand upon and recast my brief discussion of this topic as presented in my lecture and in the first chapter of this book.

[1] Geoengineering is defined in various ways in the literature. To some, it includes planting trees to absorb CO2. To others, it may involve carbon capture and storage, or enhanced take up of CO2 by the oceans. For a comprehensive treatment, see Keith (2000). Here I focus deliberately on an option that differs fundamentally from "carbon management."

[2] Economists have been perhaps a little more willing to discuss the concept; several distinguished economists, for example, participated in the Panel on Policy Implications of Greenhouse Warming (1992). Most economic analyses of climate change, however, have ignored geoengineering. I did not refer to it in my earlier book (Barrett 2005). It is not mentioned in *The Stern Review* (Stern 2007).

[3] In the same issue of *Climatic Change*, Ralph Cicerone, the president of the National Academy of Sciences, wrote, "I am aware that various individuals opposed the publication of Crutzen's paper, even after peer review and revisions, for various and sincere reasons that are not wholly scientific" (Cicerone 2006: 221).

The suggestion here is that it would be better if countries could commit themselves not to resort to geoengineering. That way, the world would have no alternative but to reduce emissions.

There are, however, serious incentive problems associated with reducing emissions—problems that explain why so little has been done thus far, even with geoengineering being little discussed as a possible fallback. Indeed, even if emissions were reduced sharply and soon, we may prefer to keep the geoengineering option open because of the residual risk of abrupt climate change.

Moreover, it may be impossible for countries to keep a commitment to abstain from experimenting with geoengineering. The incentives for countries to reduce emissions on a substantial scale are too weak, and the incentives for them to develop geoenegineering are too strong, for commitment to be a realistic prospect. Indeed, these two incentives combined are so powerful that many countries may be prepared to develop and deploy geoengineering unilaterally. That, I believe, is the greater danger.

Finally, and following on these two observations, a new governance arrangement is needed that places climate change policy in a broader context, recognizing that the objective should be to reduce climate change risk and that this requires a combination of efforts—on reducing emissions, certainly; but also on R&D into new energy technologies, on adaptation assistance to the poorest countries, and, yes, on geoengineering. This new framework should determine the circumstances under which geoengineering is to be permitted and proscribed.

A brief overview of geoengineering

Two fundamental forces determine the Earth's climate: the amount of solar radiation that strikes the Earth and the amount of this radiation trapped by the atmosphere. The latter effect is determined by the concentration of greenhouse gases. The former depends on the solar cycle and the Milankovitch cycles that determine, over very long periods of time, how solar radiation is distributed.

Policy can shape these two forces by means of greenhouse gas and solar radiation management.4 There does not exist a widely accepted definition of geoengineering, but as noted in the introduction I shall take it to mean deliberate climate modification by solar radiation management. This essentially means deflecting sunlight.

This already happens naturally. The eruption of Mount Pinatubo in the Philippines in 1991 injected huge quantities of sulfur dioxide into the stratosphere, lowering the Earth's surface temperature by about 0.5ºC the year following the eruption (Crutzen 2006). Human activities are also causing backscattering now—unwittingly. When coal is burned, sulfate particles are thrown

[4] Climate change is also determined by land surface properties, and policy could seek to change the Earth's surface albedo. However, this approach is also problematic and less efficient than atmospheric scattering; see MacCracken (2006).

into the troposphere, increasing albedo.[5] These particles, however, are harmful to human health and ecosystems; they should be, and increasingly are being, reduced. Indeed, it is partly for this reason that solar radiation has increased. Reducing concentrations of sulfate particles exacerbates "global warming."

The sulfate particles we put into the atmosphere are inefficient deflectors. Particles injected higher up into the stratosphere linger for longer—years rather than weeks. Engineered particles are expected to perform better still, reducing the total mass of material that would have to be injected to achieve a given cooling effect.

Geoengineering is a stopgap measure, a "quick fix," a "Band-Aid." It is akin to adding ground limestone to Sweden's pH-sensitive lakes and soils. Though only reductions in acidic emissions can prevent acid rain, liming preserves pH balance; it prevents acid rain damage. Geoengineering would have a similar effect. It would not address the underlying cause of climate change, but if it worked as intended it would prevent temperatures from rising against a background of elevated atmospheric concentrations of greenhouse gases.[6]

Its main advantage might be in stemming abrupt and catastrophic climate change. Abrupt climate change would take place over a period of perhaps a decade or two—too short a period for emission reductions to be able to stop it. By contrast, the climate response of albedo enhancement would take hold in a matter of months (Crutzen 2006). Catastrophic climate change would likely unfold over a number of centuries, but avoiding it will require a technological revolution, and geoengineering might help to "buy time" to develop and diffuse these new technologies (Wigley 2006).

Here is another way to look at this: It has been widely suggested that global mean temperature should not be allowed to increase by more than 2º C. At a concentration level of 550 parts per million CO2, mean global temperature is likely to rise 1.5º to 4.5º C.[7] Put differently, to be confident (but not certain) of limiting temperature change to 2º C, concentrations would have to be capped at a level far below 550 ppm—to a level more like 380 ppm (Caldiera, Jain, and Hoffert 2003: 2052). That would mean capping concentrations at the current level, and without a mass adoption of "air capture," this goal is essentially unattainable. Geoengineering might therefore be an indispensable ingredient of a policy aiming to ensure that mean global temperature rises by no more than 2º C.

Would geoengineering work? As mentioned previously, the effect of volcanoes and sulfate pollution has been measured; we know that these natural and inadvertent interventions work. So far, the efficacy of deliberate climate engineering has been demonstrated only in computer models. Wigley (2006: 452) reasons that, since the Mount Pinatubo eruption did not "seriously disrupt the climate system," deliberately adding the same loading should "present minimal climate risks." Simulating the effects of adding a Mount Pinatubo eruption every year, every two

[5] The condensation trails left by jet aircraft may have a similar effect; see Travis et al. (2002).
[6] For a more general discussion of quick fixes, see Sterner et al. (2006).
[7] According to the latest IPCC assessment (IPCC 2007: 9), climate sensitivity is "*likely* to be in the range of 2 to 4.5º C with a best estimate of about 3º C, and is *very unlikely* to be less than 1.5º C."

years, and every four years, he finds that the biennial eruption "would be sufficient to offset much of the anthropogenic warming expected over the next century."

Though global mean temperature can be controlled by changing solar reflectivity as well as by limiting greenhouse gas concentrations, the physics of these approaches differ. They may have different effects on the geographic distribution of temperatures. Computer simulations by Govindasamy and Caldeira (2000) and Govindasamy, Caldeira, and Duffy (2003), however, have shown that geoengineering would likely have little effect on the spatial pattern of surface temperatures. The distribution of temperature seems to be determined by more fundamental forces.

Geoengineering would affect more than the climate; it would have other environmental effects. Stratospheric aerosols could destroy ozone, as did the aerosols released by Mount Pinatubo. However, this damage is expected to be modest (Robock 2002). According to Paul Crutzen (2006: 215), a co-recipient of the 1995 Nobel Prize in chemistry for research on the ozone layer, the geoengineering needed to compensate for a doubling in carbon dioxide concentrations "would lead to larger ozone loss but not as large as after Mount Pinatubo"—and this against a background of expected rising ozone levels overall because of the success of the Montreal Protocol. As well, the risks from geoengineering would be bounded; aerosols pumped into the stratosphere would survive only a few years, much less than greenhouse gases (some of which can persist for more than a millennium). Geoengineering may even offer environmental benefits, the main one being the blocking of harmful UV radiation by engineered particles (Teller et al. 2003). Here again, however, there would be a trade off, as it is likely that such particles would also extend the atmospheric life of other greenhouse gases, reducing the overall cooling effect.

Particles thrown into the stratosphere would be transported towards the poles (their residency would thus be maximized if released over the equator) where they would "rain out." The effects may not be significant, however, since the amounts that would be added are a small fraction of the current input by pollution and volcanic eruptions (Crutzen 2006: 213).

Like volcanic eruptions, geoengineering would change the color of the sky. Volcanic particles whiten the sky by day (an environmental loss, presumably, though one that is already being caused by atmospheric pollution), but make sunsets and sunrises more vibrant (Crutzen 2006).

Some of the consequences of geoengineering may surprise us. Geoengineering would constitute a large-scale experiment (though that is also true of the experiment geoengineering is meant to correct, that of rising concentrations of greenhouse gases). Computer simulations offer a hint as to the likely consequences, but they can provide no more than this. The geoengineering experiment could be undertaken on a limited scale—a small volume of aerosols might be added initially, and released over the higher latitudes. Very importantly, the experiment could be halted, should adverse effects appear. Barring irreversibilities, the effects of geoengineering—positive and negative—would only be transitory.

Still, geoengineering amounts to putting something into the environment that wasn't previously there; reducing emissions, by contrast, amounts to not adding something that wasn't there. Of the two approaches, mitigation is the more conservative option—the reason it is preferred by scientists. However, the risks are not so one-sided. Mitigation cannot be relied upon to be benign. To reduce emissions substantially and in the near term will require an expansion in nuclear power, creating problems for safety, waste storage, and proliferation (Ansolabehere et al. 2003). Carbon capture and storage holds the promise of allowing countries to burn coal without releasing greenhouse gases into the atmosphere, but sinking carbon into the oceans would also amount to adding something to the environment that wasn't previously there; it would therefore also entail environmental risk (Anderson and Newell 2004).

One effect of geoengineering is unambiguous: it would do nothing to address the related problem of ocean acidification. The oceans absorb a portion of the carbon dioxide pumped into the atmosphere. This decreases the pH level of the oceans and is likely to change the process of calcification, endangering animals such as corals (which may, however, be bleached by rising ocean temperatures long before geoengineering is ever tried) and clams. Limestone could be added to the oceans, just as we have added limestone to acid-sensitive lakes, but liming is likely to be feasible only for certain sensitive areas (Royal Society 2005). It is not a comprehensive answer to the problem.

Geoengineering economics

The economics of geoengineering are—there is no better word for it—incredible. Upon reviewing the options in depth, the Panel on Policy Implications of Greenhouse Warming (1992: 460) concluded by saying that, "one of the surprises of this analysis is the relatively low costs at which some of the geoengineering options might be implemented." The Panel (1992: 452, 454) calculated that adding stratospheric aerosol dust to the stratosphere would cost just pennies per ton of CO2 mitigated. Drawing on this study, Nordhaus (1994: 81) concluded that offsetting all greenhouse gas emissions today would cost about $8 billion per year—an amount so low that he treats the geoengineering option as being costless. According to Teller *et al.* (2003: 5), engineered particles would be even cheaper (mainly because of the reduced volume of material that would need to be put into the stratosphere); they estimate that the sunlight scattering needed to offset the warming effect of rising greenhouse gas concentrations by the year 2100 would cost just $1 billion per year. Keith (2000: 263) thinks this is an optimistic estimate, but says that, "it is unlikely that cost would play any significant role in a decision to deploy stratospheric scatterers because the cost of any such system is trivial compared to the cost of other mitigation options."

Taking into account the effect of engineered particles on scattering harmful UV radiation, Teller and his colleagues calculate that this health-related benefit for the U.S. alone would exceed the total cost of geoengineering by more than an order of magnitude (Teller et al. 2003: 5-6). If correct, the economics are even more favorable than suggested above.

Deliberate climate modification would also allow carbon dioxide concentrations to remain elevated—an aid to agriculture.[8]

Just as important as the cost of geoengineering relative to emission reductions is the nature of these two options. Geoengineering constitutes a large project (Schelling 1996). By means of this technology, a single country, acting alone, can offset its own emissions—and those of every other country. By contrast, mitigating climate change by reducing emissions requires unprecedented international cooperation and very substantial costs. Stabilizing atmospheric concentrations requires a 60 to 80 percent cut in CO2 emissions worldwide. In the years since the Framework Convention on Climate Change was adopted, global emissions have risen about 20 percent. Even if the Kyoto Protocol is implemented to the letter, global emissions will keep on rising. So will concentrations. Theory points to the difficulty in achieving substantial and wide scale cooperation for this problem, and the record to date sadly supports this prediction.[9]

A quick calculation hints at the temptation presented by geoengineering. According to Nordhaus and Boyer (2000: 131), climate change might cost the United States alone about $82 billion in present value terms. Using a three percent rate of discount, this is equivalent to an annual loss of about $2.5 billion. If the United States cut its emissions, it could reduce this damage somewhat. If it turned to geoengineering, it could eliminate this damage. If geoengineering is as cheap and effective as is claimed, the U.S. might prefer the geoengineering option. So, of course, might other countries.

Denote the benefits to Country *i* by *Bi* and assign numerical labels to countries that reflect their relative benefits, such that $B1 \geq B2 \geq \ldots \geq BN$. Finally, let the cost of geoengineering be denoted *C*. Then, so long as $B1 \geq C$, we can be pretty sure that geoengineering will be tried (using it would be the Nash equilibrium). It may not be tried by Country *1*. Any country *j* for which $Bj \geq C$ would be willing to try it, should all others not try it. Countries might even agree to pool their resources, to share the costs. We cannot predict which country or group of countries will bear the cost, but it is clear that the incentive for geoengineering to be tried is very strong so long as the costs are low. Even if the costs turn out to be much higher (such that $C \geq B1$), and no country has an incentive to try geoengineering unilaterally, a coalition of *k* countries would have an incentive to do so collectively so long as $B1 \ldots Bk \geq C$. (In this case, using geoengineering would be a Nash equilibrium but so would not using geoengineering).

Climatologist Michael MacCracken (2006: 238) argues that, "Although it might be conceivable for one nation to actually commit to such a program, it seems rather unlikely that a global coalition of nations could be kept together to sustain such a diversion of

[8] Govindasamy et al. (2002) estimate that the global dimming needed to offset a doubling in CO2 concentrations (a 1.8 percent reduction in solar flux) would reduce net primary productivity by about 3 percent, whereas the higher CO2 would increase net primary productivity about 76 percent. Though beneficial for agriculture overall, these changes would also affect the balance of sensitive ecosystems.

[9] On the theory of cooperation in this area, see Barrett (2005). In Barrett (2006a) I consider what I believe to be a particularly promising approach. However, even here the prognosis is discouraging. It was only after writing this paper that I began to consider seriously the possibility of geoengineering.

resources for a task that would seem, to the typical citizen, to generate no immediate or direct benefits." I disagree. There is no need for countries to commit to sustaining a geoengineering intervention. It is true that there are a huge number of Nash equilibria to the cost-sharing game. But were a geoenegineering effort to be shut off, the climate would respond very rapidly (Wigley 2006). Any country that had an incentive to join a coalition of countries in financing a geoengineering project initially would have at least as strong an incentive to continue with it later—unless, of course, in the meantime, previous efforts at reducing emissions succeeded in lowering atmospheric concentrations.

This last possibility is the scenario examined by Wigley (2006). He considers the role that geoengineering might play in "buying time" for a policy needed to stabilize concentrations. To be more specific, he shows how geoengineering could be used to smooth the hump caused by overshooting a concentrations target. This may be an attractive use of geoengineering, but in this case there is a commitment problem. If geoengineering should prove benign, the incentive to reduce atmospheric concentrations would be muted. A promise to use geoengineering only temporarily may thus lack credibility.

Geoengineering governance

Ironically, the attributes that make geoengineering attractive also make it worrying. Because it consists of a single project, it can be undertaken unilaterally or minilaterally. Because of its low cost, the incentives for it to be tried are very strong. The consequences of one country or a small number of countries using it, however, would be global; and they might not all be welcome (Schneider 2001).

So, who is to decide whether geoengineering should be deployed? Should a country be allowed to do so unilaterally? Could it be prevented from doing so? Some countries are expected to benefit from climate change, at least gradual climate change through this century. According to Nordhaus and Boyer (2000: 131), for example, Russia, China, and Canada would all gain. Would these countries need to be compensated for damages resulting from a geoengineering intervention to limit climate change? If the losers from climate change use geoengineering to cool temperatures, might the winners use geoengineering to *absorb*, rather than to scatter, radiation? (Might there be geoengineering wars?) Could *they* be prevented from doing so? Would countries be allowed to engineer any temperature, or would they only be permitted to limit change from the recent historical average? The world's poorest countries are especially vulnerable to climate change, and yet they are likely to be the least able to develop and deploy a geoengineering effort. Should the more capable states be required to do so for them?[10] Should they be made to pay compensation if they do not? Suppose geoengineering affected the spatial distribution of climate, even if it succeeded in preventing the global (average) climate from changing. Should the countries adversely affected be compensated? How would damages be

10 There is a similarity here with the new norm of "the responsibility to protect," which requires that the major powers intervene to stop genocide. As the current situation in Darfur shows, the problem here is that the major powers are declining to act; they are declining to fulfill their responsibility. See the concluding chapter of Barrett (2007).

determined? Which countries would be expected to pay compensation? How could the obligation to pay be enforced? What about countries that have different attitudes towards risk, or that object to the idea of deliberately altering the climate whatever the benefits may be? Should their views be heeded?

Two precedents offer a glimpse into how these concerns might be addressed. The first concerns experiments with a different kind of particle. The Large Hadron Collider being built in Europe is intended to test the Standard Model of particle physics. The knowledge gained from this project will be a global public good, but there is a small chance that the experiment could create something called a strangelet—an object that, by a process of contagion, might possibly "transform the entire planet Earth into an inert hyperdense sphere about one hundred metres across" (Rees 2003: 121). It is even conceivable that the particle smashes might create a growing black hole—a phenomenon that might destroy not just the Earth but the entire universe. A report written for the backers of the Large Hadron Collider concludes that there is "no basis for any conceivable threat" (Blaizot et al. 2003: iii). But the likelihood of a strangelet being created is impossible to calculate with certainty, since the experiment has never taken place before. Existing theories are reassuring, but they have not been tested. And do we really want to test them? Are we sure that the global public good of new knowledge outweighs the global public bad of the risk of annihilation?

More importantly, who should decide whether the experiments should go ahead? So far, the decision has been left to the parties who are financing the project—the 20 European members states of CERN (officially, the European Organization for Nuclear Research), the organization that is building and that will run the Large Hadron Collider, and its partners on this project—India, Japan, Russia, and the United States.[11] But should other countries have been consulted? Should other countries have a veto?

The second precedent concerns the remaining stocks of smallpox virus. Smallpox was eradicated in 1977, yielding every country a huge dividend (Barrett 2006b). Provision of this global public good meant that people no longer needed to die of this disease. It meant also that there was no longer a need for people to be vaccinated. Unfortunately, reaping this dividend has exposed countries to a new risk. If smallpox were somehow reintroduced today, the world would be more vulnerable than ever to an epidemic. So long as smallpox exists, this risk remains. Concern about a possible accidental release caused laboratories around the world to destroy or transfer their stocks; by 1983, known stockpiles of smallpox virus were held by just two World Health Organization (WHO) "collaborating centers," one in Atlanta and the other in Moscow. But were these the *only* remaining stocks left? Unfortunately, no one could be sure. Some people suspected that covert stocks might have been retained by other states. That concern persists today.

[11] The members of CERN include Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Norway, the Netherlands, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, and the United Kingdom.

What to do with the last two known stockpiles? In 1986 and again in 1990, the WHO's Committee on Orthopoxvirus Infections recommended that the stocks held in Atlanta and Moscow should be destroyed. But while destruction would eliminate the risk of an accidental release, it would also foreclose the option of using the remaining stocks to develop improved diagnostic tools, antiviral drugs, and a novel vaccine—innovations that would benefit the whole world should covert stocks exist and should smallpox virus be released deliberately some day. As with geoengineering, the decision to destroy the remaining stores of smallpox entails a risk-risk tradeoff. It also has implications for every country.

Again the question: Who should decide? The two states that possess the virus obviously have the upper hand (just as the major powers would have the upper hand in developing a geoengineering project), but being WHO collaborating centers, the labs in Atlanta and Moscow are obligated to serve the global interest.

In 1998, the WHO polled its 190 members. Did they want the last known stocks to be retained or destroyed? The survey revealed a split. Russia wanted to hold onto its samples; Britain, France, Italy, and the United States were undecided; every other country (74 other countries responded) favored destruction. Concerned about the risk of a bioterrorist attack, the United States changed its position in 1999, asserting a need to keep its stockpile. When the World Health Assembly met shortly after this, a compromise was worked out. A resolution was proposed that reaffirmed the goal of *eventual* destruction but permitted Russia and the U.S. to retain their stocks for research purposes for a period of three years. The resolution passed by acclamation. Later the reprieve was extended; and, today, smallpox virus is still kept at the two WHO centers. Inspectors have satisfied the WHO's Advisory Committee on Variola Virus Research that the stocks are secure, and the Committee has verified that the research undertaken at both labs has progressed. They have also confirmed, however, that the job is not yet finished. Their judgment is that there is still reason to retain smallpox for research purposes.

The arrangements surrounding the decision to retain the smallpox stocks are very different from those connected with the conduct of possibly dangerous experiments. The latter are being undertaken by a relatively small number of countries, without wider consultation let alone approval. The smallpox decision, by contrast, has been undertaken in a setting in which all the world's countries were invited to take part. To be sure, in this case the power relations among countries are vastly unequal. But the process that emerged favored consensus—an especially fortunate outcome. Since every country will be affected by whatever is decided, it is as well that each should agree with the decision. As matters now stand, the situation with geoengineering is more akin to the regime for carrying out particle collider experiments than to the smallpox decision. Currently, there is no institutional arrangement that says what countries are allowed to do or not to do as regards geoengineering. By default, therefore, countries are pretty much free to explore geoengineering options or not as they please. It may be unlikely that countries would seek to act unilaterally (Bodansky 1996), or as part of a "coalition of the willing," but that possibility will remain unless and until climate engineering is brought into an institutional framework of some kind.

How to proceed? Three steps are needed. First, the possibility of geoengineering should be examined in detail by the Intergovernmental Panel on Climate Change, in a special report. Its pros and cons need to be evaluated, and all countries need to be made aware of them. Second, and drawing on this technical work, the Framework Convention on Climate Change should be revised. This agreement has the great advantage of having nearly universal participation (the only non-parties are Andorra, Brunei, the Holy See, Iraq, and Somalia, and these states are free to join when their circumstances permit). Currently, however, the Framework Convention embraces the objective of stabilizing atmospheric concentrations of greenhouse gases; it does not mention geoengineering. A revised convention should emphasize the need to reduce climate change risk—a broader objective that would encompass not only efforts to reduce atmospheric concentrations but also adaptation (which is mentioned in the Convention), R&D into new energy technologies, and geoengineering. Finally, and building upon the first two steps, a new protocol should be added that specifies whether and under what conditions geoengineering should be allowed (even if only for research purposes), or possibly even required, and how the costs of any efforts should be shared.[12]

Conclusion

Mitigating, forestalling, or averting global climate change is a global public good. Supplying it by means of reducing emissions is vulnerable to free riding. Too few countries are likely to participate in such an effort, those that do participate are likely to reduce their emissions by too little, and even their efforts may be overwhelmed by trade leakage (Barrett 2005). Geoengineering presents a very different set of incentives. A single country can deploy a geoengineering project on its own—and the economics of geoengineering are so attractive that it seems likely that a country, or perhaps a small group of countries, may want to try to do so at some point in the future, especially should the worst fears about climate change ever unfold.

The challenge posed by geoengineering is not how to get countries to do it. It is to address the fundamental question of who should decide whether and how geoengineering should be attempted—a problem of governance (Barrett 2007). Failure to acknowledge the possibility of geoengineering may or may not spur countries to reduce their emissions, but it will mean that countries will be unrestrained should the day come when they would want to experiment with this technology.13 This, to my mind, is the greater danger.

[12] Cost sharing has the advantage of widening decision making to include a greater number of countries; see Barrett (2007), Chapter 4. The conditions noted here could include a moratorium, as suggested by Cicerone (2006).

[13] A secondary problem is that the countries capable of using geoengineering may not use it to help countries in need but lacking such a capability. This is allied to the problem of the rich countries providing adaptation assistance to the poor, and another reason why all the policy dimensions of climate change need to be evaluated jointly.

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Reducing emissions of greenhouse gases may be well intentioned and even helpful. But as the sole strategy for climate change control it is nevertheless inflexible, expensive, risky, and politically unrealistic, according to this government economist. Such a strategy could even make matters worse. Fortunately, there is a better solution

Alan Carlin

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The environmental community has done a great planetary service by highlighting the need for worldwide climate change control. There has been remarkably little analysis of the specific problems posed by global warming, however, and of the best ways to respond to them. Instead, most advocates have endorsed a panacea that I will characterize as exclusive regulatory de-carbonization, or ERD. They argue that since greenhouse gases are the cause, the solution must be mandated cuts in emissions or possibly removal of gases already in the atmosphere. This is a well-meaning conclusion consistent with previous pollution control efforts. But while ERD can help, recent research shows that it would not be enough to solve the most serious problems posed by a rapidly warming world. Fortunately, there is an option that would solve most of these problems, more quickly, effectively, and efficiently, and without the need for alterations in lifestyle: solar radiation management, or SRM. The one problem that cannot be resolved through such an approach (detailed below) may well be beyond the capability of regulatory de-carbonization as well, so SRM may be our best hope of coping with a changing world.

By now it is well known that efforts to reduce emissions of GHGs in only a few countries — whether under the Kyoto Protocol, regional agreements, or national programs — cannot achieve the temperature limits the European Union believes are necessary to avoid dangerous changes to the environment. What is less well known is that these measures would be unlikely to do so even with the full cooperation of every person and every nation on the Earth. Considering the high levels of atmospheric GHGs and the as-yet unrealized warming from climate system lag, this disturbing conclusion is hard to escape. It is made worse by factoring in the drastic, immediate cuts that would be required; the unwillingness of people, and therefore politicians, to pay the costs and endure the requisite reductions in energy services; the strong economic incentives to continue increasing energy services; and the extreme difficulty of achieving and maintaining a precise heat balance for the Earth through what would amount to centralized world energy planning.

Even worse, pursuing regulatory de-carbonization as the only control strategy — whether through cap-and-trade, carbon taxes, efficiency standards, bio-fuel subsidies, or plain-old facility emissions limits — is likely to bring about the very effects that the environmental community has worked so hard to publicize, by diverting the world's attention and resources from

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more effective solutions. Both in financial terms and in lost opportunities, the cost of this single-minded approach is likely to be huge.

Our myopia in the global warming area is caused in part by a confusion of goals. Too often the end result of climate change control is expressed as reducing GHG emissions, even though this is merely a means. Thus the first task is to identify what the risks are and establish performance measures to evaluate proposed solutions. There appear to be three major problems to be solved:

Problem 1. Gradually increasing world temperatures and the immediate effects on humans and ecosystems is the most well known risk. Some people (those living in colder climes) may welcome this. Others (those living in coastal areas) will probably be flooded out. Almost everyone will face adaptation costs.

Solar radiation management could be a far more effective and economical climate policy

Problem 2. Dangerous, self-reinforcing climate change. This appears to be the most critical risk. The concerns most often mentioned are release of large quantities of methane (a potent GHG) from thawing permafrost or from under the ocean floor, melting of the Greenland and West Antarctic ice sheets, and a breakdown of the ocean currents that warm Western Europe. Any of these could cause a regional or global disaster.

Problem 3. Non-temperature effects of increasing GHGs, particularly the effects of increasing carbon dioxide levels on the oceans. The resulting acidification is believed to be already affecting shellfish and coral reefs. This risk is the most difficult to solve.

Although most public discussion has addressed the first risk, the technical discussion has rightly centered on the second as the basis for setting de-carbonization goals, since the feared environmental changes could well be catastrophic and possibly irreversible. To this end, the EU has adopted a target of restricting global warming to less than a 2º Celsius (3.6º Fahrenheit) increase from pre-industrial levels to prevent "dangerous . . . interference with the climate system." This goal has also been implicitly adopted by many environmentalists and climatologists and the British, German, and Swedish governments.

Recent modeling work, however, suggests that the proposed implementation of this goal by all four of these jurisdictions would actually result in a near certainty of more than a 2ºC increase if applied worldwide. Research published this year by James Hansen, head of NASA's Goddard Institute for Space Studies, and others supports the view that even smaller increases may be dangerous. Worse, a 2007 study by Nathan Rive of the Center for International Climate and Environmental Research in Oslo can be used to show that Hansen's prediction of a 15-foot rise in sea level by 2100 because of disintegrating ice sheets cannot be avoided by achievable emissions reductions. This would mean that without mega-engineering projects to protect them, London, Miami, Mumbai, New York, Tokyo, Shanghai, and much of the Netherlands and Bangladesh, among other regions, would be under water by the end of this century, unless some other approach is used to control global temperatures. Al Gore has envisioned a 20-foot sea level rise and like Hansen advocates the use of ERD.

Even if Hansen's predictions should be wrong, the Rive study also shows that the world would need to reduce GHG emissions by 80 percent to obtain a mere 50 percent chance of preventing a 2ºC increase. The marginal cost of abatement would be $3,500 per ton of carbon in this scenario, assuming average projections and early action. This is 10 or more times higher than most previous estimates. Naturally, most people would not want just a 50 percent chance of avoiding the risks posed by Problem 2. Given current GHG concentrations, however, a more acceptable 75 percent chance of avoiding such risks is probably unachievable. A 10-year delay would make even a 50 percent chance unachievable.

Another way of looking at this problem is the reduction in energy use needed to achieve even this modest risk reduction. Even when future economic growth is left out of the calculation, global energy

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efficiency per person would have to be increased by roughly 87 percent or human services provided by energy use reduced by 87 percent per person, or some combination of the two. (The reductions required to meet Hansen's concerns would be even larger, if they were achievable.) Energy efficiency can be increased, but only slowly and at considerable cost. It appears unlikely that all the reductions that would be needed could be implemented rapidly enough to meet the 2ºC target using only energy efficiency measures, particularly inexpensive ones.

Alternatively, energy services could be cut, either voluntarily or by government mandate. This won't be easy. Stephen Pacala and Robert Socolow of Princeton's Carbon Mitigation Initiative propose to reduce per capita average vehicle-miles traveled from 10,000 annually to 5,000 through better urban design, mass transit, and telecommuting. But to entice drivers out of their vehicles for half their trips would require monumental social investments and individual subsidies; the more likely prospect is coercion. The even more drastic proposal for individual emission rationing reported to be under consideration in Great Britain is a logical extension of the ERD approach, but it is difficult to see how it would attract much support. While increased energy efficiency may eventually contribute significantly, the deep, almost immediate cuts in energy services required to stay below 2ºC is politically unrealistic.

Too often the end result of climate change control is expressed as reducing GHGs, even though this is only a means

Avoiding Problem 2 is thus either impossible or very risky through ERD. The limited experience to date is that those jurisdictions with some of the most active programs (such as California and Britain) have been roughly holding their own in recent years. Given economic and population growth, this may be the most that can be achieved by regulatory de-carbonization through energy efficiency and reduced energy services. Even if more can be achieved in particular countries, it would not approach the 80 percent needed on a worldwide basis. Except under special circumstances, such as the collapse of Eastern European industry after 1989, most countries have experienced a gradual increase in emissions, and some are growing rapidly. Most countries have also been unwilling or unable to participate in emission cuts. More than governmental cooperation would be needed, but the idea that all the people of the world would cooperate to make something effective happen is unlikely.

ERD probably won't solve Problem 3, ocean acidification, either. Though it has received scant attention, the projected change in pH of the world's oceans may be the most constraining in terms of the degree of control required. One prominent scientist working in the field, Ken Caldeira of the Carnegie Institution of Washington's Department of Global Ecology, has stated that human-caused carbon dioxide emissions need to be reduced by 98 percent in order to save the world's coral reefs. The 80 percent global reductions believed necessary to have a 50 percent probability of meeting the 2ºC target are already practically infeasible; a 98 percent cut would require that human-caused emissions return almost to pre-industrial levels.

A Notable Lack of Candor

Perhaps the most unfortunate aspect of the disjunct between the necessary and the possible is that many of the technical experts advocating ERD have not been forthright about explaining the needed sacrifices or the small chance of success to the public. A worrisome scenario is that politicians who impose significant reductions would be voted out of office and less stringent measures enacted to take their place.

A central problem with ERD is the fact that most of the world would have to drastically reduce GHG emissions if the 2ºC temperature goal is to be met, not just a few countries. Reductions by only the major developed countries may decrease the growth in emissions but cannot meet this goal. So far the less developed world has shown little willingness to impose reductions, and is not likely to do so until their citizens demand it. That would require the same sort of concerted public information effort that has occurred in the United States, Europe, and Japan. The major existing measure to coordinate international reductions, the Kyoto Protocol, suffers from this problem and is furthermore unenforceable. It is unlikely to achieve even its modest goals. ERD supporters respond that if only the United States were to enact drastic reductions, the rest of the world would come along. Although there might be advantages in the United States' showing leadership, if the intent is to influence the behavior of the rest of the world, we would have more leverage before we enact stringent reductions because we could still bargain. Enacting them first would also put the United States at a competitive disadvantage in the likely event that not everyone enacts equivalent cuts.

In sufficiently wealthy countries where the change in energy costs may have a smaller impact on the public, it may be possible for politicians to persuade their constituents to accept some measures involving increased energy efficiency if they do not impose too large a burden or result in the loss of too many jobs, but in less developed countries, where prices of com-

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mon forms of energy are often subsidized due to strong popular demand, even increases in prices due to using more energy efficient devices could easily prove politically unpalatable.

Proponents of GHG control argue that the cost would be just a few percent of GDP and that future growth will be many times the costs involved. Even if these broad generalizations were correct, those who will have to pay these costs, particularly if it is not a very broad cross-section of the population, will object strongly. They will see it as a tax rather than an investment in the future.

There are strong economic incentives not to reduce GHG emissions. These incentives could be changed by governmental action, but they are so fundamental that this will prove to be difficult. As illustrated by the problems many EU countries and Canada face in meeting their commitments under Kyoto, politicians would be required to maintain unusually strong resolve as the population learns what the real effects of the measures will be. Under current circumstances, politicians can argue that higher energy prices are a result of the operation of the laws of supply and demand. But if markedly higher prices or energy use restrictions were imposed for the purpose of reducing global warming, they would face a tougher situation.

It is difficult to see why politicians would be willing to force their constituents to adopt unpopular and expensive constraints on their activities, or why many constituents would not pursue every available loophole rather than reduce their welfare and freedom of choice. Grandmothers, for example, may not agree that trips to see their grandchildren on the opposite coast can be dispensed with or priced out of their reach. Global warming has all the psychological characteristics — a long time horizon, uncertainty, and no visible effects to remind people that there is a problem — needed to keep it at a

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modest level of priority, even with a huge public education campaign.

Another fundamental problem with ERD is that it has many of the characteristics of economic planning, such as picking technological and economic winners in advance rather than leaving this to the market. Governments would determine the allowable GHG emissions and seem anxious to dictate the precise means of doing so too. This is already happening, by attempts to legislate the percentage and even the type of renewable energy sources that must be used. Unfortunately, the history of economic planning has shown it to be very unsuccessful and inefficient because of political interference with economic decisions and the inability of governments to finely regulate economic activities they may not understand.

If Hansen's predictions are correct, major catastrophes that would make New Orleans look like a minor event can be expected if the energy balance of the Earth is not stabilized soon. As he points out, events that would reasonably precede his predicted ice sheet disintegration are already happening. But global warming will continue until the energy balance of the Earth is actually stabilized, not when proposals by politicians say it should some time in the future. The balance needed is fairly precise since nature, unlike humanity, does not fudge. The natural systems creating this balance are exceedingly complicated, constantly changing, not well understood, and need fine adjustments — all of which ERD-style world central energy planning is most unlikely to deliver in a timely way, particularly in a world of sovereign states requiring extended negotiations just to agree on what to do let alone actually doing something effective. The experience to date with the Kyoto Protocol suggests what can be expected from continued pursuit of ERD.

Regulatory decarbonization picks technological and economic winners rather than leaving it to the market

A Long Ignored Alternative

Fortunately, there is an alternative to relying on ERD, although it is almost never mentioned by environmentalists and not widely known, much less understood, by the public — solar radiation management, sometimes called stratospheric geoengineering or engineered climate selection. An extensive review of management strategies and currently available alternative technologies for global climate control gives the inescapable conclusion that SRM is the most effective and efficient first step toward solving most of the problems that ERD supporters are concerned about, quickly and easily.

SRM would control temperatures by reducing the radiation reaching the earth from the sun. This would be accomplished by adding particles to the stratosphere to scatter a small, carefully calculated portion of selected wavelengths of incoming sunlight back into space. These particles would naturally slowly drop out of the stratosphere, and would have to be replaced, making relatively rapid adjustments possible. This and similar approaches could be viewed much like any other aerospace project, would cost a fraction of the cost of ERD (roughly 2 to 10 cents per ton of carbon compensated for, not hundreds or thousands of dollars), would need no public involvement once a decision had been made to proceed, would not require the alteration of lifestyles or standards of living, and would provide the flexibility needed to rapidly respond to any warning signs of imminent danger — thus solving all of the problems except ocean acidification. SRM would also avoid the need for extensive economic and energy planning by leaving GHG emission decisions to the private sector, possibly using an institution patterned on the Federal Reserve Board or International Monetary Fund to make periodic adjustments to incoming solar radiation to achieve the desired global energy balance.

As pointed out by Paul Crutzen in 2006 and the National Academy of Sciences in 1992, we have a planet-wide proof of concept: when major volcanic eruptions occur, approximately once a decade, they shoot huge amounts of particles into the air, cooling the planet for several years. One of the best known examples was the explosion of Mt. Tambora in 1815, which caused the "year without a summer" in Europe. The sulfur-containing particles thrown out by eruptions are probably less than optimal. It appears reasonable to believe, however, that humans could improve on nature substantially by refining the type of particles used and minimizing other possible environmental side effects with a little research and development.

SRM would cost less than 10 cents per ton of carbon compensated, rather than hundreds or thousands of dollars through ERD

The reason that SRM cannot solve ocean acidification is that carbon dioxide levels would continue to rise. ERD would help in theory, but given the impossibility of meeting a 98 percent reduction worldwide to prevent the destruction of the world's coral reefs, it may not be a useful solution to this problem either. Fortunately, recent research illustrates that nature has worked out an efficient system for removing carbon dioxide from the seas: fertilizing ocean plankton to

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stimulate them to absorb carbon dioxide (much as plants do) and transport it to the sea floor. Humans have not yet figured out a very efficient way to emulate nature in this regard — seeding the ocean with iron particles has been suggested — but ocean fertilization may be the best current hope, whether under either the ERD or the SRM approach. Given the magnitude of the threat, research on and implementation of geoengineering or other solutions to ocean acidification also needs to become a top priority.

GHG reductions to a level not seen since the Industrial Revolution would be required to solve ocean acidification

Some scientists have suggested a related strategy: using SRM immediately to bring down temperatures during the long period required to reduce GHG emissions, thus avoiding all the adaptation costs and risks of using regulatory de-carbonization alone, while helping the oceans a bit. This appears to be much more expensive than an SRM approach since extensive de-carbonization expenses would be incurred as well, but it would solve Problem 2, the one of most concern because of the possibility of catastrophic effects, in the interim. And it is clearly safer than an ERD approach. Others have advocated using SRM as an insurance policy to back up de-carbonization. The problem with this is that very large adaptation and de-carbonization expenses would be incurred in the meantime. And the world may be totally unprepared to use SRM when an emergency arises unless decisionmaking processes for using it are actively developed and research and development is carried out to optimize the particles and minimize the environmental effects. This is unlikely to happen unless there are real plans to deploy SRM in the immediate future. Even though any nation with the technical and financial resources could implement such a solution on its own, it would be much better to use an international institution to make decisions on how and when such projects should be undertaken and maintained, given their global impact.

Numerous arguments against SRM have been made, such as the risk of unintended consequences. Certainly there is a need for research to better determine the other environmental effects of SRM. But although great care needs to be taken in pursuing SRM, it is not often recognized that ERD is also likely to engender unintended consequences, as it already has by encouraging the destruction of rain forest to increase the production of palm oil as a fuel, for example.

As author Jay Michaelson wrote almost ten years ago there exists an extensive inventory of other arguments for and against SRM, but the issue really turns on a metaphysical question. Even though most GHG control supporters believe that humans are causing major climate changes, they would rather let nature translate human actions in increasing or decreasing GHG emissions into the ultimate effects on climate. Advocates of SRM and other geoengineering approaches, on the other hand, argue that it would be better for humans to determine the desired climatological outcomes (such as lower average temperatures) directly and relatively precisely rather than letting nature, which has no incentive to help humans, sort out the net effects of GHG producing activities. More research could refine geoengineering solutions, but de-carbonization supporters generally oppose it, so there is currently no way to find out what the most refined solutions might be.

Humans have advanced as much as they have in no small part because they have used fossil fuel energy to provide services that once depended on animal and muscle power. The way forward is not to turn back the clock, but rather to search for and implement solutions to each of the problems posed by global climate change using the best engineering and scientific knowledge in the most effective and efficient manner. Unfortunately, the major effect of relying entirely on the hope of drastically reducing carbon emissions may well be to delay the time when effective action is taken to actually solve the three problems. Developing, testing, and deploying refined versions of SRM and determining its environmental effects needs to be a priority.

Any approach to climate change control needs to be able to handle all credible threats. It needs to be flexible, to rapidly adapt to new knowledge or events. It needs to be inexpensive enough to minimize damage to the economy but effective enough to protect us. Although regulatory de-carbonization can play a useful role, this is really a description of SRM or some combination of SRM and regulatory de-carbonization. Building, testing, and deploying a workable SRM capability is the best investment we can currently make to control climate change. Unfortunately, we are not taking this modest step and probably will not as long as we remain fixated on solutions that demand wholesale reform of the world's energy economy. •

The conclusions reported here are based on three technical papers: "Global Climate Change Control: Is there a Better Strategy than Reducing Greenhouse Gas Emissions?" University of Pennsylvania Law Review, June 2007; "Implementation & Utilization of Geoengineering for Global Climate Change Control," Sustainable Development Law and Policy, Winter 2007; and "New Research Suggests that Emissions Reductions May Be a Risky and Very Expensive Way to Avoid Dangerous Global Climate Changes," http://yosemite.epa.gov/EE/epa/eed.nsf/WPNumberNew/2007-07.

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