GEOENGINEERING: ENCOURAGING RESEARCH AND OVERSEEING IMPLEMENTATION

An Editorial Comment

Ideas on how to engineer Earth's climate, or to modify the environment on large scales to counter human impacts, do not enjoy broad support from scientists. Refereed publications that deal with such ideas are not numerous nor are they cited widely. Paul Crutzen (2006) analyzes the idea of intentionally injecting sulfur into the stratosphere, to enhance the albedo of Earth, so as to slow the warming of the planet due to greenhouse gases. He notes that such an intervention might become necessary unless the world becomes more successful in limiting greenhouse gas emissions and/or if global warming should proceed faster than currently anticipated partly due to cleaning the lower atmosphere of sulfur pollution (Andreae et al., 2005; Charlson et al., 1991).

I am aware that various individuals have opposed the publication of Crutzen's paper, even after peer review and revisions, for various and sincere reasons that are not wholly scientific. Here, I write in support of his call for research on geoengineering and propose a framework for future progress in which supporting and opposing viewpoints can be heard and incorporated. I also propose that research on geoengineering be considered separately from actual implementation, and I suggest a path in that direction.

1. Geoengineering – Past Ideas and Their Results

Schelling (1996) has noted that while "geoengineering" is not fully defined, that "it seems to imply something global, intentional and unnatural". Thus, not all human-caused changes to Earth's surface, biota and flows of minerals and water would qualify. For example, Vitousek et al. (1986) and Pauly and Christensen (1995) have estimated that humans are using or diverting significant fractions of primary productivity on land and at sea, respectively, and Postel et al. (1995) have shown that humans are using significant fractions of the fresh water available globally from evapotranspiration and runoff, partly through damming of rivers to convert energy of falling water to electricity and for water management. Similarly, large changes to Earth's surface have occurred due to clearing of forests and grassland for agriculture and pastures, and Brewer (1997) has estimated that adding CO_2 to ocean waters has measurably decreased carbonate ions, increased bicarbonate, lowered pH (see also, SCOR, 2004) and increased oceanic volume. Brewer also noted that the accumulated total production of water from combustion of fossil fuels exceeds the volume of one of the Great Lakes (Erie). Other similar indicators of disturbance

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such as synthetic fertilizer usage and energy consumption (Clark, 1989) led Crutzen (2002) to coin the term "anthropocene" to describe our epoch of history. While intentional geoengineering to counter anthropogenic environmental problems does not seem to be included in the term "managing the planet" (Clark, 1989), humans might, one day, accept responsibility to manage the planetary environment.

In the face of such human impacts, various suggestions have been made on how to engineer countermeasures but very few refereed papers have appeared. A proper review is not my purpose here. MacCracken (1991) and COSEPUP (1992) have reviewed some of the literature. Often, suggestions have been reported verbally or in sketchy writing and were taken directly to government organizations in search of funding. I will mention several cases where normal scientific publication procedures were used because they illustrate useful points.

Stix (1989) showed how IR lasers might be used to dissociate (multi-photon process) CFC's in the lower atmosphere to retard their growing concentrations in the troposphere to slow the greenhouse effect and to reduce their flow into the stratosphere (where chlorine from CFC's destroys ozone). He described the concept and the underlying physics, obtained quantitative estimates of how much electricity would be used to power the lasers and concluded that the idea was far from practical. Cicerone et al. (1991) introduced an idea to suppress the annual destruction of ozone in the Antarctic polar stratosphere by injecting ethane or propane there, identified many assumptions, numerically modeled simplified governing equations (chemical kinetics) and estimated the effectiveness. Elliott et al. (1994) improved this modeling with updated chemical reaction schemes and showed that recently discovered reactions would vitiate the usefulness of the idea, and possibly cause added alkanes to worsen ozone depletion. In these cases, normally accepted scientific process allowed schemes to be explored responsibly.

Fertilizing the world's oceans with iron was suggested by Martin et al. (1990) as a way to enhance marine productivity in Fe-poor regions, thus drawing more carbon dioxide from the air. A number of revealing field experiments and model calculations have been conducted in response, and while prospects for reducing or stabilizing atmospheric CO_2 in this way are not good, a great deal of valuable science has been accomplished (Peng and Broecker, 1991; Boyd et al., 2004; Gnanadesikan et al., 2003).

Other geoengineering ideas have been described in different degrees of fullness, including: injecting small metallic particles into the stratosphere to radiate energy more effectively to space (US patent by Chang and Shih, 1991), to loft sulfur into the stratosphere by balloons and/or large guns (COSEPUP, 1992). Floating reflecting balloons or orbiting mirrors to reflect sunlight to counter warming have been studied semi-seriously and carbon sequestration is now being analyzed scientifically. Restoring stratospheric ozone by producing ozone at Earth's surface w/electrical discharges then transporting it to the stratosphere (failing to understand that ozone destruction is continuous and catalytic as opposed to one-time, stoichiometric replacement !) were suggested repeatedly in past years. Other similar ideas have included extracting useful electricity from the aurora with antennae (poor concept and quantification but money was wasted on it). Obtaining solar energy from collectors in earth orbit, beaming it to Earth's surface has also been studied. Hail suppression, cloud seeding, storm prevention are topics that attract interest from time to time, and vague suggestions as to spreading carbon soot over snow and ice surfaces, or covering the oceans with white foam or particles have been made. In a few cases, manuscripts have been prepared for submission to journals and were then withdrawn or were rejected.

As environmental problems grow, one can expect demand for geoengineering solutions to increase. Thus, Dickinson (1996) said "As global greenhouse warming continues to intensify, it is likely that demands to employ technologies of climate engineering will become increasingly insistent." Similarly, people in those regions or nations who feel most threatened by the environmental problem will be most willing to use technological intervention (Kellogg and Schneider, 1974; Cicerone et. al., 1992). I believe that refereed papers are to be encouraged in this field; they will permit poor or dangerous ideas to be seen as such and meritorious ones to develop further.

1.1. HOW SHOULD GEOENGINEERING RESEARCH BE CONDUCTED AND PUBLISHED?

We should proceed as we would on any other scientific problem, at least for theoretical and modeling studies. First, the underlying concepts should be identified and described. Then one should develop one or more mathematical models based on scientific principles and mechanisms, identifying and stating assumptions and writing the governing equations. Quantitative computations should follow, with evaluation of the sensitivity of system to candidate interventions. Side effects that can be anticipated should be analyzed and unanticipated side effects should be sought. Any irreversible feature of the intervention or its consequences should be identified. For example, adding sulfur would have to continue indefinitely. Results should be submitted for publication. Crutzen's paper generally follows this path. In this way, some concepts will be seen to be flawed, and can be identified as such but could still be published to advance the science. Indeed, Stix showed how distant his goal would have been, Cicerone et al. (1991) and Elliott et al.(1994) demonstrated how key assumptions weakened their original idea and how newly discovered chemical reactions undercut it. Also, on scientific grounds, Crutzen rejected the idea of releasing carbonyl sulfide (OCS) at ground level even though it must have been attractive to him, given his hand in discovering OCS in Earth's atmosphere. In those future cases where geoengineering ideas continue to look feasible, further modeling studies could proceed, with fewer or more realistic assumptions.

To support such research, we should also be willing to evaluate journal papers and proposals for research grants for theoretical studies or small-scale prototype experiments with an open mind, and to participate in relevant research conferences. Proposals for actual engineering intervention can be handled separately; see below.

2. Objections, Fears, Pro's and Cons

A commonly held view is that commitment to geoengineering would undercut human resolve to deal with the cause of the original problem, greenhouse gases in the case of climate change; Crutzen states such concerns as did Cicerone et al. (1992), Schneider (1996), and Schelling (1996). There is a widespread, perhaps universal belief that humans must first attempt to limit these emissions. Crutzen notes that worldwide agreements may not prove to be effective. Most scientists believe that there is also a danger from ignorance of harmful side effects, and there are other reservations against geoengineering on ethical grounds.

While some people fear that research will lead to direct experimentation and to geoengineering interventions, I believe that we should encourage research, and separate research from actual interventions (see below). Research is needed to reduce ignorance, and it is likely that gaining an acceptable amount of knowledge before intervention will take many years. Freedom of inquiry itself has moral value.

2.1. THE PRACTICE OF GEOENGINEERING

While a strong scientific basis is necessary for geoengineering, it is far from sufficient. Many ethical and legal issues must be confronted and questions arise as to governance and monitoring, as several authors have noted (e.g. Kellogg and Schneider, 1974; Schneider, 1996; Bodansky, 1996). A useful step might be for scientists to defer participation in geoengineering interventions (while supporting research), which moratorium would continue until acceptable agreements were in hand. Such an agreement would, ideally, include provision for expert, international peer review before actions would be mounted, for significant public involvement, and the establishment of a qualified agency to oversee the design, implementation and monitoring of the experiment.

In the mid-1970's scientists debates and agreed to defer certain experiments aimed at transferring genes from one species to another. A variety of forums eventually (quickly) led to the creation of acceptable ethical guidelines and controls over laboratory experimental types and conditions (Berg et al., 1975a,b) and Berg (2004). Leaders in the new fields of molecular genetics and recombinant DNA technology exercised self-restraint without preventing progress; they involved supporters and opponents with participation from all of those concerned (Berg, 2005).

For geoengineering, a question that would be in the minds of many as they considered any time proposed to end the moratorium is whether humans had done enough to limit greenhouse gas emissions. If a moratorium is proposed, provision should be made for field experiments of smaller scale, such as the iron additions or CO_2 additions to ocean water and terrestrial systems (such as FACE), experiments whose intentions are scientific, not to alter the global environment. Two questions raised by Clark (1989) in a discussion of managing the planet would be relevant: what kind of world do we want? And what kind of world can we get?

In summary, I believe that two steps are needed in response to Crutzen's paper: Step 1. Encourage research, adopting the framework outlined above, or something similar. Journal editors, past editors and leaders of scientific funding agencies, public and private, should define criteria.

Step 2. Scientific leaders should meet to consider proposing a moratorium on large-scale field manipulations until conditions to be defined further are met. They would probably include establishing a body to oversee the planning and conduct of any engineering interventions. Attendees at meetings to discuss a moratorium need careful thought; the scientific community should initiate them and be central, then as actual experiments or engineering interventions are contemplated, more public involvement would be needed.

Many people fall into one of two (polar opposite) groups: one believes that the environment is seriously threatened by human activity and has little faith in science and technology (especially technology) as a solution, and the other group is unconcerned about environmental impacts of humans and has great faith in S&T (especially T). Plans for geoengineering will require both of these groups to listen and perhaps to agree on proper actions, while research on geoengineering should proceed independently.

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