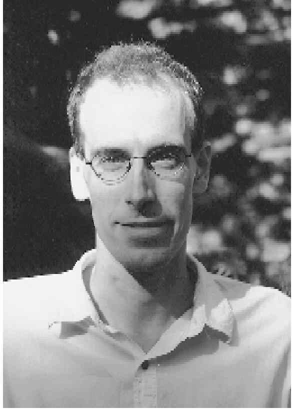

Geoengineering Climate

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Geoengineering is the intentional large-scale manipulation of the global environment. The term has usually been applied to proposals to manipulate the climate with the primary intention of reducing undesired climatic change caused by human influences. These geoengineering schemes seek to mitigate the effect of fossil-fuel combustion on the climate without abating fossil fuel use; for example, by placing shields in space to reduce the sunlight incident on the Earth.

Possible responses to the problem of anthropogenic climate change fall into three broad categories: abatement of human impacts by reducing the climate forcings, adaptation to reduce the impact of altered climate on human systems, and deliberate intervention in the climate system to counter the human impact on climate — geoengineering.

It is central to the common meaning of geoengineering that the environmental manipulation be deliberate, and be a primary goal rather than a side-effect. This distinction is at the heart of the substantial moral and legal concerns about geoengineering. For example, while it may be argued that modern agriculture constitutes geoengineering, the global-scale transformations of the nitrogen cycle it causes is a side-effect of food production, and is usually viewed differently from the deliberate modification of the global environment.

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Examples of Geoengineering Proposals

A variety of geoengineering schemes are summarized in Table 6. A taxonomy of geoengineering is presented in Figure 19. Technical discussion of geoengineering is omitted here. Summary articles are described in the annotated bibliography below.

Evaluating Geoengineering

Most discussion of geoengineering has focused on assessments of technical feasibility and approximate cost. However, it is probable that issues of risk, politics, and ethics will prove more decisive factors in real choices about implementation. This is true both because of the strong negative reactions often provoked by most geoengineering proposals, and because many geoengineering schemes are inexpensive relative to abatement or adaptation.

Economics and Risk Analysis

The simplest economic metric for geoengineering is to compute the "cost of mitigation" — the ratio of cost to the amount of mitigation effected (typically measured in dollars per ton of carbon emission mitigated). This measure permits comparison between geoengineering schemes and between geoengineering and the abatement of emissions. Table 6 includes the cost of mitigation for various schemes. The costs are highly uncertain. For albedo modification schemes additional uncertainty is introduced by the somewhat arbitrary conversion from albedo change to equivalent reduction in CO_2.

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Geoengineering Scheme	COM*	Technical Uncertainties	Risk of Side Effects	Non-Technical Issues
Injection of CO_2 into the ocean.	30-80	Costs are much better known than for other geoengineering schemes. Moderate uncertainty about fate of CO_2 in ocean.	Low risk. Possibility of damage to local benthic community.	Like abatement this scheme is local with costs associated with each source. Potential legal and political concerns over oceanic disposal.
Injection of CO_2 underground.	30-80	Cost are know as for CO_2 in ocean; less uncertainty about geologic than oceanic storage.	Very low risk.	Is geologic disposal of CO_2 geoengineering or a method of emissions abatement?
Ocean fertilization with phosphate	1-3	Uncertain biology: can ecosystem change its P:N utilization ratio?	Moderate risk. Possible oxygen depletion may cause methane release. Changed mix of ocean biota.	Legal concerns: Law of the Sea, Antarctic Treaty. Liability concerns arising from effect on fisheries; N.B. fisheries might be improved.
Ocean fertilization with iron	0.3-3	Uncertain biology: when is iron really limiting?	As above.	As above.
Intensive forestry to capture carbon in harvested trees.	3-100	Uncertainty about rate of carbon accumulation, particularly under changing climatic conditions.	Low risk. Intensive cultivation will impact soils and biodiversity.	Political questions: how to divide costs? Whose land is used?
Solar shields to generate an increase in the Earth's albedo.	10-100	Costs are large and highly uncertain. Uncertainty dominated by launch costs.	Very low risk. However, albedo increase does not exactly counter the effect of increased CO_2.	Security, equity and liability if system used for weather control.
Stratospheric SO_2 to increase albedo by direct optical scattering.	$<< 1$	Uncertain lifetime of stratospheric aerosols.	High risk. Effect on ozone depletion uncertain. Albedo increase is not equivalent to CO_2 mitigation.	Liability: ozone destruction.
Tropospheric SO_2 to increase albedo by direct and indirect effects.	< 1	Substantial uncertainties regarding, aerosol transport and their effect on cloud optical properties.	Moderate risk: unintentional mitigation of the effect of CO_2 already in progress.	Liability and sovereignty because the distribution of tropospheric aerosols strongly effects regional climate.

Table 6
Summary comparison of geoengineering options.
(*) Cost of Mitigation (COM) is in dollars per ton of CO_2 emissions mitigated. While based on current literature, the estimates of risk and cost are the author's alone.

Examination of the cost of mitigation reveals that it varies by more than two orders of magnitude between various schemes, and that for some (*e. g.*, stratospheric aerosols) the costs are very low compared to either abatement or adaptation. However, such direct cost comparisons have little meaning given the very large differences in the non-monetary aspects of these responses to climate change; *e. g.*, risk of side effects, certainty of effect, and social distribution of cost.

Geoengineering as a Fallback Strategy

Geoengineering may serve as a fallback strategy by putting an upper bound on the costs of mitigation should climate change be more severe than we expect. In this context a fallback strategy must either be more certain of effect, faster to implement, or provide unlimited mitigation at fixed marginal cost. Various geoengineering schemes meet each of these criteria. The notion of geoengineering as a fallback option provides a central, or perhaps the only justification for taking large-scale geoengineering seriously. A fallback strategy permits more confidence in adopting a moderate response to the climate problem: without fallback options a moderate response is risky given the possibility of a strong climatic response to moderate levels of fossil-fuel combustion.

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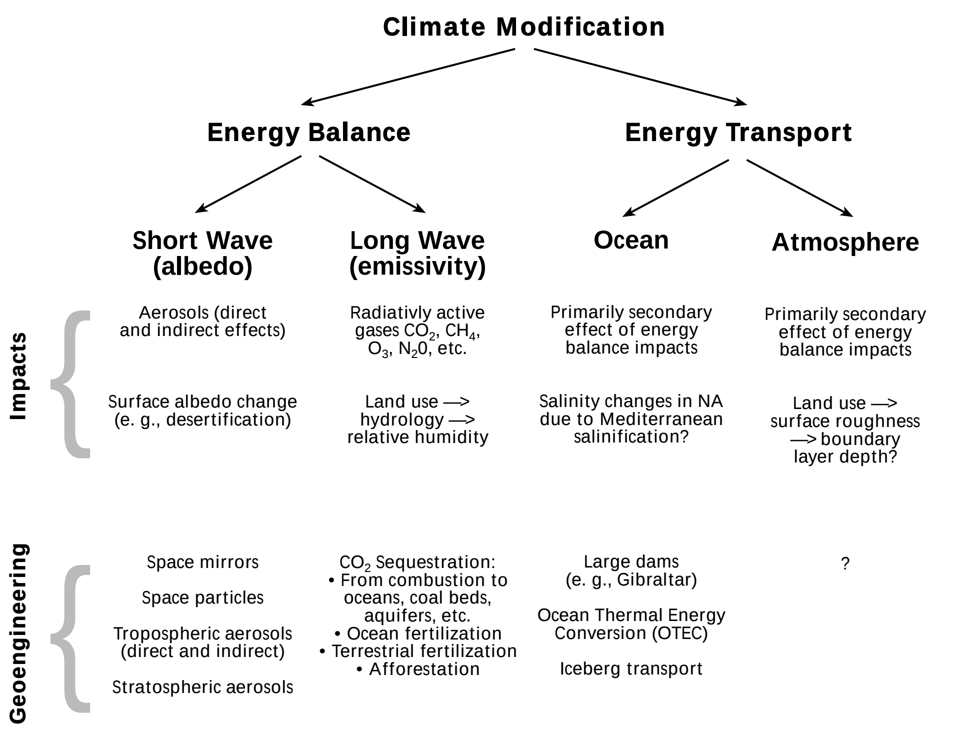

Figure 19
Taxonomy of Geoengineering and Climate Impacts
David Keith, 1998

Risk Assessment

Questions about the advisability of geoengineering revolve around risk: risk of failure and risk of side effects. Climate prediction is too uncertain to allow quantitative assessment of risk. However, if a geoengineering scheme works by imitating a natural process, we can make a qualitative risk assessment by comparing the magnitude of the engineered effect with the magnitude and variability of the natural process, and then assume that similar perturbations entail similar results. For example, the amount of sulfate released into the stratosphere as part of a geoengineering scheme and the amount released by a large volcanic eruption are similar. We may estimate the magnitude of stratospheric ozone loss by analogy. Even crude qualitative estimates of risk can give insight into the relative merits of various geoengineering schemes when considered in conjunction with other variables. Table 7 illustrates this with a comparison of risk and cost.

Table 7
Comparing risks and costs of various options

Risk	Cost		
	Low	**Medium**	**High**
Low	—	Intensive forestry for carbon sequestration	Solar shields CO_2 sequestration
Medium	Tropospheric SO_2 Ocean fertilization with iron	Inert stratospheric aerosols Ocean fertilization phosphate	Balloons in the stratosphere
High	Stratospheric SO_2	—	—

Political Considerations

The cardinal political reality of geoengineering is that unlike other responses to climate change (*e. g.*, abatement or adaptation), geoengineering could be implemented by one or a few countries acting alone. Various political concerns arise from this fact with respect to security, sovereignty, and liability; they are briefly summarized below.

Some geoengineering schemes raise direct security concerns; solar shields, for example, might be used as offensive weapons. A more subtle but perhaps more important security concern arises from the growing links between environmental change and security. Whether or not they were actually responsible, the operators of a geoengineering project could be blamed for harmful climatic events that could plausibly be attributed — by an aggrieved party — to the geoengineering. Given the current political disputes arising from issues such as the depletion of fisheries and aquifers, it seems plausible that a unilateral geoengineering project could lead to significant political tension.

In general, international law has little bearing on geoengineering. However, Bodansky (1996) points out that several specific proposals may be covered by existing laws; for example, the fertilization of Antarctic waters would fall under the Antarctic Treaty System, and the use of space-based shields would fall under the Outer Space Treaty of 1967.

Discussion of geoengineering commonly elicits strong negative reactions. Within the policy analysis community there has been vigorous debate about whether discussion of geoengineering should be included in public reports that outline possible responses to climate change.

As in the current negotiations under the Framework Convention on Climate Change, geoengineering would raise questions of equity. In this case, geoengineering might simplify the politics. As Tom Schelling (1996) points out, geoengineering "… totally transforms the greenhouse issue from an exceedingly complicated regulatory regime to a simple — not necessarily easy, but simple — problem in international cost sharing." One must note that not all geoengineering schemes are amenable to centralized implementation. For example, carbon management requires diffuse implementation at the manifold sources of fossil fuel combustion.

Ethics

Discussion of geoengineering commonly elicits strong negative reactions. Within the policy analysis community, for example, there has been vigorous debate about whether discussion of geoengineering should be included in public reports that outline possible responses to climate change. Fears have been voiced that its inclusion in such reports could influence policymakers to take it too seriously, and perhaps to defer action on abatement given knowledge of geoengineering as an alternative (see Schneider, 1996 for discussion of the debate over geoengineering in the 1992 National Academy of Sciences panel). While these concerns are undoubtedly serious and substantive, it is difficult to disentangle their various roots and, in particular, to separate pragmatic from ethical concerns.

Many of the objections to geoengineering that are cited as "ethical" have an essentially pragmatic basis. Three common ones are:

- **The Slippery Slope Argument:** If we choose geoengineering solutions to counter anthropogenic climate change, we open the door to future efforts to systematically alter the global environment to suit humans. This is a pragmatic argument, because in the future we will be as free as we are now to choose to what extent we wish to geoengineer. An ethical argument must define why such large-scale environmental manipulation is bad, and how it differs from what humanity is already doing.
- **The Kluge Argument:** Geoengineering is a technical fix, kluge, or end-of-pipe solution. Rather than attacking the problems caused by fossil fuel combustion at their source, geoengineering aims to add new technology to counter their side-effects. Such solutions are commonly viewed as inherently undesirable, but not for ethical reasons.
- **The Unpredictability Argument:** Geoengineering entails messing with a complex, poorly understood system; since we cannot reliably predict results, it's unethical to geoengineer. Because we are already perturbing the climate system with consequences that are unpredictable, this argument depends on the notion that intentional manipulation is inherently worse than manipulation that occurs as a side-effect.

One may analyze geoengineering using common ethical norms; for example, one could consider the effects of geoengineering on intergenerational equity, or on the rights of minorities (*e. g.*, the inhabitants of low-lying countries). However, these modes of analysis say nothing unique about geoengineering, and could be applied in a similar manner to many other technological choices. Some people would argue that such analysis fails to address a particular ethical abhorrence they feel about geoengineering and that we should look for an ethical analysis that addresses geoengineering in particular; *e. g.*, an environmental ethic.

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The simplest formulations of environmental ethics proceed by extension of common ethical principles that apply between humans. A result is "animal rights" in one of its variants; *e. g.*, Regan (*The Case for Animal Rights*, University of California Press, Berkeley, 1983). Such formulations locate "rights" or "moral value" in individuals. When applied to a large-scale decision such as geoengineering, an ethical analysis based on individuals reduces to a problem of weighing conflicting rights or utility. As with analyses that are based on more traditional ethical norms, such analysis has no specific bearing on geoengineering. Alternative, and more controversial formulations of environmental ethics locate moral value in systems of individuals, such as a species or a biotic community (see for example Callicott, *In defense of the Land Ethic*, State University of New York Press, Albany, 1989). It is plausible that such a formulation of environmental ethics could more directly address the ethics of geoengineering.

Because we are already perturbing the climate system, the "unpredictability" argument depends on the notion that intentional manipulation is inherently worse than manipulation that occurs as a side-effect.

Annotated Selected Bibliography

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David Keith describes a geoengineering option.