a few percent in order to offset 2X or 4X increases in atmospheric CO_2. The proponents believe that Govindasamy (2003) shows that their remedies would provide reasonably good compensation for any global warming due to higher CO_2 levels. The proponents have tried to anticipate and answer many other potential criticisms of their proposals as well. A recent news report[28] provides some interesting insights into the motivation for the Livermore papers and the internal questioning, research such as that mentioned above, and ultimately agreement that went on within the Laboratory concerning these proposals.

5.3.3 Optimized Radiative Forcing Using Space-based Deflector (Remedy H)

A space-based deflector is likely to take substantially longer to put into place and be much more expensive than stratospheric particles, but just as effective in reducing incoming sunlight, much more permanent, more flexible, have less environmental side effects, and involve lower maintenance costs. Keith's (2001) estimate is that the equivalent cost per ton of carbon removed is 20 cents to $2, although there is no evidence that this is based on a careful engineering assessment of the problems involved. One of the more important additional benefits compared to Remedy G would be the ability to respond even more rapidly (presumably immediately if adequate planning and coordination were accomplished ahead of time and the system was planned with this in mind) to unanticipated changes in global temperatures, such as may occur as a result of major volcanic eruptions or abrupt climate changes. It presumably would also avoid most or all of the possible environmental side effects possibly resulting from placing particles in the stratosphere. But it would involve something beyond what has ever previously been accomplished, namely, to assemble and maintain a large structure far out in space. Despite the recent problems of the space shuttle, there are no obvious reasons that this could not be done, but it might well require significant time as well as technical and other resources to accomplish. Only a very careful engineering study could fully estimate the costs involved. Since it would also take much longer to design, transport, and build, one possibility might be to consider this as a possible longer term, more permanent solution that could be built during a period when optimized stratospheric particles are used to control global temperatures as an "interim" measure.

5.4 General Conclusions Concerning Alternatives for Controlling Climate Change

Geoengineering is more than a little controversial; the disparity in views is illustrated by the following:

> Schneider (2001) argues that although "adaptation alone may prove inadequate," he would "prefer to slowly decrease our economic dependence on carbon fuels rather than to try to counter the potential side effects with centuries of injecting sulphuric acid into the atmosphere or iron into the oceans. Laying stress instead on carbon management, with little manipulation of biogeochemical or energy fluxes in nature, is a much less risky prospect…."
>
> Michaelson (1998) argues that "the response to the claim that geoengineering 'just won't work' is to argue that such a claim is premature in practice and foolish in principle. Of course, the case for any new technology is 'uneasy,' and uncertainty will remain up until a geoengineering project is put into place, but such uncertainty is not sufficient reason to fail to initiate research now. Nor can we be daunted by the prospect of vast, unforeseen secondary consequences of tampering with the Earth's climate; again, it is too early to tell. Caution is wisdom--but inordinate skepticism flies in the face of a century of technological achievement."

Considering only temperature-related effects, it is hard to find anything to like about remedy B other than that it is already largely in place in terms of its structure, at least until 2012. As outlined in Section 3, continued substantial reliance on it is most likely to result in substantial global warming because of its ineffectiveness,[29] dependence on individuals making decisions against their own self-interest, and its potential effect of limiting efforts to find better alternatives. Remedy B also appears useless as a way to control global cooling. And the economic efficiency of this option appears to be strongly negative. The other potential remedies (other than A, no change) range somewhere between B and G in their attractiveness. Remedies E through H appear to offer positive efficiency and make lower demands on individuals for implementation, but have varying costs and environmental side effects. Option G appears to be equal to or better than all the other options under each criterion (although H offers lower environmental risks at potentially much higher costs in time and money), so would appear with one important footnote to be reasonably called a superior option for dealing with gradual global warming despite Schneider's reservations concerning geoengineering options. There are many unanswered implementation questions, however, concerning whether this option really has been optimized, exactly how it would be implemented, exactly how much it would cost, who would pay for it, and the nature and extent of non-global warming environmental effects that would need to be answered before actual implementation could reasonably be undertaken. But there would appear to be a case for undertaking an early but limited research and development effort to answer the geoengineering implementation questions *before* making large investments in any high-cost remedies that might be undertaken under the Kyoto Protocol approach. Remedy G can also be viewed as a rapidly implemented interim measure while longer-term CO_2 reducing remedies are put into place and become effective and as an emergency response measure in the case of rapid climate changes such as major volcanic eruptions.

Although there is less experience with using these options than with option B, the technical risks would appear controllable through careful experimentation. In the unlikely event that such experimentation should show that all the permutations of option G have significant environmental side effects, this would suggest the use of option H. Rejecting geoengineering approaches because of their remaining technical uncertainties or unfamiliarity, as Schneider appears to do, does not appear to be a conclusion based on careful analysis. The major footnote to this conclusion concerns mitigating the non-temperature effects of increases in GHG levels (Problem 2 as defined in Section 1.1), which the radiative forcing approaches would not affect, but which will be discussed in more detail in Section 5.6.2.

The experience to date with the Kyoto Protocol has not shown that that approach can be effective in significantly reducing the growth of GHG emissions or stabilizing atmospheric CO_2 levels. There would obviously be considerable difficulty in reaching an international agreement to undertake geoengineering not covered by the Kyoto Protocol, although the same would be true of follow-ons to the Protocol. The advantage of the geoengineering approaches, however, is that once agreed upon, there is no need for individual cooperation of most of Earth's energy-using population, as would be required for effective, worldwide energy conservation or other mitigation efforts on the scale that would be needed to bring CO_2 emission levels back to levels that would stabilize atmospheric levels at less than "dangerous" levels. And if (as seems almost certain) there are major volcanic eruptions that send material into the stratosphere or if there should be a collapse of the ocean conveyor belt or other abrupt or unforeseen climate changes, there would appear to be no other feasible remedy that could effectively mitigate these changes. Careful preparations for geoengineering approaches involving remedy G may be justifiable even if they are never used for reducing global warming as an insurance policy against abrupt adverse climate changes such as these.

Continued pursuit of only the Kyoto approach (remedy B) appears to be counterproductive given the implementation problems inherent in it. Unfortunately, an unintended consequence may be that to discourage consideration of more effective measures during the long period needed for the major deficiencies of remedy B to become evident to all. Thus although the Kyoto approach is strongly favored by many environmentalists, the net result of pursuing it alone may be to postpone effective action to control global warming for as long as it takes for the world to recognize that this approach is very unlikely to significantly decrease atmospheric GHG levels.

5.5 Other Management Approaches Besides the Kyoto Protocol

In Section 1.2 several other possible management tools besides the Kyoto Protocol were briefly listed. The question now is how the conclusions above might differ if these other management tools were used. The analysis appears to yield the following conclusions:

(MA1a) This management option involves purely voluntary efforts by individuals/corporations concerned enough to do something, either with or without public educational efforts to persuade them to do so. This presumably eliminates the potential political backlash from angry constituents whose GHG-producing activities would be reduced. It should also result in the use of relatively efficient control measures. Similarly, only those willing to be internationally less competitive would undertake such solutions, so that presumably would eliminate that as a political problem. Although such efforts are likely to have a positive effect and deserve to be encouraged, it appears unlikely that a purely voluntary effort will have a significant effect on one or more of the four problems since the effects are likely to be very small compared to what would be required to meet the UNFCCC goals as currently interpreted. Kyoto was undertaken in large part because of concern that purely voluntary actions would be unlikely to meet the UNFCCC goals. This seems unlikely to have changed.

(MA2b) If one or even a few local jurisdictions should decide to take a decentralized approach as a result of a political decision (such as has recently occurred in California and may occur in other "blue" states) or a judicial interpretation of the law (such as might or might not occur as a result of *Commonwealth of Massachusetts v. EPA*), the result might be progress in solving a small portion of the larger problem originating in that local jurisdiction or jurisdictions. Or if one or even a few nations decided to pursue an approach that was independent of those taken by any international body or uncoordinated with a group of nations with significant emissions, the same would appear to be the case for those nations. But except if only low cost solutions were imposed, or if the country/jurisdictions pursued one of the radiative forcing options (which appears highly unlikely in the case of local jurisdictions given that such efforts are likely to be necessarily based on existing national laws rather than new laws), the results would presumably be less efficient and effective than under the Kyoto management approach since the jurisdictions involved would presumably be the only ones to pursue this approach and would be limited to whatever control measures may be available under current national laws in the case of local jurisdictions. In the (unlikely) case of the radiative forcing options, a technologically advanced and wealthy country could indeed "go it alone" and institute a very effective and efficient solution but at the cost of possible condemnation by the rest of the world since the cost to that country would apparently be low. The costs would presumably be higher under non-radiative forcing solutions since a locally-based approach using existing law is likely to be less efficient than one based on new national legislation tailored to minimizing the costs of control for these particular pollutants (such as by the use of economic incentives such as cap and trade). This does not mean, of course, that decentralized decisions could not be used to "push" the political process at the national level by local jurisdictions by creating costly or otherwise unpalatable alternatives unless alternative political decisions were made at the national level.

(MA2c) One or more countries could adopt liability laws/legal precedents that make it very expensive for companies to sell/use very high GHG emitting products. The State of California, for example, has recently filed suit against the world's six largest automakers asking that they pay damages for the GHGs that their vehicles emit.[30] Unless all countries adopted them and had similarly effective legal institutions, the results would probably be worse than under the Kyoto scenario. Presumably only those countries with strong judicial systems, liability-based legal traditions, and strong motivation could effectively utilize this approach. In addition, such an approach is unlikely to result in the adoption of the lowest cost control options given that no one executive branch institution would coordinate the control efforts for that purpose. Finally, it is difficult to see how any of the lower cost radiative forcing options could be implemented under this approach. As in MA2c, however, it is entirely possible that climate change torts could be used to "encourage" the political process to take other actions to solve the problem. But if this process actually determined the control measures used, the results would probably be less efficient and effective than under the Kyoto approach.

(MA4) This option is a hypothetical new international approach utilizing the best of all the other management approaches and using all available technologies and including all sources of GHG emissions, but using a better rationale based on relative responsibility for the problem and the "polluter pays" principle. It would appear to be primarily useful if the world decides to make a serious effort to control ocean acidification since all the other problems can be more effectively and efficiently be controlled us-using MA3, engineered climate selection. One possibility would be the creation of an international fund based on past and present emissions.[31] This is intended as something of an "ideal" approach that solves some of the major problems of Kyoto while also providing an international framework for coordinated reductions in GHG emissions. The intention here is to fashion a replacement for Kyoto that corrects at least some of its major deficiencies, as discussed earlier in Section 3.3. The place to start would appear to be to correct the weak rationale for Kyoto. As outlined in Section 3.3.7, a much more logical basis for such an international agreement would be to base it on the "polluter pays" principle as opposed to the "rollback" approach with exemptions embodied in Kyoto. Those countries responsible for present and past GHG emissions would pay an amount based on the lesser of the damages these emissions have caused/will cause and the cost of solving the resulting problems.[32] Presumably some allowance could be arranged for countries to spend a portion of what they would owe internally for climate control purposes. Where the damages/costs for past and present emissions are roughly the same, as in the case of CO_2, the amount paid by paid by each country would presumably be proportional to their total anthropogenic emissions since human-caused emissions started causing problems. Where past emissions cause less damage/cost less to control than current emissions, the total amount paid by each country would be the sum of the damages/costs from past and from current emissions. These payments, in turn, would be used to provide incentives for the development and application of technology that reduces GHG emissions. Since all countries that have emitted GHGs that have not dissipated in not injurious ways would be obligated to pay, all such countries would have an incentive to reduce emissions. Although the payments would be mandatory, the emission decisions would be voluntary. In the case of CO_2, all emissions since atmospheric levels of CO_2 started to rise would be included since these emissions are still in the atmosphere or have been absorbed by the oceans, with a deleterious effect on ocean acidification. Such a fund could be used to pay for the least expensive and most effective remedies regardless of where they may occur and the technology used, including engineered climate selection, nuclear power, incentives to reduce CO_2 emissions from air travel, and public educational efforts where they are likely to be effective. It would appear important that this "ideal" successor to Kyoto be fully enforceable. One of the major design issues would presumably be how to establish fair and equitable payments for emissions. The ideal would be levels that would just accomplish the desired goals—say a limit of 2^oC on world temperature increases and a corresponding (but as yet not established) goal for limits on ocean acidification. If the temperature goals were to be achieved using stratospheric radiative forcing only, the fee levels would presumably be very low—probably so low that such a complicated agreement might not be worth pursuing. If, on the other hand, a serious effort were undertaken to prevent ocean acidification, much higher levels would be required. It would be important to allow some flexibility so that prices could be changed if goals were or were not being met. Such an approach would encourage an incentive approach rather than a coercive approach to climate change control. Individuals and nations could decide whether to burn and pay or use alternatives and not pay. They could also choose to accept financial assistance from the fund or not to.

It must be emphasized that such a new hypothetical proposal would not solve all the problems of Kyoto. The principal remaining difficulty would be the high cost of preventing ocean acidification and the reluctance of people and governments to paying that cost. But if the world wants to achieve that goal, this may offer a possible way forward towards that end that just might provide a basis on which the nations of the world could agree. All countries would be liable, but most (but not all) of the cost would still be paid by the developed world.

5.6 Conclusions with Respect to Specific Climate Change Problems

Section 5.4 summarized the general conclusions regarding efficiency and effectiveness of each remedy for the climate change problem as a whole. This section applies these conclusions to suggesting solutions for each of the four specific climate change problems delineated in Section 1.1 and Table 1.

5.6.1 Gradual Increase in Global Temperatures (Problem P1)

This corresponds to problem P1 in Section 1.1 and in Table 1. The general conclusions outlined in Section 5.4 apply to this problem without change, so that remedy G appears to be the superior option for dealing with this problem. Gradually increasing global warming could most efficiently and effectively be controlled using one of the radiative forcing remedies. Attempts to control it through greenhouse gas control are unlikely to be successful because of the lifestyle changes required and high cost of doing so. The principal result of efforts to do so may be to delay effective action. Radiative forcing remedies are some of the few realistic alternatives available. They could best be carried out on an internationally cooperative basis, but could also be done on a "go-it-alone" basis at the risk of possible international condemnation.

5.6.2 Non-temperature Effects of Higher Atmospheric GHG Levels (P2)

Some of these effects appear to be positive rather than negative; the positive ones actually favor the use of remedy G since they would not disturb the increasing atmospheric CO_2 levels. The primary example is the positive effect of elevated CO_2 levels on some plant growth. Presumably both those plants whose growth is stimulated by higher CO_2 concentrations as well as animals and humans who consume them will be better off by such higher concentrations. Current research suggests that cultivated crops and some weeds[33] may particularly benefit, perhaps at the expense of other plants that are not stimulated by higher CO_2 levels, however. The stimulation of cultivated crops should be a very major benefit to humans. The major adverse non-temperature-related effect of elevated GHG levels appears to be increased ocean acidification. Any of the remedies other than A, F, G, and H can be used to decrease/control the growth of atmospheric CO_2 levels and therefore ocean acidification. Remedy C, CO_2 sequestration, can also be used to directly remove CO_2 from the atmosphere. Other possibilities are to capture and use CO_2 for enhanced oil recovery and to add limestone or other alkaline minerals to streams of newly generated CO_2 or possibly directly to the oceans. Both of these can only be done in limited geographical settings, however. The Royal Society (2005) report argues that using limestone is infeasible on an oceanwide basis but does not comment on its use in CO_2 streams and does not provide cost estimates or other bases for judging this. There would therefore appear to be several questions needing answers: What would be the benefits gained from increased output of cultivated agriculture, what would be the costs of reducing CO_2 emissions into the atmosphere, and what would be the cost of neutralizing using limestone? Another question is whether the cheaper and more effective of these alternatives would be worth doing given what is likely to be a high cost in either case. Despite the efforts by the Royal Society (2005) to discuss remedies, we may still be in the early stages of analyzing what can and should be done about ocean acidification. Since all the current CO_2 mitigation strategies have been designed to treat problem P1, some effort is probably required to refine them for treating only ocean acidification. This problem is likely to be the most difficult of the four to solve, however, because of the potentially high cost, and may even be equally expensive as those for remedy B analyzed in this paper if CO_2 mitigation is the best available option and the benefits of reducing ocean acidification exceed the costs of doing so in this way.

If it is worthwhile from an economic viewpoint to control ocean acidification, it appears likely that the most effective remedies are those that can be implemented without the need for personal involvement in lifestyle decisions. That would suggest primarily remedy C, CO_2 sequestration. Obviously there are some (non-Kyoto) aspects of remedy B that do not involve personal involvement, like a possible decision to expand nuclear power, but which might prove to be deeply divisive politically. It is also likely to be higher cost and take longer to build than fossil fuel-derived power.

5.6.3 Potential for Triggering "Tipping Points"(P3)

It appears reasonable that the risks from "tipping points" or other abrupt climate changes may be proportional to global or regional temperature changes. The lower the increase in temperatures, the lower the chance that a "tipping point" will be hit. If global temperatures could be brought back to those typical for an interglacial period, presumably the chances would be even less. But conversely, any time that a higher "target" CO_2 level is adopted, the risk is presumably increased. Thus failure to actually achieve a given goal or target may carry with it an increased risk of abrupt climate change. The EU and others have decided that an increase of less than 2^oC does not carry with it significant risks, but there is no way to know whether this is actually the case without carrying out the experiment. It appears more plausible that there is rather increasing risk regardless of whether specific levels are exceeded. So if, for example, the Kyoto approach does not achieve a particular objective, there is likely to be some increase in the risk relative to the situation if it were met.

Since this paper has argued that the Kyoto approach is unlikely to meet many targets, it is important to ask which remedies may offer something useful if it becomes evident that a particular "trigger point" is about to be hit or an abrupt climate change is about to occur. In this case, only the radiative forcing remedies among those discussed in this paper might be implemented rapidly enough to control global temperatures and thereby avert the pending risk. There may also be imminent threats of a purely natural sort, and here too it would appear feasible to use radiative forcing remedies in a "rapid response" mode to greatly reduce these risks if advance preparations are in place. The issue here is the ability to react rapidly enough to increasing signs that a "tipping point" is approaching so as to avoid actually triggering it. All of the remedies have the potential to curb the gradual increase in temperatures, but only F, G, and H appear to have the flexibility to actually take evasive action if a "tipping point" should appear imminent. Because of its extreme flexibility, remedy H has perhaps the greatest potential, with remedy G next. It is important to note that these remedies would have to be "in place" and "ready to go" in order to be useful in most "rapid responses" such as envisioned in this paragraph and the next one, Section 5.6.4. Waiting until the need becomes evident to make these preparations would make an effective response more problematic. In the case of Remedy G, being in place and ready to go involves carrying out the needed further development work discussed in this paper, building international agreement as to how this remedy would be employed if needed, and arranging for the needed manufacturing and delivery means. In the case of Remedy H it would mean actually building the solar deflector and building a command and control capability to use it effectively. Remedies B through E have very little to nothing to offer with regard to this problem.

5.6.4 Short-term Cooling from Major Volcanic Eruptions (P4)

Because of the unexpected nature of such eruptions and the need to respond in a very short period of time if global cooling is to be avoided, only remedies G and H have the potential to play a useful role in responding them, with H probably more useful than G because of the possibly lower lag time required to move a deflector than to launch particles into the stratosphere. Depending on the particles used, there might also be conflict with the sulfur compounds emitted by the volcano involved.

5.7 Implications for the Choice of Remedies

There would appear to be two conclusions from this analysis:

● The participating Annex I nations appear to have selected one of the more difficult, expensive, and probably ineffective approaches (the Kyoto Protocol) to climate change control examined in this paper. If it could be fully and effectively implemented and expanded upon in future agreements, it might help to control ocean acidification (problem P2), but the available evidence indicates that all the other presently known climate change problems could be mitigated more rapidly, cheaply, efficiently, and effectively using engineered climate selection involving radiative forcing (remedy G or possibly F or H). Even if effectively implemented, Kyoto would not provide protection against global cooling from major volcanic eruptions (problem P4) or the ability to attempt to evade "tipping points" (P3) if not recognized decades in advance. Kyoto does appear to be more effective and efficient than most of the alternative management tools examined in Section 5.5 with the exception of a "go-it-alone" strategy involving radiative forcing.

● An efficient and effective solution would seem to be to actively pursue both geoengineering approaches involving radiative forcing as well as a new effort to reduce ocean acidification, with immediate priority given to the former in order to rapidly solve the potentially most critical problems. Although significant efforts would be needed to fine tune the proposals to implement these geoengineering approaches, build an international mechanism for making decisions, and to manufacture and launch the needed material/hardware, this approach could be used to rapidly reduce the risks from adverse feedback/tipping point problems from global warming and global cooling from major volcanic eruptions, and to rapidly stabilize global temperatures at any desired level. At the same time, the current global warming control effort could be refocused on the problem of reducing ocean acidification, with an early review of how acidification can best be mitigated and how the present international global warming reduction efforts could be modified to make them much more efficient and effective for this new (but probably closely related) purpose. The net result would be much earlier and more efficient control of three of the more detailed problems and at least the same progress (or lack thereof) in controlling ocean acidification as under the Kyoto approach. This would appear to provide significant gains and no losses compared to the Kyoto-only approach. This should also allow a little time for a new effort to better understand ocean acidification and design and carry out a careful program to reduce it directly, or possibly to decrease the CO_2 levels themselves to the extent that this is the most effective and lowest cost approach. If the latter, this should result in the lowest possible costs of carbon dioxide control by stretching out the period in which they would be made given the sensitivity of the costs of carbon dioxide emissions reductions to the rapidity with which they occur. Wigley (2006) provides some atmospheric modeling along these lines. It might also provide time to build a better replacement for Kyoto that remedies some of its most glaring problems.

The proposed priorities among the various remedies are shown in Table 1. The rationale is as follows. Remedy G appears to be very inexpensive and very effective in solving all the climate change problems other than ocean acidification very rapidly. So it is given the highest priority or 1. Reducing ocean acidification appears to be addressed most efficiently by using limestone to neutralize those streams of CO_2 near oceans and sources of limestone or to use it for advanced oil recovery. So remedy C is accorded the second highest priority or 2. If it appears efficient to further reduce ocean acidification, it would appear that the most effective remedies would involve CO_2 sequestration somewhere other than the ocean since this could be done without worldwide cooperation of the world's population. So still remedy C. If it appears efficient to go beyond what CO_2 sequestration can efficiently accomplish into other approaches that do involve worldwide public cooperation, that would presumably be accomplished under something similar to MA4. So it is accorded a priority of 3. Finally, for the reasons outlined in Section 5.3.3, there are some advantages of remedy H over remedy G. The only problems are the technological and other resources and the time that would be required to implement it. So presumably this should be a longer-term remedy that might usefully receive early research and engineering efforts but would not be implemented until more experience is gained with remedy G by actually trying to implement it. Hence this remedy is accorded a priority of 4.

From an economic viewpoint, whether ocean acidification reduction is worth pursuing beyond purely voluntary efforts would appear to be the most difficult analytical issue. An economic evaluation of the issue based on currently available information depends critically on the value of avoiding further ocean acidification offset by the value of the positive effects of CO_2 buildup in the atmosphere. The Royal Society report (2005) suggests that if the world follows a business-as-usual approach with regard to the buildup of CO_2 in the atmosphere the resulting ocean acidification would in time have very severe effects on the ocean ecosystem. This could indeed have very large damages to humans as well. Given the potentially very large cost of mitigating this effect, a greatly expanded research program would appear to be crucial to making an informed decision on whether and how rapidly to proceed with these very expensive CO_2 mitigation efforts. Assuming that a decision is made that CO_2 mitigation is worthwhile because of these effects, the inexpensive geoengineering approaches which would hopefully already be underway should prove to be a wise investment since they would reduce global warming until the ocean acidification mitigation efforts may be effective and provide an insurance policy against abrupt adverse climate changes in either direction such as those that will result from future major volcanic eruptions. Thus what have long been viewed as competitive solutions should better be regarded as complimentary solutions of a very complex environmental problem. In the case where a decision was made to proceed with conventional CO_2 emission reduction after remedy G had already been implemented, the relatively small added costs of remedy G would not be lost since all the problems except ocean acidification would have been addressed earlier and the added capability to address problems (3) and (4) would presumably have proved useful in themselves. It should be noted that without advance development, planning, international agreements, manufacturing, and delivery systems, remedies G and F could not fulfill these shorter-term climate control functions.

6. Likely Major Objections to Engineered Climate Selection

Assuming that any remaining technical problems in implementing optimized radiative forcing could be resolved through a proposed limited development program such as the proponents have proposed, the primary objections to engineered climate selection solutions are likely to be philosophical, legal, governmental, and strategic.[34]

6.1 Philosophical

The major argument is likely to be whether humans should take direct management responsibility for determining global temperatures. Although humans have been having an increasing effect on temperatures, it has been heretofore been left to nature rather than man to determine the outcome from this important aspect of the environment. The argument is likely to be that it is not acceptable to directly change nature by changing Earth's radiation balance directly. It is acceptable to change it by decreasing GHG emissions but not by overt decisions. In other words, it has until recently been acceptable to increase GHG emissions as long as it is done for non-climatic reasons such as human gain or convenience and it was generally unknown what the effects would be, and it is all right to decrease GHG emissions to an earlier level since that is merely removing some of man's effects on the environment. But some may argue that it is not all right to deliberately remove GHGs already in the atmosphere or change Earth's radiation balance directly even though it would be for exactly the same purpose—to decrease global warming. That, it may be argued, would be interfering with "nature." A very good case, however, can be made that human-induced GHG releases and mitigation are already interfering with "nature," just in a less overt way. And directly managing global temperatures focuses attention on the environmentally important issue—the desired temperature regime for the Earth.

6.2 Legal

Attempts to use of engineered climate selection to "solve" the problem might run into the problem that much of the Western legal system assumes that there is no recovery for damages resulting from "acts of God." But if someone or some government deliberately alters Earth's radiation balance, even for a positive purpose, this may open the possibility that those responsible could be sued for damages by those who believe that damages they sustained from climate-related events were due to the actions of those who they believe attempted to alter nature. The most obvious solution to this problem would be a change in the law to either deny recovery of damages from the use of governmental engineered climate selection approaches to climatic temperature control or to make such liabilities fall onto governments, which would have to fund them out of taxes. This appears to be an area where legal inputs would be much needed.

6.3 Governmental

In a world of sovereign countries, an international process would need to be worked out to determine if, when, and how to deliberately alter global temperatures. This would have to include processes to determine when the results were unsatisfactory and how policy changes would be instituted to solve problems that might be encountered. Although this would not be without difficulty, it is hard to imagine that it would be more difficult than the negotiations that led to the Kyoto Protocol and would be needed if there are to be enforceable follow-on agreements, if such can even be accomplished. But once an agreement was reached, the actual implementation of such agreements would not depend on the cooperation of many governments and people, as is the case under Kyoto.

6.4 Strategic

There may be those who may oppose the proposal made in this paper on the grounds that if the gradual global warming problem is "solved" through engineered climate selction through radiative forcing then they will find it harder to persuade people to reduce fossil fuel use. The problem with this thinking is that it raises the question of whether the object is to solve environmental problems or to achieve some other objective. The position taken here is that the purpose should be to solve important environmental problems, and to do so in the most effective and efficient way available. Those who advocate a Kyoto-only approach are in great danger of achieving nothing and contributing to the increasing risks facing our planet at considerable risk from climate change in hopes of achieving a different objective. It appears better to separate the various problems—gradual global warming, ocean acidification, global warming tipping points, and global cooling from volcanic eruptions—and design a realistic program to tackle each one rather than risking everything for what some may regard as a single overall solution that appears unlikely to be achieved if pursued in this way.

7. Conclusions

This paper assumes that global climate change poses a major environmental problem--perhaps the most difficult one that the world has ever faced. For the purposes of this paper the climate change problem is defined as including four related problems: continued gradual global warming over the next few centuries, non-temperature-related adverse effects of increasing levels of greenhouse gases in the atmosphere such as ocean acidification, the potential effects of "tipping points" where warming may trigger particularly serious abrupt adverse effects, and shorter-term episodes of global cooling caused by volcanic eruptions. The paper asks how effective and efficient a variety of management approaches, particularly the Kyoto Protocol, would be in preventing or mitigating each of these problems, and whether there are alternative approaches that would be more so? The paper takes a very broad view of the problem by including the control of both long and short-term impacts of human activities and natural forces on global temperatures and greenhouse gas levels since it is only by looking at all the major aspects of the problem that effective and efficient solutions can meaningfully be discussed.

The paper concludes that the Protocol will certainly not prevent either global warming or cooling, and that it is unlikely that the mitigation of global warming will meet European Union interpretations of the meaning of the UN goals for maximum temperature increases. If fully implemented, it would probably result in minor decreases in the temperature rise that would otherwise occur and would not provide any capability to respond to global cooling. One of the fundamental problems is that in order for a Kyoto-type approach to achieve the UN goals as defined by the European Union would require the cooperation and participation of most of the world's governments and population to restrict energy use in ways that would directly reduce their welfare but does not provide effective incentives/penalties to bring about such cooperation and participation. 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 of their constituents would not pursue every available loophole or other avenues to avoid observing the constraints that are imposed. It appears unlikely that possible Kyoto follow-on agreements could overcome these implementation problems. In addition to being very difficult to implement, the mitigation likely to be undertaken under the Kyoto approach appears to be economically inefficient, very expensive if it were to have a major impact on global temperatures, and particularly unsuited to affecting global temperatures rapidly or flexibly. Trying to use it in this way to rapidly decrease global warming would be even more expensive because of the resulting expense of replacing greenhouse gas emitting equipment early in its life cycle. Continued pursuit of the Kyoto-only approach appears to be counterproductive given the implementation problems inherent in it. Unfortunately, the principal result of pursuing this approach is likely to be to prevent serious consideration of more effective measures during the long period needed for the major deficiencies of this approach to become evident to all as greenhouse gas emissions increase upward and shorter-term climate change problems are not effectively addressed.

Given these very serious problems with the Kyoto approach, the paper then asks if there are some other superior management and technological alternatives for controlling climate change; the paper reviews a wide array of control options using economic efficiency and other relevant criteria. It concludes that there appear to be superior alternatives involving radiative forcing that appear to be technically sound, would allow continued growth of fossil fuel use, very dramatically lower control costs, be economically efficient, avoid the need for individual actions to reduce greenhouse gas emissions, and permit relatively precise, rapid, and flexible adjustment of global temperatures, but would not affect non-temperature-related adverse effects of greenhouse gases, of which the most serious appears to be ocean acidification.

With this as background, the paper then extends the analysis to the four more detailed climate change problems:

(P1) **Gradually increasing global warming** could most efficiently, effectively, and rapidly be controlled using some of the more interesting radiative forcing or engineered climate selection remedies. Attempts to control it through greenhouse gas control under the Kyoto Protocol in particular are likely to be largely unsuccessful in terms of meeting current interpretations of its goals and very slow because of its unenforceability, the worldwide cooperation and personal lifestyle changes required, and the high cost of meeting goals that would actually make a significant difference. Other management approaches based on disaggregated, local, or voluntary controls, or liability for emissions would probably be even less successful and efficient. However well intentioned and helpful they may be if they reduce less-expensive-to-control emissions, there is also a danger that they will end up delaying effective action by providing a false hope that they will solve the problem. Radiative forcing remedies are some of the few realistic alternatives available to meet the goals. They could best be carried out on an internationally cooperative basis, but could also be done on a "go-it-alone" basis at the risk of possible international condemnation.

(P2) **The non-temperature-related effects of increasing greenhouse gases in the atmosphere** are both positive and negative. The major positive effects of carbon dioxide (on plant growth) would be lost if atmospheric levels were returned to "normal" levels. The most serious negative problem appears to be ocean acidification, but is not well understood as yet. The principal choices for dealing with this problem appear to be using limestone to neutralize streams of newly generated carbon dioxide in advantageous circumstances, sequestering it, and reducing atmospheric carbon dioxide emissions, in that order of decreasing likely effectiveness and increasing cost.

(P3) It appears likely that the **risks from "tipping points" or abrupt climate changes** would be reduced to the extent that atmospheric GHG levels or global temperatures were reduced. But if, as also appears likely, atmospheric GHG levels are not rapidly reduced to "normal" levels, the radiative forcing remedies could be used to directly control global temperatures and thereby greatly reduce these risks; if imminent dangers should threaten, it appears feasible to use some radiative forcing remedies in a "rapid response" mode to greatly reduce these risks *if advance preparations are in place to do so*.

(P4) **Shorter-term episodes of global cooling from major volcanic eruptions** are a certain and possibly even a catastrophic risk, and can *only* be addressed through radiative forcing approaches among the remedies reviewed in this paper. Advance preparations would again be required.

An effective and efficient solution would seem to be to actively pursue a combination approach involving both engineered climate selection using radiative forcing by means of stratospheric particles optimized for this purpose as well as a new effort to reduce ocean acidification, with immediate priority given to the former in order to solve all the non-ocean acidification problems quickly while the more difficult, much slower, and much more costly effort to reduce ocean acidification is undertaken and carried out. Although significant effort would be required to fine tune the proposals to implement these engineered climate selection approaches, build an international mechanism for making decisions, and to manufacture and launch the needed material/hardware, this approach could be used to rapidly reduce the risks from adverse feedback/tipping point problems from global warming and from global cooling from major volcanic eruptions, and to rapidly stabilize global temperatures at any desired level. This should also allow some time to design and carry out a careful program to reduce ocean acidification, or possibly to decrease the CO_2 levels themselves if this proves to be worthwhile and the best approach. If the latter, this should result in the lowest possible costs of carbon dioxide control by stretching out the period in which they would be made given the sensitivity of the costs of carbon dioxide emissions reductions to the rapidity with which they occur. Substituting lower emission technology will be much cheaper if the goods in which it is embedded need to be replaced anyway because of old age or technological obsolescence.

A useful early task would seem to be a review of how acidification can best be mitigated and how the present international global warming reduction efforts could be modified to make them much more efficient and effective for this new (but possibly closely related) purpose. The net result would be much earlier and more efficient control of three of the more detailed problems and no less progress in controlling ocean acidification than under the Kyoto approach. This would appear to provide a very useful and necessary insurance policy against future major climate problems on Earth.

Thus what have sometimes been viewed as competitive solutions should better be regarded as complimentary solutions of an important set of separable but inter-related environmental problems. Several management approaches other than Kyoto are discussed, but are found to be inferior to it except in the case of an "ideal" replacement for Kyoto and radiative forcing, which could be effectively implemented by one country with sufficient technological talent and resources, but at the cost of possible international condemnation.

The paper also reviews several other management approaches involving voluntary efforts, government-determined de-carbonization to reduce global warming problems including decentralized decision-making and liability-based efforts to decrease GHG levels in the atmosphere, and a new approach involving use of all available technologies. It finds that the voluntary and the currently discussed government-determined de-carbonization possibilities are likely to be less effective and efficient than the Kyoto approach. It does suggest a replacement for Kyoto, however, which would correct a number of the deficiencies of Kyoto.

It appears likely that if the world follows Kyoto or any of the other government-determined de-carbonization approaches considered in this paper, both global temperatures and atmospheric carbon dioxide levels will continue to increase at roughly current rates. At some point in the future this may well become all too evident and engineered climate selection may be reconsidered. It would seem far better, however, not to wait until happens before using engineered climate selection since there would be reduced risks of hitting a tipping point, the possibility of warding off abrupt climate changes, protection from volcanic cooling/winters, and avoidance of various climate-induced unpleasantries in the meantime.

Finally, the paper discusses four of the primary impediments to the use of engineered climate selection approaches. Although these impediments are significant, the paper argues that they are easier to solve than the already evident problems surrounding the Kyoto approach.

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Table 1: Usefulness of Some Climate Change Control Options in Solving Detailed Climate Change Problems

Problems/ Remedies	(P1) Gradual Global Warming	(P2) Ocean Acidification	(P3) Risks from "Tipping Points"	(P4) Risks of Short-term Cooling from Volcanic Eruptions	Proposed Priority
B. Conventional under Kyoto Protocol	Effective if ever achieved, which is very unlikely; high cost; very slow results	Effective if ever achieved; high cost	Vary with temperatures. Useless as a rapid response to imminent threats and to cooling	Useless	3
C. Artificial CO_2 sequestration/ neutralization	Effective but high cost except possibly neutralization in ideal cases	Effective but high cost except some neutralization	Probably useless except for increasing temperatures by releasing concentrated CO_2	Where CO_2 is in concentrated form, it could be released if cooling threatened	2
G. Optimized particles in stratosphere	Effective immediately; lowest cost	No effect	Can be quickly reduced with temperatures and also used for fairly rapid response	Effective as soon as particles are distributed unless there are interactions with volcanic emissions	1
H. Deflector in space	Effective if and when built; probably much higher cost than G	No effect	Can be quickly reduced and also used as an even more rapid response	Effective and more flexible if and when built than G	4

The problem numbers refer to those listed in Section 1.1. The control options are identified by letters corresponding to the row numbers in Table 2 and the remedy letters used in Sections 4 and 5. See Section 5.7 of the text for an explanation of the proposed priorities.
Prepared by Alan Carlin based on Table 2 and text.

Table 2: Evaluation of Some Alternative Approaches for Controlling Global Climate Change

Criteria Remedies	1.Effective Environ. Outcome	2.Dynamic Efficiency	3.Cost effectiveness	3a. Cost of Control[a]	4.Distributional Equity	5.Flexibility	5a. Alter Pace	5b. Global Cooling	5c. Temp. Redistribution	6.Participation & Compliance	7.Other Environmental Risks	8.Additional Considerations
R1/A. No intentional climate change control (business as usual)	Very low—depends on "dumb luck" to muddle through	Base case; not optimal due to high cost of climate change	No costs involved	DNA[b]	Costs of warming may be greatest for those near sea level including low-lying LDCs	Little desired or likely	DNA	DNA	DNA	None needed	None	Included as base case

R2/B. "Conventional" de-carbonization technologies selected by each country under Kyoto Protocol	Low given limited mitigation goals, short-term commitments, long response times, and limited incentives	Strongly negative since lower bound costs are higher than climate change benefits of perhaps $15 per ton (see text)	Low compared to some technological approaches	50-400[ac] Estimated marginal cost to achieve UNFCCC goals as interpreted by EU	Only industrial countries face targets but LDCs help shape rules. LDCs receive some adaptation assistance	Emission ceilings locked in but only for 5 years; climate response very slow	Possible but very difficult	No	No	Incentives very weak; requires massive international cooperation & bureaucratic effort; enforcement unlikely	None known	Protocol already in place calling for reductions by some countries; reductions in oil use decrease national security risks
(R2a) Non-conventional de-carbonization or sequestration												

C. CO_2 artificial sequestration using injection into ocean or underground or neutralization	Medium-high if carried out on massive scale	Strongly negative	Very low	50-150;[d] 60-300[h] for CCS underground; 80-400[h] for ocean injection	Implementation costs borne by initiators; benefits and other possible costs borne by all	Could be halted rapidly, but increase in pace could only be done slowly	Yes	Presumably possible to remove CO_2 if concentrated	No	Int'l cooperation desirable for siting purposes	Probably low risk except for ocean injection, which could contribute to ocean acidification. Potential leakage problems for underground	Some experience with old oil and gas fields; possible NIMBY problems elsewhere
D. Intensive forestry to capture carbon in harvested trees	Low because of uncertainty about rate of accumulation	Likely to be negative but some projects could be positive	Low	10-100[d]	Implementation costs borne by initiators; benefits and other possible costs borne by all	Almost no flexibility because of time required to stop, start, or harvest trees	Only very slowly	Could remove trees and burn them	No	Cooperation and approval of landowners and probably governments required	Low risk; intensive cultivation will impact soils and biodiversity	Political issues: who pays costs; whose land is used?

E. Ocean fertilization with phosphate/ iron	Medium--significant technical uncertainties	Probably somewhat positive	Medium	1-10[d]	Implementation costs borne by initiators; benefits and other possible costs borne by all	Medium to control warming but difficult to reverse once the carbon is on the sea floor	Yes	No	No	Int'l cooperation desirable for siting purposes	Probably high risk: Oxygen depletion resulting in methane release; change in ocean biota	Possible liability and other legal concerns
R3. Engineered climate selection												
F. Sulfur-containing particles added to stratosphere to control global warming	Very high; proven by major volcanic eruptions	Strongly positive; CO_2 increases would also aid agriculture	Very high for cooling purposes	<<1[d]	Probably fairer.[e] Implementation costs borne by initiators; benefits and other possible costs by all	High at least to control warming. Changes depend on residence time in stratosphere	Intensify rapidly; 5 year lag to decrease intensity	Not without changing substance used	Possible but only to cool	Not required once remedy agreed on	High--possible adverse interactions with other stratospheric species; sky whitening	Possible liability if disasters can be shown to result; no ocean acidification mitigation

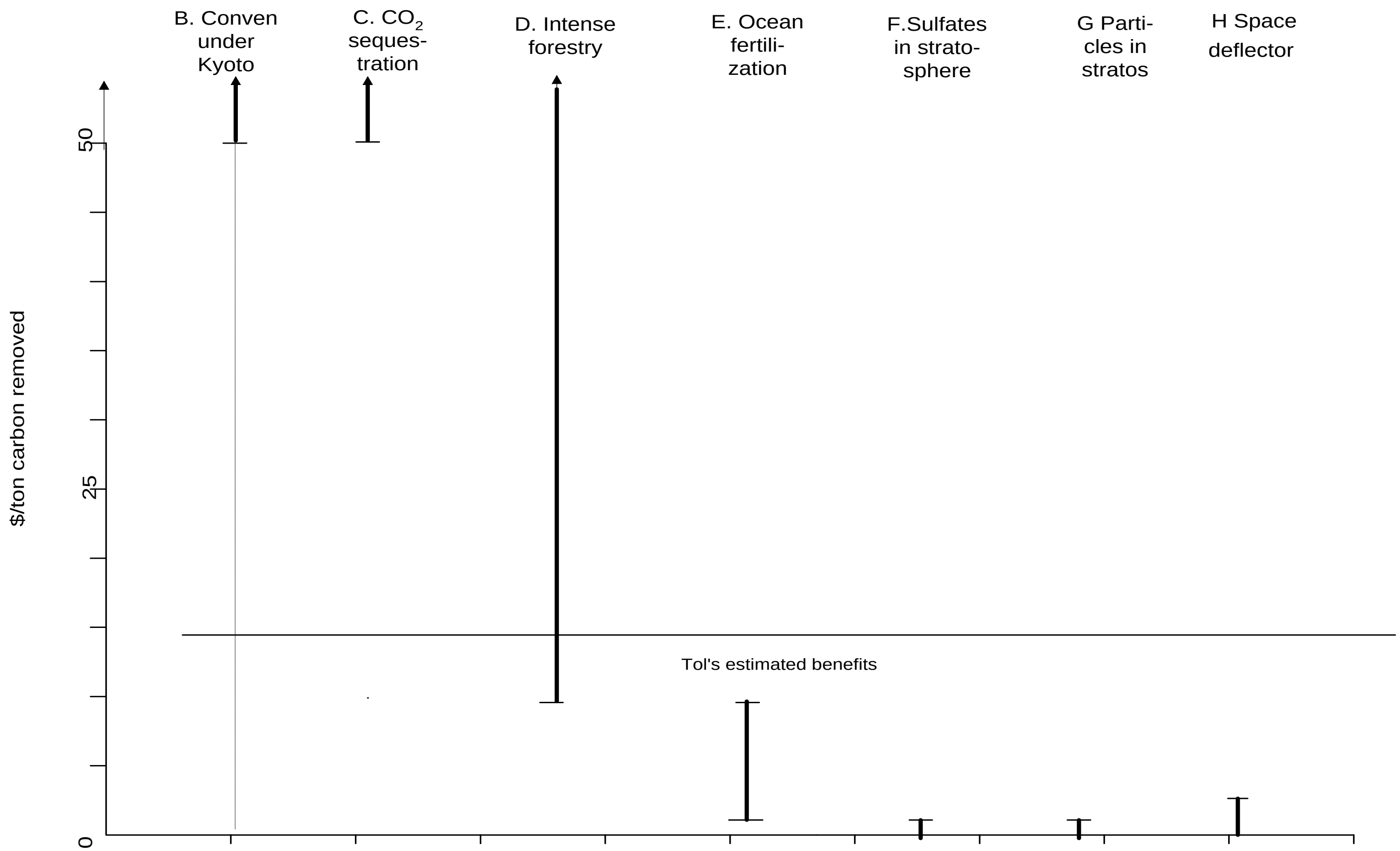
G. Optimized radiative forcing by injecting specialized substances in stratosphere, e.g., see endnote 22	Very high based on (F) but unproven in real world trials with specified particles	Strongly positive for warming. Other benefits, e.g., UV protection, plant growth, offset volcanic eruption	Very high for both heating and cooling	<<1[f], or, at the risk of trying to be too precise, 0.02 to 0.1[g]	Probably fairer;[5] implementation costs borne by initiators; benefits and other possible costs received/ borne by all	High for both warming and cooling. Good chance for controlling abrupt climatic changes, as from volcanic eruption	Intensify rapidly; 5 year lag to decrease intensity	Yes by changing substances used	Possible by varying application by latitude	Not required once remedy agreed on	Probably low risk but needs careful research, particularly on impact on stratospheric chemistry. Ocean acidification not addressed	Could reduce adverse effects of solar radiation on earth. Possible liability problem. No ocean acidification mitigation.
H. Optimized radiative forcing by building flexible deflector in space between Earth and Sun as specified in endnote 23	High but no experience with building and maintaining anything so large so far from Earth	Appears to be high for warming. Other benefits, e.g., UV protection, plant growth, offset volcanic eruption	High for both heating and cooling unless cost is very high	0.2-2[f] (costs much less certain here, and probably underestimated —see text)	Probably fairer;[e] implementation costs borne by initiators; benefits and other possible costs received/ borne by all	Extremely high for both warming and cooling. Best chance for controlling abrupt climatic changes as from volcanic eruption	Intensify almost immediately by adjusting deflector	Yes by changing deflector placement	Not clear from available info; research required	Not required once remedy agreed on	Probably even lower risk than G but still needs careful research; quickly reversible if unforeseen problems. Ocean acidification not addressed.	Possible liability problem; no ocean acidification mitigation.

Prepared by Alan Carlin based on alternatives analyzed by Lasky, 2003 (remedy B), Keith 2000 (remedies C, D, E, and F), IPCC 2005 (E), NAS 1992 (F), Keith 2001 (G and H), Michaelson 1998 (columns 1, 4, & 6), and Teller et al. 1997, 1999, and 2002, and Wood's presentation in Tyndall 2004 (F, G, and H).

Footnotes for Table 2:

[a] Marginal cost in US dollars per ton carbon of CO_2 emissions (or equivalent) mitigated for row B only. Other costs in this column represent the range of estimated costs for categories of technology. There will be some cases where the costs of row B remedies are a lot less than the marginal cost.
[b] Does not apply; since none are mitigated, there is no cost of mitigation.
[c] Lasky (2003); see text for further discussion.
[d] Keith (2000).
[e] Michaelson (1998)
[f] Keith (2001).
[g] This range of estimates assumes an estimated cost of $0.2-1.0 billion per year (from Wood, 2005) and an assumed offset of approximately 10 gigatons of carbon per year. Ten gigatons is representative of the carbon emission reduction needed to achieve a 450 ppmv CO_2 level in the atmosphere compared to projected IS92a emissions in 2060.
[h] IPCC (2005); based on Table SPM.5 with dollar values for capture from new large scale power plants with dollars per ton CO_2 converted to dollars per ton carbon.

Figure 1: Costs and Benefits of Carbon Removal



Prepared by Alan Carlin based on Table 2 for costs and Tol (2003) for benefits. Marginal cost in US dollars per ton carbon of CO_2 emissions (or equivalent) mitigated for column B only. Other costs represent the range of estimated costs for categories of technology. There will be some cases where the costs of row B remedies are less than the marginal cost and even less than benefits.

Endnotes for Main Text

[1] William J. Broad, "How to Cool a Planet (Maybe)," *New York Times*, June 27, 2006; also Crutzen (2006).

[2] See Breiterman for a recent survey of this literature. A very recent study suggests that there is a correlation between solar sunspot activity and global temperatures prior to 1970, and that the sun may be going into a quiescent period in which global temperatures could fall by 0.2oC. See Stuart Clark, "Global Warming: Will the Sun Come to Our Rescue?" *New Scientist.com*, September 16, 2006. Available at http://www.newscientist.com/article.ns?id=mg19125691.100&print=true

[3] "Eight Glacial Cycles from an Antarctic Ice Core," *Nature*, Volume 429, June 10, 2004, pp. 623-8.

[4] "Climate Warning as Siberia Melts," *New Scientist*, August 11, 2005, p. 12; Stafford (2006), Walter et al (2006).

[5] "Ice Sheet Instability," *Science*, Vol. 311, March 24, 2006, pp.1698-1701.

[6] Walker, Gabrielle, 2006, "The Tipping Point of the Iceberg," *Nature*, Vol. 441, No. 15, June.

[7] Tim Stephens, "New Findings Show a Slow Recovery from Extreme Global Warming Episode 55 Million Years Ago," *UC Santa Cruz Currents Online*, Vol. 9, No. 41, June 13, 2005; available at http://currents.ucsc.edu/04-05/06-13/ocean.asp

[8] "Confronting the Bogeyman of the Climate System," *Science*, Vol. 301, October 31, 2005, pp. 432-3.

[9] Defined as one that has a Volcanic Explosivity Index (VEI) of 8.

[10] H.R. 5642 (introduced in June 20, 2006) and S. 3698 (introduced July 20, 2006).

[11] BBC News, "Europe 'Behind on Kyoto Pledges,'" http://news.bbc.co.uk/2/hi/uk_news/politics/4561576.stm, December 26, 2005.

[12] *Ibid.*

[13] Norm Dixon, "Global Warming: Can Kyoto Really Help?" *Baltimore Chronicle and Sentinel*, February 18, 2005.

[14] Figure 6, available at http://www.eia.doe.gov/oiaf/ieo/highlights.html

[15] Sources for "Extra Annual Emissions of CO2" figure: UDI-Platt's, U.S. Energy Information Administration, and industry estimates; prepared by Scott Wallace, Staff Member, *Christian Science Monitor*, December 23, 2004.

[16] The International Energy Agency's World Energy Outlook (WEO) Reference Scenario projects that, based on policies in place, by 2030 CO2 emissions will have increased by 63 percent from today's levels, which is almost 90 percent higher than 1990 levels. Even in the WEO 2004's World Alternative Policy Scenario—which analyzes the impact of additional mitigation policies up to 2030—global CO2 emissions would increase 40 percent on today's level, putting them 62 percent higher than in 1990. See http://www.iea.org/textbase/npsum/ccsSUM.pdf

[17] Report on a presentation by Malte Meinshausen at a climate conference in Exeter, England, as reported in the *New Scientist*, February 3, 2005, http://www.newscientist.com/channel/earth/climate-change/dn6964

[18] One of the most prominent "prescriptions" (Pacala and Socolow, 2004) as to how emissions can be drastically cut includes an example of (2) since it proposes that annual average miles driven per vehicle be reduced from 10,000 miles to 5,000 miles based on "urban design, mass transit, and telecommuting." To the extent that this is done through coercion rather than voluntary change (almost certain given people's widely observed reluctance to give up using their cars), this would be an example of (2). An even more drastic proposal for actual individual emission rationing is reported under consideration in Great Britain. See David Adam, "Swipe-card plan to ration consumers' carbon use," *Guardian Unlimited*, July 19, 2006, http://www.guardian.co.uk/climatechange/story/0,,1823853,00.html

[19] Andrew C. Revkin, "Yelling 'Fire' on a Hot Planet," *New York Times*, April 23, 2006.

[20] See Section 5.1 for a discussion of the economic costs. Some of the proponents of the Kyoto Protocol approach have recently made (Edenhofer et al, eds., 2006) quite sophisticated arguments concerning the effects of endogenous technical change on the costs of control, which they believe will bring down the cost of meeting the UNFCCC goal considerably. Although there would undoubtedly be endogenous technical change under their scenarios, these arguments are questionable on a number of grounds. They assume that much of the relevant technical change will result from "learning by doing" rather than from unrelated developments in other sectors. Experience with the development of motor vehicle hybrids, however, which depend on sophisticated computer technology, among other developments, make such assumptions dubious. They also appear to assume that increased R&D on emissions reduction technology will not have serious adverse effects on other sectors from which scarce R&D resources would be diverted since these costs appear not to have been factored in.

[21] For the most recent, see Wood's presentation in Tyndall (2004):
More specifically, for global warming prevention:

* Controlled scattering of incoming sunlight back into space, by sub-microscopic *minimum-feature-size…*
– Dielectrics – e.g., 100±20 nm spherules: σ~V2 << λ6
– Metals – e.g., "optical chaff;"super-P metal balloon-ettes
– Resonant scatterers – e.g., coated dye molecular clusters; fluorescence options: strato-heating; brighter photosynthetic bands
* 'Engineered scatterers' put into the stratosphere.
For global cooling prevention:
* "Long wave infrared chaff": 10 µm mesh Al screen & 0.1 µm 'ribs'
* Semiconductor (e.g., Si)-walled super-P balloon-ettes--pass optical insolation; reflect Earth-sourced long wave infrared.

22 Technically, the deflector would be ideally placed at the L-1 Lagrange point between the Earth and the Sun and could be moved as needed from slightly off (to prevent ice ages) to directly on (to prevent global warming) the Earth-Sun line. The L-1 (Lagrange 1) point is a point in space on a direct line between the Earth and the sun, 1.5 million kilometres away. At that point, the gravity of the Earth is balanced with that of the Sun in such a way that anything placed there will, if gently nudged back into place every 25 days or so, orbit the Sun once every year. This means that it will remain directly between Earth and Sun with almost no fuel expenditure. Currently there is a solar observatory satellite called SOHO there. The more technical specifications of this option as proposed by Wood in Tyndall (2004) are:
• Total mass of 3,000 tons emplaced over 100 yrs.
– 1 Shuttle-launch per year of construction mass
– Area of 10^4km^2
• 'Raw' –cf. 10 MT previous design; ~0.01 MT 'dressed'
• ~30 µm-pitch (e.g., Al) metal screen –with ~25 nm 'ribs.'

23 See Allenby (2003) for an expression of this. One example is to be found in the 2001 IPCC report, which has a very brief and general discussion of geoengineering approaches. It states that "although there may be possibilities" for it, "human understanding of the system is still rudimentary. The prospects of unanticipated consequences are large, and it may not even be possible to engineer the regional distribution of temperature, precipitation, etc. Geo-engineering raises scientific and technical questions as well as many ethical, legal, and equity issues. And yet, some basic inquiry does seem appropriate."

24 Based on the chart on page 81.

25 Although a dotted vertical line has been added to remedy B in Figure 1 to show the full range of costs.

26 See also Casper Henderson, "Paradise Lost," *New Scientist*, Vol. 191, No. 2563, August 5, 2006, pp. 28-33, for a recent summary of the effects of acidification on the oceans.

27 Based on an Email to the author from Lowell Wood of Stanford University and Lawrence Livermore National Laboratory. See also Schneider (2001) for similar views.

28 Anne McIlroy, "Going to Extremes to Fight Global Warming," *Toronto Globe and Mail,* June 3, 2006; available at http://www.workopolis.com/servlet/Content/fasttrack/20060603/WARMING03?section=Science

29 Ruddiman (2005a) has a description of what the world might look like under these circumstances.

30 Nick Bunkley, "California Sues 6 Automakers over Global Warming," *New York Times*, September 21, 2006, p. C2.

31 One recent suggestion along these lines has been made by Jagdish Bhagwati, "A Global Warming Fund Could Succeed Where Kyoto Failed," *Financial Times*, August 16, 2006. Available at http://www.ft.com/cms/s/7849f5b2-2cc3-11db-9845-0000779e2340.html/

32 A related "Brazilian" proposal was actually considered in the negotiations leading to the Kyoto Protocol and has received some attention since. For a discussion see Chapter 7 of Baumert, 2002.

33 Henry Fountain, "Climate Change: The View from the Patio," *New York Times*, June 4, 2006.

34 For a much more comprehensive discussion of first three of these and other likely objections, see Michaelson (1998).