Selected Bibliography

Abraham, E.R., C.S. Law, P.W. Boyd, S.J. Lavender, M.T. Maldonado, and A.R. Bowie (2000). "Importance of Stirring in the Development of an Iron-Fertilized Phytoplankton Bloom." *Nature*, 407: 727-730.

Investigates the development of phytoplankton blooms initiated by oceanic iron fertilization in the Southern Ocean. Argues that significant blooms were produced through a process of stirring, growth, and diffusion, and derives an estimate of the optimal stirring rate. Cautions that stirring in oceans is likely to have varying results.

Allenby B. (2000). "Earth Systems Engineering and Management." *IEEE Technology & Society Magazine*: 19: 10-24.

Provides analysis as to the means through which human activities and technologies have interacted with natural systems, and how such activities and technologies are related to efforts and plans to intentionally engineer the climate system. Describes the complex conceptual challenges that must be met before geoengineering strategies can be successfully implemented.

Angel, R. (2006). "Feasibility of Cooling the Earth with a Cloud of Small Spacecraft near the Inner Lagrange Point (L1)." *Proceedings of the National Academy of Sciences*, 103: 17184-17189.

Evaluates the effects and feasibility of a space sunshade used to block 1.8% of solar flux to alleviate increasing temperatures, and presents three possible implementation strategies. Concludes that such methods could be developed within 25 years at a cost of less than 0.5% of world GDP over that time.

Badescu, V., R.B. Cathcart, and R. Schuiling (eds), (2006). Macro-Engineering: A Challenge for the Future. Water Science and Technology Library, Vol. 54. Dordrecht: Springer.

Examines a variety of large-scale engineering projects which involve significant modification of natural systems and analyzes their global and regional ecological impacts. Contains materials pertaining to geoengineering projects based on alleviating the problems associated with climate change.

Bala, G., P.B. Duffy, and K.E. Taylor (2008). "Impact of Geoengineering Schemes on the Global Hydrological Cycle." *Proceedings of the National Academy of Sciences*, 105: 7664-7669.

Addresses the impact of geoengineering strategies on the global hydrological cycle. Concludes that the hydrological cycle is more sensitive to temperature adjustment by changes in solar radiation than by changes in greenhouse gas concentrations, implying that solar radiation management strategies could offset temperature changes or hydrological changes from greenhouse warming, but could not offset both *simultaneously.*

Bala, G., K. Caldeira, and P.B. Duffy (2003). "Geoengineering Earth's Radiation Balance to Mitigate Climate Change from a Quadrupling of CO_2." *Global and Planetary Change*, 37: 157-168.

Examines the effects of solar radiation management strategies meant to offset the temperature changes expected from a quadrupling of atmospheric carbon dioxide concentrations. Concludes that residual climate changes in such a geoengineering scenario are much smaller than the changes in a scenario with no geoengineering, although caution should be taken before extrapolating these results into plans for implementation.

Bala, G., S. Thompson, P.B. Duffy, K. Caldeira, and C. Delire (2002). "Impact of Geoengineering Schemes on the Terrestrial Biosphere." *Geophysical Research Letters*, 29: 2061.

Analyzes the impact of solar radiation management on the terrestrial biosphere using a coupled atmosphere-terrestrial biosphere model. Concludes that climate stabilization via solar radiation management would limit changes in vegetation distribution induced by climate change and could lead to higher net primary productivity, although there are still concerns associated with the implementation of this strategy.

Bala, G. and K. Caldeira (2000). "Geoengineering Earth's Radiation Balance to Mitigate CO_2-Induced Climate Change." *Geophysical Research Letters*, 27: 2141-2144.

Examines the extent to which solar radiation management strategies can effectively mitigate regional and seasonal climate change. Results derived from a NCAR CCM3 atmospheric general circulation model show that the injection of aerosol particles into the stratosphere could diminish regional and seasonal climate change, although some environmental risks remain.

Barrett, S. (2009). "Geoengineering's Role in Climate Change Policy." AEI Geoengineering Project.

Discusses questions of governance surrounding a potential geoengineering regime. Analyzes geoengineering's place in a climate policy risk portfolio, as well as geopolitical issues such as winners and losers under various geoengineering regimes and the possibility of unilateral geoengineering. Advocates for rules governing geoengineering, including research and development, to be incorporated within and under the U.N. Framework Convention on Climate Change.

Barrett, S. (2008). "The Incredible Economics of Geoengineering." *Environment and Resource Economics*, 39: 45-54.

Develops analysis of the incentives for nations to implement geoengineering strategies *and finds the incentives to pursue such strategies to be far stronger than incentives to mitigate greenhouse gas emissions. Concludes that future application of geoengineering appears "more likely than not", and argues that a new governance arrangement is necessary to ensure efficiency and risk reduction.*

Barrett, S. (2008). "Rethinking Global Climate Change Governance." *Economics*, Discussion Paper 2008-31.

Identifies recent failures to adopt effective global climate change policy as a result of an inability to enforce targets and timetables. Analyzes the effects of potential trade restrictions as a means of enforcing climate policy, and eventually proposes R&D-based approaches that address different gases and sectors using different instruments. Notes the advantages and drawbacks of geoengineering proposals in the scope of long-term climate policy.

Barrett, S. (2007). Why Cooperate? The Incentive to Supply Global Public Goods. New York: Oxford University Press.

Describes the need for a global solution to the problems associated with climate change in terms of the provision of public goods. Argues that international cooperation, institutional design, and proper incentives can create a scenario in which nations find it advantageous to cooperate and supply this global public good.

Bengtsson, L. (2006). "Geo-Engineering to Confine Climate Change: Is it at all Feasible?" *Climatic Change*, 77: 229-234.

Provides an overview of the major concerns regarding the feasibility of geoengineering strategies. Foremost among these are the lack of accuracy in climate prediction, differences in timescales between the effects of greenhouse gases and the effects of aerosols, and environmental problems other than warming attributed to increasing carbon dioxide concentrations.

Bickel, J.E. (2010). "The Climate Engineering Option: Economics and Policy Implications." AEI Geoengineering Project.

Analyzes the potential value of solar radiation management strategies. Finds that SRM has potential benefits in the tens of trillions of dollars, and may be a relatively cheap option for dealing with climate tipping points. Also cautions that relying on SRM only once a tipping point is imminent is risky, and observes that the magnitude of SRM needed over the next century via geoengineering is less than that of inadvertent anthropogenic emissions. Concludes that greater resources should be devoted to an SRM research agenda.

Bickel, J.E. and L. Lane (2009). "An Analysis of Climate Engineering as a Response to Climate Change. Copenhagen Consensus Center, Copenhagen Consensus on Climate.

Offers a preliminary and exploratory assessment of the potential costs and benefits of solar radiation management and air capture. Suggests that SRM offers larger net benefits than AC. Direct benefit-cost ratios of stratospheric aerosol injections and cloud albedo enhancement are estimated to be 25 to 1 and 5000 to 1, respectively. Advocates for a research program intended to address the uncertainties regarding the science and engineering of SRM options. The potential importance of transaction costs and "political market failures" is also stressed.

Bishop, J.K.B., T.J. Wood, R.E. Davis, and J.T. Sherman (2004). "Robotic Observations of Enhanced Carbon Biomass and Export at 55°S During SOFeX." *Science*, 304: 417-420.

Presents data on the effects of sea-surface iron fertilization in the Southern Ocean obtained via autonomous floats profiling in high-nitrate, low-silicate waters. The observed biomass buildup and export were significantly higher than expected for iron-amended, low-silicate waters.

Blackstock, J.J., D.S. Battisti, K. Caldeira, D.M. Eardley, J.I. Katz, D.W. Keith, A.A.N. Patrinos, D.P. Schrag, R.H. Socolow, and S.E. Koonin (2009). "Climate Engineering Responses to Climate Emergencies." Novim.

Presents a decade-long research agenda focused on stratospheric aerosol injections. Develops conceptual frameworks and methods for assessing alternative means of reducing solar radiation, as well. Divides the aerosol-based research agenda into three phases: 1) Non-invasive laboratory and computational research; 2) Field experiments; and 3) Monitored deployment.

Bodansky, D. (1996). "May We Engineer the Climate?" *Climatic Change*, 33: 309-321.

Examines the legal implications of geoengineering proposals, as well as the international political ramifications of implementing such proposals. Suggests that an international decision-making mechanism would be difficult to create, and fear of risky consequences may lead the international community to prohibit all forms of geoengineering.

Bower, K., T. Choularton, J. Latham, J. Sahraei, and S. Salter (2006). "Computational Assessment of a Proposed Technique for Global Warming Mitigation via Albedo-Enhancement of Marine Stratocumulus Clouds." *Atmospheric Research*, 82: 328-336.

Uses a marine stratocumulus cloud model to examine the sensitivity of Latham's albedo-enhancement proposal to cloud and environmental aerosol characteristics, as well as seawater aerosol characteristics. Conclusions provide support for the physical viability Latham's mitigation proposal.

Boyd, P.W. (2004). "Ironing Out Algal Issues in the Southern Ocean." *Science*, 304: 396-397.

Comments on papers by Coale et al., Bishop et al., and Buesseler et al. that report results from large-scale experiments in which ocean waters were enriched with iron. Analyzes *results in an effort to test the hypothesis that enhanced iron supply leads to enhanced export of particulate organic carbon.*

Boyd, P.W., et al. (2000). "A Mesoscale Phytoplankton Bloom in the Polar Southern Ocean Stimulated by Iron Fertilization." *Nature*, 407: 695-702.

Reports the findings of a mesoscale iron fertilization experiment in the polar Southern Ocean. Results show a large drawdown of carbon dioxide and macronutrients, though no increase in the downward export of biogenic carbon. Concludes that iron supply controls phytoplankton growth and composition, but the fate of algal carbon remains largely unknown.

Brewer, P.G. (2007). "Evaluating a Technological Fix for Climate." *Proceedings of the National Academy of Sciences*, 104: 9915-9916.

Describes the development of geoengineering strategies and their progression into more mainstream dialogues. Identifies the dangers associated with solar radiation management, and concludes that the unknown consequences and the unanswered questions of these strategies are too severe to allow for implementation.

Buesseler, K.O., J.E. Andrews, S.M. Pike, M.A. Charette (2004). "The Effects of Iron Fertilization on Carbon Sequestration in the Southern Ocean." *Science*, 304: 414-417.

Examines the impact of changes to sea-surface iron input on the flux of carbon to the deep ocean. Results from experiments in the Southern Ocean indicate that the flux of carbon is generally similar in magnitude to that of natural oceanic blooms, and thus small relative to global carbon budgets.

Buesseler, K.O. and P.W. Boyd (2003). "Will Ocean Fertilization Work?" *Science*, 300: 67-68.

Analyzes results from iron fertilization experiments undertaken in the Southern Ocean. Concludes that sequestration of 30% of the annual anthropogenic carbon dioxide release could only be offset by fertilization of a region more than a magnitude of order larger than the entire area of the Southern Ocean, which makes oceanic iron fertilization a very unattractive option unless technological developments occur.

Caldeira, K. and L. Wood (2008). "Global and Arctic Climate Engineering: Numerical Model Studies." *Philosophical Transaction of the Royal Society A*, 366: 4039-4056.

Performs numerical simulations of the atmosphere, sea ice, and upper ocean to examine possible effects of decreasing solar radiation. Concludes that geoengineering strategies can make a high-CO_2 *climate more similar to a low-*CO_2 *climate in respect to temperature and water than can business-as-usual plans that do not incorporate geoengineering. Finds that latitude plays little role in the overall effects of geoengineering strategies across different regions.*

Carlin, A. (2008). “Why a Different Approach is Required if Global Climate Change is to be Controlled Efficiently or Even at All.” *Environmental Law and Policy Review*, 32: 685-757.

Asserts that strategies for alleviating the problems associated with climate change which focus solely on the reduction of greenhouse gas emissions are ineffective and dangerous. Outlines the advantageous qualities of strategies which focus on solar radiation management, and advocates greater attention be given to such strategies.

Carlin, A. (2007). “Global Climate Change Control: Is There a Better Strategy than Reducing Greenhouse Gas Emissions?” *University of Pennsylvania Law Review*, 155: 1401-1497.

Identifies four major global climate change problems and assesses the ability of various emission reduction strategies and geoengineering strategies to effectively alleviate these problems. Concludes that stratospheric aerosol injection is both the most effective and the most efficient solution to these problems.

Carlin, A. (2007). “Implementation and Utilization of Geoengineering for Global Climate Change Control.” *Sustainable Development Law and Policy*, 7: 56-58.

Describes options available for further research, and ultimately implementation, of geoengineering strategies. Concludes that the greatest potential benefits come from widespread recognition of the legitimacy of such implementation, which can best be attained through multilateral cooperation. Given this, international organizations are best equipped to govern research, testing, and implementation.

Carlin, A. (2007). “Risky Gamble.” *The Environmental Forum*, 24: 42-47

Discusses the shortcomings of climate policy focused entirely upon emissions reductions, including high costs, inflexible terms, and political realities. Advocates for further consideration of solar radiation management as a first step towards solving the problems associated with increased temperatures.

Chandler, David L. (2007). “A Sunshade for the Planet.” *New Scientist*, 2613: 42-45.

Catalogues the major geoengineering strategies and describes the risk associated with any dependency on geoengineering that could develop. Advocates for increased research in geoengineering due to potential damages that could be caused by emissions to date.

Cicerone, R.J. (2006). “Geoengineering: Encouraging Research and Overseeing Implementation.” *Climatic Change*, 77: 221-226.

Describes the fairly widespread opposition to arguments for increased research on geoengineering strategies, and addresses the flaws in much of this opposition. Advocates further geoengineering research, which would be undertaken separately from implementation of geoengineering strategies, and proposes a framework for future efforts *that would incorporate both supporting and opposing viewpoints.*

Cicerone, R.J., S. Elliott, and R.P. Turco (1992). "Global Environmental Engineering." *Nature*, 356: 472.

Argues for more serious consideration and research to be devoted to geoengineering strategies to mitigate the depletion of global ozone.

Coale, K.H., et al. (2004). "Southern Ocean Iron Enrichment Experiment: Carbon Cycling in High- and Low-Si Waters." *Science*, 304: 408-414.

Investigates the potentially differential effects of oceanic iron enrichment in regions with high and low concentrations of silicic acid. Analyzes results from experiments undertaken in the Southern Ocean in terms of control of carbon uptake and regulation of atmospheric partial pressure of carbon dioxide.

Cooper, D.J., A.J. Watson, and P.D. Nightingale (1996). "Large Decrease in Ocean Surface CO_2 Fugacity in Response to In-Situ Iron Fertilization." *Nature*, 383: 511-513.

Presents the findings of an in-situ iron fertilization experiment in which the relationship between levels of dissolved iron and surface-water carbon dioxide fugacity was examined. Concludes that iron supply can strongly modulate the local short-run source of carbon dioxide to the atmosphere, but has little long-run influence on atmospheric carbon dioxide partial pressure.

Crutzen, P.J. (2006). "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" *Climatic Change*, 77: 211-219.

Provides an argument for renewed research devoted to geoengineering in response to the relative failures of mitigation efforts. Examines the effects of aerosol particles on ozone depletion via analysis of the Mount Pinatubo eruption, and concludes that such depletion may be insignificant in magnitude given proper deployment methods.

Crutzen, P.J. and V. Ramanathan (eds), (1997). Clouds, Chemistry and Climate. NATO ASI Series/Global Environmental Change. Berlin: Springer-Verlag.

Provides an overview of recent developments and emerging technology in the study of clouds and atmospheric chemistry. Contains material on sulfate aerosol scattering and cloud albedo modification.

Dickinson, R.E. (1996). "Climate Engineering: A Review of Aerosol Approaches to Changing the Global Energy Balance." *Climatic Change*, 33: 279-290.

Assesses geoengineering proposals to inject aerosols in the troposphere to seed clouds and in the stratosphere to directly scatter solar radiation. Concludes that at least ten times the amount of aerosol particles would be needed in the troposphere as would be *needed in the stratosphere to achieve similar results.*

Early, J.T. (1989). "Space-Based Solar Shield to Offset Greenhouse Effect." *Journal of the British Interplanetary Society*, 42: 567-569.

Proposes the construction of a solar shield constructed from lunar materials for the purpose of offsetting the temperature increases associated with rising greenhouse gas concentrations. Gives consideration to the photon thrust of the shield, shield size, effective blockage, and possibilities for shield design.

Falkowski, P.G. (2002). "The Ocean's Invisible Forest." *Scientific American*, 287: 38-45.

Describes the importance of phytoplankton in regard to natural systems, and particularly in the context of carbon capture. Uses data obtained from satellite observations and oceanographic research projects to analyze the sensitivity of phytoplankton to changes in global temperatures, ocean circulation, and nutrient availability, and relates these findings to the potential for atmospheric carbon dioxide drawdown.

Flannery, B.P., H. Kheshgi, G. Marland, and M.C. MacCracken (1997). "Chapter 8: Geoengineering Climate" in Engineering Response to Global Climate Change: Planning a Research and Development Agenda, R.G. Watts (ed). Boca Raton: CRC Press.

Describes various prominent geoengineering proposals, and advocates for increased research to be devoted to these proposals. Further advocates for research designed to increase confidence in climate modeling results, so as to better understand the implications and consequences of geoengineering.

Fleming, J.R. (2007). "The Climate Engineers." *The Wilson Quarterly*, 31: 46-60.

Presents historical allusions to climate engineering and weather modification in juxtaposition with modern geoengineering debate. Cautions against the underestimation of the inherent uncertainties of geoengineering strategies, especially given the somewhat unflattering history of such plans.

Fleming, J.R. (2006). "The Pathological History of Weather and Climate Modification: Three Cycles of Promise and Hype." *Historical Studies in the Physical and Biological Sciences*, 37: 3-25.

Examines the historical patterns of ideas, plans, and attempts to modify the climate through technological innovation. Emphasizes the failures of historical attempts to do so, and uses these examples as warnings to be heeded by those in the current policy debate.

Gao, Y., S.M. Fan, and J. Sarmiento (2003). "Aeolian Iron Input to the Ocean through Precipitation Scavenging: A Modeling Perspective and its Implication for Natural Iron Fertilization in the Ocean." *Journal of Geophysical Research*, 108(D7): 4221.

Uses an atmospheric general circulation model to simulate Aeolian dust transport and removal to determine the effects of this natural iron fertilization of oceans. Concludes that annual input of dissolved iron by precipitation is equal to approximately 4-30% of total Aeolian iron fluxes.

Gnanadesikan, A., J. Sarmiento, and R. Slater (2003). "Effects of Patchy Ocean Fertilization on Atmospheric Carbon Dioxide and Biological Production." *Global Biogeochemical Cycles*, 17: 1050.

Examines the effects of iron fertilization in small oceanic regions for limited time periods, using an ocean general circulation model. Finds reduction of atmospheric carbon dioxide between 2% and 44%, depending upon the recovery time of surface nutrient and carbon fields after fertilization. Expresses concern over the possibility that iron-induced carbon dioxide drawdown may lead to a severe, long-term decline in similar biological productivity.

Hamwey, R.M. (2007). "Active Amplification of the Terrestrial Albedo to Mitigate Climate Change: An Exploratory Study." *Mitigation and Adaptation Strategies for Global Change*, 12: 419-439.

Analyzes the effectiveness of geoengineering through albedo amplification, using a static, two-dimensional radiative transfer model. Concludes that albedo amplification can offset the global annual average level of radiative forcing caused by anthropogenic greenhouse gases by as much as 30%, which could provide an additional 25 years to develop low-emission energy conversion technologies.

Hoffert, M., et al. (2002). "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet." *Science*, 298: 981-987.

Identifies and examines a range of options for producing emission-free power in the long-term. Argues that energy technology innovations are necessary for stabilizing the fossil fuel greenhouse, and therefore advocates further geoengineering research so as to provide an insurance policy should other methods prove ineffective.

Hoffman, R.N. (2002). "Controlling the Global Weather." *Bulletin of the American Meteorological Society*: 83: 241-248.

Posits that the ability to control weather patterns is within the reach of mankind, and outlines general steps that must be taken to develop this ability. Included in these steps are technological advances in the gathering of weather data and the creation of machinery that could become part of a "Global Weather Control System".

Iklé, F. and L. Wood (2008). "Climatic Engineering." *National Interest*, 93: 18-24.

Describes the severity of the climate change issue by outlining the relative failures of *emissions reduction targets and international agreements. Explains the potential role of geoengineering in alleviating, but not fully correcting, some of these failures, and advocates for further geoengineering research to be undertaken.*

Jamieson, D. (1996). "Ethics and Intentional Climate Change." *Climatic Change*, 33: 323-336.

Identifies a number of ethical concerns regarding climate change policy, and proposes a set of conditions that must be satisfied for a global project addressing climate change to be morally acceptable. Concludes that these conditions have not currently been met, but geoengineering research should continue as long as certain conditions continue to be met.

Joos, F., J.L. Sarmiento, and U. Siegenthaler (1991). "Estimates of the Effect of Southern Ocean Iron Fertilization on Atmospheric CO_2 Concentrations." *Nature*, 349: 772-775.

Presents estimates as to the maximum possible effect of iron fertilization on atmospheric carbon dioxide concentrations above the Southern Ocean. Finds large uptake of carbon dioxide given a century of iron fertilization, but concludes that such results are unlikely to be achieved in practice due to other constraints. Also notes uncertainty regarding the effect of iron fertilization on oceanic ecology.

Keith, D.W. (2009). "Engineering the Planet" in Climate Change Science and Policy, S.H. Schneider, A. Rosencranz, M.D. Mastrandrea, and K. Kuntz-Duriseti (eds). Washington, DC: Island Press.

Describes geoengineering proposals that have been set forth, and speculates as to the ethical repercussions of their implementation. Concludes that humans will likely gain the ability to control the climate in the relatively near future, and therefore will engage in debate regarding its use. Cautions that humans should learn to minimize the side effects of their intentional interference with the climate before attempting to geoengineer it on a large scale.

Keith, D.W. (2001). "Geoengineering." *Nature*, 409: 420.

Provides an overview of the conceptualization behind various geoengineering strategies, as well as assessments of the current status of each strategy.

Keith, D.W. (2000). "Geoengineering the Climate: History and Prospect." *Annual Review of Energy and Environment*, 25: 245-284.

Outlines a range of geoengineering proposals and research, including historical background on the development of various geoengineering strategies and the potential effects of policies that would implement such strategies.

Keith, D.W. and H. Dowlatabadi (1992). "A Serious Look at Geoengineering." *Eos, Transactions, American Geophysical Union*, 73: 289-293.

Provides estimates and observations on the costs, consequences, feasibility, and equity implications of various geoengineering proposals. Advocates for a more systematic research agenda with particular focus on geoengineering strategies that are low in cost and risk.

Kheshgi, H. (1995). “Sequestering Atmospheric Carbon Dioxide by Increasing Ocean Alkalinity.” *Energy*, 20: 915-922.

Describes the process by which ocean alkalinity could be increased, thereby allowing for greater oceanic carbon dioxide absorption. Analyzes the feasibility of such an approach, particularly with regard to the use of naturally occurring substances such as soda ash and limestone, as well as the limits to its potential success.

Kiehl, J.T. (2006). “Geoengineering Climate Change: Treating the Symptom over the Cause?” *Climatic Change*, 77: 227-228.

Provides a description of the scientific and ethical dilemmas that have been inherent to debate over geoengineering proposals. Argues that further modeling studies be carried out to increase knowledge of the benefits, and the risks, of geoengineering strategies. Specifically addresses the concern that all models have their limitations, which therefore constitutes an important constraint on the enactment of such strategies.

Kitzinger, U. and Frankel, E.G. (eds), (1998). Macro-Engineering and the Earth: World Projects for the Year 2000 and Beyond. Chichester: Horwood Publishing Ltd.

Includes selections identifying large-scale climate change problems, and develops some geoengineering strategies for addressing these problems.

Kravitz, B., A. Robock, L. Oman, G.L. Stenchikov, and A.B. Marquardt (2009). “Sulfuric Acid Deposition from Stratospheric Geoengineering with Sulfate Aerosols.” *Journal of Geophysical Research*, 114: D14109.

Uses a general circulation model to simulate stratospheric injections of sulfur dioxide and evaluate the deposition of sulfate that follows. Assuming tropical or Arctic SO_2 *injections, the primary additional surface deposition occurs in midlatitude bands. Concludes that the estimated surface deposition is not great enough to negatively affect most terrestrial ecosystems.*

Lackner, K.S. (2003). “A Guide to CO_2 Sequestration.” *Science*, 300: 1677-1678.

Discusses the advantages and disadvantages of a variety of carbon sequestration techniques. Concludes that sequestration should be undertaken through underground injection and neutralization rather than through environmentally active carbon pools such as oceans, and that in the short and medium term, sequestration is likely cheaper than a complete transition to nuclear, wind, or solar energy.

Lackner K.S., H.J. Ziock, and P. Grimes (1999). "Carbon Dioxide Extraction from Air: Is it an Option?" Proceedings of the 24th International Conference on Coal Utilization & Fuel Systems: 885–896.

Identifies the benefits associated with a system of carbon sequestration focused on extracting carbon dioxide from the atmosphere rather than at the source level. Concludes that the major costs associated with carbon sequestration are in sorbent recovery, not in the capture process.

Lampitt, R.S., et al. (2008). "Ocean Fertilization: A Potential Means of Geoengineering?" *Philosophical Transactions of the Royal Society A*, 366: 3919-3945.

Assesses the efficacy and consequences of various methods of stimulating oceanic carbon sequestration through the supply of essential nutrients. Concludes that such methods do have the potential to stimulate sequestration, though the current level of scientific knowledge does not allow for useful recommendations of implementation strategies. Advocates for further research on the subject to be undertaken.

Lane, L. (2006). <u>Strategic Options for Bush Administration Climate Policy</u>. Washington, DC: AEI Press.

Examines climate policy through the Bush administration, and concludes that rejection of the Kyoto Protocol and other cap-and-trade systems was economically advantageous, although greater steps should be taken to enact a carbon tax or geoengineering strategies.

Lane, L. (2002). "The Need for Back-Up Strategies on Climate Change." *Climate Policy Center*, November 2002.

Addresses the problem of growing greenhouse gas emissions in the developing world, and underscores the inability of the developed world to stabilize atmospheric GHG concentrations with such rapidly rising emissions from the developing world. Analyzes distribution of control costs and incentives to free-ride as potential challenges to effective climate policy, and sanctions and geoengineering as potential solutions to problems associated with climate change.

Lane, L. and J.E. Bickel (2009). "Solar Radiation Management and Rethinking the Goals of COP-15" in "Advice for Policymakers", Copenhagen Consensus on Climate.

Summarizes the findings of Bickel and Lane (2009) with regard to preliminary benefit-cost ratios of stratospheric aerosol injections and marine cloud whitening. Concludes that deploying solar radiation management could produce large net benefits, though important uncertainties remain.

Lane, L. and D. Montgomery (2008). "Political Institutions and Greenhouse Gas Controls." AEI

Center for Regulatory and Market Studies, Related Publication 08-09.

Analyzes the extent to which political institutions limit the adoption of efficient greenhouse gas control policies. Examples of such institutional constraints include differing national interests, lack of third party enforcement, and high transaction costs. Identifies institutional constraints that are country-specific, as well. Concludes that adaptation and geoengineering measures should be explored, and that this entails broadening the scope of climate policy analysis to include the lessons of political economy.

Lane, L., K. Caldeira, R. Chatfield, and S. Langhoff (2007). "Workshop Report on Managing Solar Radiation." NASA Ames Research Center, Carnegie Institute of Washington Department of Global Ecology, NASA/CP-2007-214558.

Identifies the information pertaining to solar radiation management strategies that would be most necessary for policymakers to make more knowledgeable choices regarding research and implementation. Provides analysis of the advantages of such strategies, as well as analysis of risks, uncertainties, and objections associated with them.

Lane, L., K. Caldeira, D. Day, W. Fulkerson, and M. Hoffert (2005). "Climate Change Technology Exploratory Research (CCTER)." *Climate Policy Center*, December 2005.

Proposes the establishment of an extension of the Climate Change Technology Program (CCTP) to allocate seed money for research into potential cost-effective technological breakthroughs. Provides examples of potential research projects, as well as proposals outlining the mission, organization, and costs of such a venture.

Latham, J., P.J. Rasch, C.-C. Chen, L. Kettles, A. Gadian, A. Gettelman, H. Morrison, K. Bower, and T. Choularton (2008). "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds." *Philosophical Transactions of the Royal Society A*, 366: 3969-3987.

Assesses the scientific and meteorological dimensions of proposals to use cloud seeding to increase cloud albedo and produce a cooling effect. Concludes that, given resolution to complicating factors and questions, the negative forcing due to cloud seeding could potentially offset the positive forcing associated with substantially increased CO_2 *concentrations.*

Latham, J. (2002). "Amelioration of Global Warming by Controlled Enhancement of the Albedo and Longevity of Low-Level Maritime Clouds." *Atmospheric Science Letters*, 3: 52-58.

Proposes a technique for enhancing droplet concentrations in marine clouds through the surface-level release of seawater droplets acting as cloud condensation nuclei. This process in turn increases cloud albedo and longevity, and is meant to provide a cooling effect.

Latham, J. (1990). "Control of Global Warming?" *Nature*, 347: 339-340.

Provides an introduction to the process by which the droplet concentrations of clouds can be modified so as to increase reflectivity and thus produce a cooling effect. Proposes that experiments and modeling be carried out so as to examine the feasibility and effectiveness of such processes.

Lawrence, M.G. (2006). "The Geoengineering Dilemma: To Speak or not to Speak?" *Climatic Change*, 77: 245-248.

Despite the pessimistic scenarios laid out by the IPCC and many in the scientific community regarding the effects of global climate change, research into geoengineering proposals has largely been dismissed or criticized as "irresponsible." The sources of this phenomenon are documented, and the dilemma as to the role of geoengineering in the current policy debate is analyzed.

Lenton, T.M. and N.E. Vaughan (2009). "The Radiative Forcing Potential of Different Climate Geoengineering Options." *Atmospheric Chemistry and Physics Discussions*, 9: 2559-2608.

Examines the climate cooling, or radiative forcing potential, associated with a number of geoengineering options. Finds that only stratospheric aerosol injections and space-based sunshades allow for cooling to temperatures recorded in the pre-industrial state by 2050. Also finds that some land carbon cycle geoengineering strategies can have comparable cooling effects to mitigation wedges.

Lovelock, J. (2008). "A Geophysiologist's Thoughts on Geoengineering." *Philosophical Transactions of the Royal Society A*, 366: 3883-3890.

Assesses the widely held conception of the Earth as a self-regulating system maintaining a steady-state climate and surface chemical composition, and suggests that the Earth be regarded as a physiological system. Likens geoengineering strategies to nineteenth century medicine.

Lunt, D., A. Ridgwell, P.J. Valdes, and A. Seale (2008). "Sunshade World: A Fully Coupled GCM Evaluation of the Climatic Impacts of Geoengineering." *Geophysical Research Letters*, 35: L12710.

Investigates the climate change associated with the implementation of reflective mirrors to decrease incoming solar radiation, using a General Circulation Model. Concludes that such a strategy would result in cooling of the tropics, warming of high latitudes, sea ice reduction, reduced intensity of the hydrological cycle, reduced ENSO variability, and increased Atlantic overturning.

MacCracken, M.C. (2006). "Geoengineering: Worthy of Cautious Evaluation?" *Climatic Change*, 77: 235-243.

Describes the inadvertent nature of anthropogenic climate change to date, as well as the difficulties associated with movement away from dependence upon fossil fuels. Comments on the merits of Crutzen's recommendations, taking into account relevant scientific, legal, ethical, and societal issues.

MacCracken, M.C. (1991). "Geoengineering the Climate: Approaches to Counterbalancing Global Warming." Lawrence Livermore National Laboratory, Report: UCRL-JC-108014.

Provides an overview of a variety of geoengineering proposals, including carbon sequestration, solar radiation management, and oceanic macro-engineering. Acknowledges that mitigation efforts likely need to continue in the long-run, and that there is great uncertainty in terms of the timeframe with which geoengineering projects would need to be continued should they be implemented.

Marland, G. (1996). "Could We/Should We Engineer the Earth's Climate?" *Climatic Change*, 33: 275-278.

Assesses the juxtaposition of scientific and economic analysis and advocacy for policy proposals, as well as the communication of risks and ethical concerns associated with geoengineering. Argues that the implementation of geoengineering strategies in the present would be irresponsible without further research.

Marlay, Robert C. (2008). "Grand Challenges in Science for Guiding Climate Change Mitigation and Adaptation." Workshop organized by the Biological and Environmental Research Advisory Committee. 25-27 March, 2008.

Identifies the most pressing challenges facing the Climate Change Technology Program, including R&D progress, trade-offs among response strategies, and creating the conditions necessary for informed decision-making. Analyzes the feasibility and the consequences of geoengineering, especially in terms of reaching consensus on long-term objectives such as appropriate temperature goals.

Martin, J.H., et al. (1994). "Testing the Iron Hypothesis in Ecosystems of the Equatorial Pacific Ocean." *Nature*, 371: 123-129.

Evaluates the relationship between dissolved iron and oceanic phytoplankton growth. Results from testing using iron fertilization in the equatorial Pacific Ocean showed significant increases in plant biomass, chlorophyll, and plant production, indicating a strong correlation between iron levels and phytoplankton biomass and productivity, which could have important implications in terms of carbon dioxide drawdown.

Martin, J.H., S.E. Fitzwater, and R.M. Gordon (1990). "Iron in Antarctic Waters." *Nature*, 345: 156-158.

Analyzes the presence of iron deficiency in Antarctic phytoplankton and its implications *in terms of atmospheric carbon dioxide drawdown. Concludes that dissolved iron levels vary widely according to region, with some containing abundant levels and others containing levels so low that phytoplankton are able to use less than 10% of major nutrients available to them.*

Matthews, H.D. and K. Caldeira (2007). "Transient Climate-Carbon Simulations of Planetary Geoengineering." *Proceedings of the National Academy of Sciences,* 104: 9949-9954.

Analyzes potential environmental responses to geoengineering through aerosol scattering using a global climate model. Concludes that the climate system responds quickly to such processes, although prolonged aerosol scattering followed by an abrupt stoppage of such scattering could lead to severe and dangerous warming.

McInnes, C.R. (2002). "Minimum Mass Solar Shield for Terrestrial Climate Control." *Journal of the British Interplanetary Society*, 55: 307-311.

Examines the impact of a solar shield as a means for controlling solar radiation, with a specific focus on the mechanics of shield mass and location. Concludes that a shield mass of approximately 1,000 kilograms is needed to offset increases of greenhouse warming by two degrees Kelvin, signaling that such an approach requires considerable technological capabilities.

McKibben, W., A. Morris, and P. Wilcoxen (2008). "Setting the Right Green Agenda." *Brookings Global Economy and Development*, 7-9. The Brookings Institution.

Provides an approach to climate policy for a U.S. presidential administration that seeks a balance between minimizing the economic burden of climate change and generating incentives for technological innovation and greenhouse gas stabilization. Advocates for increased research devoted to geoengineering options.

Michaelson, J. (1998). "Geoengineering: A Climate Change Manhattan Project." *Stanford Environmental Law Journal*, 17: 73-140.

Analyzes the incentives for individuals and groups on both sides of the climate policy debate to embrace geoengineering, and finds that geoengineering is indeed an attractive policy option for both sides. Concludes that the international community is poorly suited to properly address climate change through mitigation, and a "Climate Change Manhattan Project" focused on geoengineering will work where current regulation does not.

National Academies, The (1992). Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base. *Chapter 28: Geoengineering*. Washington, DC: National Academy Press.

Acknowledges the costly inadvertent anthropogenic geoengineering currently underway, and evaluates the costs of various controlled geoengineering strategies, including *aerosol-based solar radiation management strategies. Concludes that naval rifles allow for injection into the stratosphere at the least cost.*

Nordhaus, W.D. (2008). A Question of Balance: Weighing the Options on Global Warming Policies. New Haven: Yale University Press.

Uses the DICE-2007 model to estimate the effects of various climate policies over a 600-year period. Finds geoengineering strategies to have net present value abatement costs and climate damages that are lower than any other policy examined. Suggests that intensive research into geoengineering strategies is justified, as no option that fits the DICE-2007 assumptions currently exists.

Nordhaus, W.D. (1994). Managing the Global Commons: The Economics of Climate Change. Cambridge: MIT Press.

Uses the DICE model to estimate the costs and benefits of different paths for slowing climate change and for analyzing the impact of control strategies over time. Concludes that even with major technological breakthroughs and stringent controls, past emissions and relative inertia in terms of policymaking will lead to severely damaging climate change.

Nordhaus, W.D. (1992). "An Optimal Transition Path for Controlling Greenhouse Gases." *Science*, 258: 1315-1319.

Evaluates five policy options to slow the impact of climate change using the DICE model. Concludes that a modest carbon tax would be far more efficient than rigid emissions or climate stabilization approaches, which would impose significant net economic costs.

Nordhaus, W.D. and J. Boyer (2000). Warming the World: Economic Models of Global Warming. Cambridge: MIT Press.

Addresses the challenges of data modeling, uncertainty, international coordination, and institutional design in confronting environmental intervention. Uses the RICE-99 and DICE-99 models to evaluate various policy options in terms of economic efficiency and environmental outcomes.

Pearson, J., J. Oldson, and E. Levin (2006). "Earth Rings for Planetary Environmental Control." *Acta Astronautica*, 58: 44-57.

Analyzes the costs and effectiveness of an artificial planetary ring comprised of controlled spacecraft or material derived from asteroids meant to diminish solar radiation insulated within the Earth's climate system. Provides a preliminary ring design and evaluates this design using a one-dimensional climate model. Concludes that rings could be effective in cooling the planet, but also introduce other environment concerns, and various types of rings could cost as little as $125 billion and as much as $200 trillion.

Peng, T.H. and W.S. Broecker (1991). “Dynamic Limitations on the Antarctic Iron Fertilization Strategy.” *Nature*, 349: 227-229.

Investigates the impact of iron fertilization in Antarctic surface waters on the drawdown of atmospheric carbon dioxide. Finds that a century of iron fertilization would lower atmospheric carbon dioxide content by approximately 10%. Concludes that even perfectly administered iron fertilization would not significantly reduce carbon dioxide concentrations.

Pielke, Jr., R.A. (2009). “An Idealized Assessment of the Economics of Air Capture of Carbon Dioxide in Mitigation Policy.” *Environmental Science & Policy*, 12: 216-225.

Evaluates air capture of carbon dioxide as a method of alleviating the negative effects of climate change. Finds that the costs of air capture are comparable to the costs of atmospheric stabilization using other methods suggested by the IPCC and the Stern Report.

Rasch, P.J., S. Tilmes, R.P. Turco, A. Robock, L. Oman, C.-C. Chen, G.L. Stenchikov, and R.R. Garcia (2008). “An Overview of Geoengineering of Climate using Stratospheric Sulfate Aerosols.” *Philosophical Transactions of the Royal Society A*, 366: 4007-4037.

Provides an overview of sulfate aerosol scattering, including the progression of research in the subject over a number of decades and the status of the current implementation proposals. Examines the likely effects of sulfate aerosol scattering on temperature, ozone, and acid rain.

Rasch, P.J., P.J. Crutzen, and D.B. Coleman (2008). “Exploring the Geoengineering of Climate Using Stratospheric Sulfate Aerosols: The Role of Particle Size.” *Geophysical Research Letters*, 35, L02809.

Assesses the effects of sulfate aerosol particle size on the climate system, and offers explanations as to why varied sizes of particles interact differently with the system. Concludes that approximately 1.5 Tg S/yr balances a doubling of carbon dioxide concentration if particles are small in size; perhaps double that amount may be needed should particles attain the size of those following volcanic eruptions.

Robock, A. (2008). “20 Reasons Why Geoengineering May Be a Bad Idea.” *Bulletin of the Atomic Scientists*, 64: 14-18.

Provides a list of concerns and uncertainties regarding geoengineering strategies that have been proposed.

Robock, A. (2008). “Whither Geoengineering?” *Science,* 320: 1166-1167.

Presents the geoengineering policy debate in the framework of ozone depletion, and uses *this example to show the relative lack of information available regarding the unintended consequences of geoengineering strategies. Advocates for a federally funded and internationally supported geoengineering research program so that geoengineering strategies can be compared to mitigation strategies to determine efficient policies.*

Robock, A. (2002). "The Climatic Aftermath." *Science*, 295: 1242-1243.

Provides an overview of the relationship between the Mount Pinatubo eruption and current geoengineering proposals. Analyzes the climatic response to the Pinatubo eruption, as well as potential policy lessons to be taken from this event.

Robock, A., A.B. Marquardt, B. Kravitz, and G.L. Stenchikov (2009). "Benefits, Risks, and Costs of Stratospheric Geoengineering." *Geophysical Research Letters*, 36: L19703.

Evaluates stratospheric sulfate aerosol injections as a means of addressing global climate change. Finds the annual costs of injecting aerosols into the stratosphere via military fighter and tanker planes to be several billion dollars, while the costs of using artillery or balloons would be much greater. Finds that stratospheric aerosol injections would produce global cooling, stop sea ice and glacier melting, slow sea level rise, and increase the terrestrial carbon sink, while also producing regional drought, ozone depletion, decreased sunlight and solar power, and obstruction of Earth-based optical astronomy.

Robock, A., L. Oman, and G.L. Stenchikov (2008). "Regional Climate Responses to Geoengineering with Tropical and Arctic SO_2 Injections." *Journal of Geophysical Research*, 113: D16101.

Uses a comprehensive atmosphere-ocean general circulation model to simulate the climate response to tropical and Arctic stratospheric injections of sulfate aerosol precursors. Finds that tropical injections would cool the global average climate, with greater cooling over continental areas, though the Asian and African summer monsoons would be disrupted. Finds that Arctic injections would produce cooling over the Arctic, and therefore reverse sea ice melting, but monsoons would also be affected and aerosols would not be confined to the polar region.

Roy, K.I. (2001). "Solar Sails: An Answer to Global Warming." *Space Technology and Applications International Forum, American Institute of Physics Conference Proceedings*, 552: 413-418.

Investigates the feasibility of a geoengineering strategy featuring solar sails as a means of solar radiation management. Concludes that this strategy is effective at providing some measure of climate control, and is easily reversible should unintended consequences develop.

Royal Society, The (2009). "Geoengineering The Climate: Science, Governance, and Uncertainty." RS Policy Document 10/09.

Examines carbon dioxide removal and solar radiation management, as well as governance issues that may arise from the deployment – or potential deployment – of either option. Finds that CDR is preferable to SRM in the long-term, though SRM may provide a useful short-term option if rapid temperature reductions are needed. Also concludes that research and development is needed, and this R&D should be both internationally coordinated and conducted within the framework of an appropriate governance structure.

Salter, S., G. Sortino, and J. Latham (2008). "Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming." *Philosophical Transactions of the Royal Society A*, 366: 3989-4006.

Proposes hardware and engineering designs to transition cloud seeding strategies from concept to operation. Focuses upon the design of wind-driven spray vessels with the capacity to treat large portions of the atmosphere.

Schelling, T.C. (2007). "Climate Change: The Uncertainties, the Certainties, and What They Imply About Action." *The Economists' Voice*: 4(3), Article 3.

Outlines the uncertainties regarding climate change, namely levels of carbon dioxide concentration in a non-mitigation scenario, levels of average global warming, various impacts of warming, and the costs of mitigation strategies, as well as the certainties, namely the impact of greenhouse gases on other planets and the effects of infrared radiation on greenhouse gases. Argues for action based on the certainties that do exist, and calls for further research and development in the field.

Schelling, T.C. (1996). "The Economic Diplomacy of Geoengineering." *Climatic Change*, 33: 303-307.

Identifies the simplifications of climate policy that would occur should geoengineering strategies be undertaken. Observes that complex regulatory systems that would be needed for emissions reductions would not be necessary for geoengineering to occur, and instead the major problem would become the relatively simpler issue of cost sharing.

Schnare, D. (2008). "Climate Change and the Uncomfortable Middle Ground: The Geoengineering and 'No Regrets' Policy Alternative." Paper delivered at the 2008 International Conference on Climate Change, 2-4 March, 2008.

Describes the "mutually exclusive" agendas of various sides in the climate policy debate in the United States, and offers an approach that will serve as a compromise with regard to scientific, political, and economic considerations. Argues for the implementation of geoengineering to delay catastrophic consequences of increased emissions, as well as greatly increased research in low-cost carbon sequestration methods.

Schneider, S.H. (2008). "Geoengineering: Could We or Should We Make it Work?"

Philosophical Transactions of the Royal Society A, 366: 3843-3862.

Describes the history of large-scale climate modification proposals, as well as a number of modern geoengineering policy options. Analyzes arguments by proponents of geoengineering, including cost-effectiveness and preparation considerations, and those given by opponents of geoengineering, including concerns over the uncertainty of the process and the political feasibility of such a global effort.

Schneider, S.H. (2001). "Earth Systems Engineering and Management." *Nature*, 409: 417-421.

Examines various geoengineering strategies, as well as the geoengineering policy debate, in the context of a growing global economy and global poverty. Analyzes the extent to which geoengineering can provide an answer to the problems of climate change while still allowing for economic development, particularly in the poorest nations of the world.

Schneider, S.H. (1996). "Geoengineering: Could – or Should – We Do It?" *Climatic Change*, 33: 291-302.

Provides a historical overview of the debate surrounding geoengineering policy options and outlines the major arguments made by proponents and opponents in the current debate. Concludes that, despite the growing potential for severe problems associated with climate change, further research needs to be completed before any action is undertaken.

Smetacek, V. and S.W.A. Naqvi (2008). "The Next Generation of Iron Fertilization Experiments in the Southern Ocean." *Philosophical Transactions of the Royal Society A*, 366: 3947-3967.

Discusses previous studies and experiments dealing with oceanic iron fertilization, and addresses the apparent consensus that strategies based upon fertilization are ineffective and unpopular. Proposes new experimentation that will be carried out at more appropriate scales and localities, thereby providing a better indication as to how effective fertilization is as a means of sequestering atmospheric carbon dioxide.

Sterner, T., et al. (2006). "Quick Fixes for Environmental Problems: Part of the Solution, or Part of the Problem?" *Environment*: 48: 20-27.

Categorizes geoengineering strategies within the subset of environment "quick fixes", and uses a short-run versus long-run framework through which to view potential solutions to environmental problems like global climate change. Argues that new approaches to governance are needed for guiding management and policy towards sustainability.

Struck, C. (2007). "The Feasibility of Shading the Greenhouse with Dust Clouds at the Stable Lunar Lagrange Points." *Journal of the British Interplanetary Society*, 60: 82-89.

Examines the viability of a space-based solar shade comprised of dust particles derived from comet fragments or lunar mining. Identifies the advantages and disadvantages of this strategy in comparison with other geoengineering approaches.

Teller, E. (1998). "Sunscreen for Planet Earth." *Hoover Digest*, No. 1.

Argues that a lack of consensus about the effects of global climate change makes vast spending and emissions reductions inefficient and undesirable. Advocates for research into much more cost-effective geoengineering strategies.

Teller, E., R. Hyde, M. Ishikawa, J. Nuckolls, and L. Wood (2003). "Active Stabilization of Climate: Inexpensive, Low-Risk, Near-Term Options for Preventing Global Warming and Ice Ages via Technologically Varied Solar Radiative Forcing." Lawrence Livermore National Laboratory.

Reviews current technology available for geoengineering strategies based upon solar radiative forcing. Concludes that the economic and social benefits of these strategies may be quite large due to their potential to protect the climate system from large-scale warming and cooling, as well as to eliminate solar UV radiation from the biosphere.

Teller, E., L. Wood, and R. Hyde (1997). "Global Warming and Ice Ages: I. Prospects for Physics-Based Modulation of Global Change." Lawrence Livermore National Laboratory, Report: UCRL-JC-128715.

Provides a technical analysis of aerosol injection based on evaluations of the scattering efficiencies of various types of aerosols. Advocates for solar radiation management through aerosol injection based on conclusions that such strategies entail greater economic benefits than costs.

Thernstrom, S. (2009). "White Makes Right? Steven Chu's Helpful Idea." *The American*, 5 June.

Describes the benefits associated with "soft" geoengineering, such as painting roofs and roads white so as to reflect more sunlight back into space. Explains that, while this approach will not have a large effect on the overall climate in the near future, discussion of soft geoengineering moves the climate policy debate beyond the narrow consideration of only cap-and-trade and carbon tax options.

Tilmes, S., R. Müller, and R. Salawitch (2008). "The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes." *Science*, 320: 1201-1204.

Analyzes the potential for geoengineering strategies meant to emulate the Mount Pinatubo eruption to effect ozone depletion. Uses an empirical relationship between ozone depletion and chlorine activation to estimate the response of polar ozone to such strategies. Concludes that an injection of sulfate aerosol particles meant to counteract a doubling of atmospheric carbon dioxide concentration would cause a 30-70 year delay in the expected recovery of the Antarctic ozone hole.

Travis, W.R. (2008). "Geo-Engineering the Climate: Time for a Technology Assessment." Institute of Behavioral Science, University of Colorado, Working Paper ES2008-0002.

Examines the advantages and disadvantages of geoengineering strategies in comparison to mitigation strategies, and advocates more complete technology assessments to determine the costs, efficiency, and feasibility of geoengineering strategies.

Trenberth, K.E. and A. Dai (2007). "Effects of Mount Pinatubo Volcanic Eruption on the Hydrological Cycle as an Analog of Geoengineering." *Geophysical Research Letters*, 34: L15702.

Analyzes the effects of the El Chichón and Mount Pinatubo volcanic eruptions on precipitation and streamflow. Concludes that the severe decreases in precipitation and runoff and river discharge into the ocean following the Pinatubo eruption signal potentially significant adverse effects which could arise from geoengineering strategies meant to simulate these natural events.

Tuck, A.F., D.J. Donaldson, M.H. Hitchman, E.C. Richard, H. Tervahattu, V. Vaida, and J.C. Wilson (2008). "On Geoengineering with Sulphate Aerosols in the Tropical Upper Troposphere and Lower Stratosphere." *Climatic Change*, 90: 315-331.

Examines evidence from nuclear weapon testing to gain insight and knowledge into the effects of geoengineering strategies based on sulfate aerosol scattering. Concludes that such geoengineering strategies involve high amounts of uncertainty covering a range of considerations, and therefore any implementation involves low predictability and the opportunity for unintended consequences.

Twomey, S. (1977). "The Influence of Pollution on the Shortwave Albedo of Clouds." *Journal of Atmospheric Sciences*, 34: 1149-1152.

Investigates the effects of pollution on cloud albedo and absorption coefficients through changes to droplet concentration and optical thickness. Concludes that increases in albedo dominate increases in absorption in thin to moderately thick clouds, producing a cooling effect, while increases in absorption dominate increases in albedo in sufficiently thick clouds, producing a warming effect.

United States Department of Energy (2002). "Response Options to Limit Rapid or Severe Climate Change: Assessment of Research Needs." National Climate Change Technology Initiative White Paper.

Acknowledges that past predictions of climate change have generally been underestimated, and that climate policy must be crafted with the realization that future climate change could potentially be severe. Presents a research and development plan for using technological solutions to deliberately avert major climate threats.

Victor, D.G. (2008). “On the Regulation of Geoengineering.” *Oxford Review of Economic Policy*, 24: 322-336.

Argues that norms governing the deployment of geoengineering strategies are needed before these strategies become viable options. Standard instruments such as treaties and assessment methods organized by the IPCC will likely be ineffective, and therefore “bottom up” efforts are crucial. Active, open research programs will make nations more willing to accept binding norms. Also suggests that geoengineering will be more complex and expensive in practice than in theory, since these interventions will be combined with other interventions meant to offset the negative consequences of geoengineering.

Victor, D.G., M.G. Granger, J. Apt, J. Steinbruner, and K. Ricke (2009). “The Geoengineering Option: A Last Resort Against Global Warming?” *Foreign Affairs*, 88: 64-76.

Traces the history of weather modification and outlines current geoengineering proposals. Offers concerns regarding the potential for unilateral geoengineering via isolated nations or even wealthy individuals. Advocates for governments to undertake research into geoengineering and work together to create international norms governing its use.

Virgoe, J. (2008). “International Governance of a Possible Geoengineering Intervention to Combat Climate Change.” *Climatic Change*, 95: 103-119.

Discusses the international governance of a geoengineering regime. Identifies the non-technical characteristics of geoengineering that may affect its governance, and analyzes approaches based through the United Nations, a single state unilaterally, and a consortium of states. Concludes that international legal instruments show that none would pose an insurmountable barrier to the deployment of geoengineering.

Watson, A.J., et al. (2000). “Effect of Iron Supply on Southern Ocean CO_2 Uptake and Implications for Glacial Atmospheric CO_2.” *Nature*, 407: 730-733.

Examines the effects of iron deposition on atmospheric carbon dioxide concentrations above the Southern Ocean. Concludes that modest atmospheric carbon sequestration via oceanic iron fertilization is possible, although questions remain regarding the time period and geographic boundaries over which the process would be effective.

Watson, A.J., et al. (1994). “Minimal Effect of Iron Fertilization on Sea-Surface Carbon Dioxide Concentrations.” *Nature*, 371: 143-145.

Examines the effects of iron deposition on surface-level carbon dioxide concentrations in the equatorial Pacific. Concludes that complete utilization of all available nitrate and phosphate did not occur, and thus surface-level carbon dioxide concentration underwent only minor changes.

Weart, S. (2006). “Climate Modification Schemes.” American Institute of Physics.

Provides historical background on the development of climate and weather modification, including the efforts of military agencies to explore "climatological warfare". Traces the shift made by governments from devoting resources towards direct weather modification to devoting these resources towards geoengineering strategies meant to address the problems associated with global climate change.

Weitzman, Martin L. (2007). "Structural Uncertainty and the Value of Statistical Life in the Economics of Catastrophic Climate Change." AEI-Brookings Joint Center for Regulatory Studies, Working Paper 07-11.

Analyzes the implications of structural uncertainty for the economics of low-probability, high-impact catastrophes. Concludes that the presence of an uncertain multiplicative parameter induces a critical "tail fattening" of posterior-predictive distributions. The influence of this uncertainty on cost-benefit analysis, coupled with a high value of statistical life, can potentially outweigh the influence of discounting.

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

Presents a strategy for addressing the negative effects of both anthropogenic warming and increasing atmospheric carbon dioxide concentrations. Proposes that sulfate aerosol scattering would effectively offset the problems associated with rising temperatures, while mitigation efforts and a reduction in dependence on fossil fuels during the additional time provided by the aerosol scattering would stabilize carbon dioxide concentrations at an acceptable level.

Wigley, T.M.L., R. Richels, and J.A. Edmonds (1996). "Economic and Environmental Choices in the Stabilization of Atmospheric CO_2 Concentrations." *Nature*, 379: 240-243.

Attempts to determine the extent to which various concentrations of atmospheric carbon dioxide coincide with a plausible transition from fossil fuel dependence. Develops stabilization profiles that incorporate considerations of the global economic system, estimate the corresponding anthropogenic emissions requirements, and provide assessments in regard to global temperatures and sea level changes.