Climate Engineering Research: A Precautionary Response to Climate Change?

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In the face of dire forecasts for anthropogenic climate change, climate engineering is increasingly discussed as a possible additional set of responses to reduce climate change's threat. These proposals have been controversial, in part because they – like climate change itself – pose uncertain risks to the environment and human well-being. Under these challenging circumstances of potential catastrophe and risk-risk trade-off, it is initially unclear to what extent precaution is applicable. We examine what precaution is and is not, and make a prima facie case that climate engineering may provide means to reduce climate risks. When precaution is applied to the currently pertinent matter of small to moderate scale climate engineering field tests, we conclude that precaution encourages them, despite their potential risks.

I. Introduction

The likely impacts of anthropogenic climate change on humans and the environment are vast. Mitigating the risks through greenhouse gas emissions abatement requires overcoming an extremely challenging collective action problem. However, efforts thus far to reduce these risks have been disappointing.

As the evidence and probable severity of climate risks have mounted, a wider range of options is now being considered. Efforts toward emissions abatement were the first global response, and then adapting society and ecosystems to new climates became a second legitimate category of action. Now, proposals to develop the means to intentionally intervene on massive scales in global physical, chemical, and biological systems in order to counterbalance climate change are being seriously discussed. While diverse, these proposed *climate engineering* (CE) or *geoengineering* methods are controversial for several reasons, including the contention that they pose uncertain but potentially serious risks to humans and the environment.

In debates over CE, precaution is often invoked. Daniel Bodansky predicted that precaution would "be invoked frequently and loudly at the international level" and possibly contribute to an international prohibition.[1] The Conference of Parties to the Convention on Biological Diversity cited "the precautionary approach" in a nonbinding advisory statement against CE activities that may affect biodiversity.[2] Moreover detractors of CE also often cite precaution as a rationale for opposing CE research and/or deployment.[3] However, in this article, we assert that a precautionary approach favours improving knowledge about CE options through research, including field experiments, but in a manner that recognizes risks.

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1 Daniel Bodansky, "May We Engineer the Climate?", 33 *Climatic Change* (1996), 309, at 312.

2 Decision X/33.8(w), Biodiversity and Climate Change: Report of the Tenth Meeting of the Conference of Parties to the Convention on Biological Diversity, UN Doc. UNEP/CBD/COP/10/27, 20 January 2011.

3 See, e.g., ETC Group, "The ABCs of Ensuring Precaution on Geoengineering", 5 October 2010, available on the Internet at <http://www.etcgroup.org/sites/www.etcgroup.org/files/geoE_ETC4COP11_final4web.pdf> (last accessed on 6 March 2013).

II. Climate Change and Climate Engineering

A brief review of the risks of and potential responses to the threat of climate change will contextualize CE. Greenhouse gas emissions have caused their atmospheric concentrations to rise at an unprecedented rate, and their emission rates continue to grow. Both temperatures and precipitation figures are rising. Because climate change lags relative to emissions, there is an unknown commitment to future climate change. Climate change is accelerating an already disturbing rate of species extinction. In terms of human impacts, analyses are highly sensitive to the assumed discount rate, and their estimated annual costs range from 1% to 20% of global economic activity.[4] Food production and water resources will be disrupted. Infectious diseases, extreme weather events, and involuntary migration will likely increase in frequency and magnitude. Low-lying coastal areas, including entire countries, will be inundated. In almost all of these aspects, poor populations will suffer disproportionately. Meanwhile, the Kyoto Protocol and the latest nonbinding commitments are unlikely to keep global warming below the target of 2°C, and further emissions cuts are at an impasse.[5] Models that extrapolate current trends estimate that warming could reach 4°C by 2100.[6] Financing of adaptation measures also appears to be inadequate.[7]

As climate change forecasts become starker, consideration of CE has moved inward from the margins. The category is broad, encompassing numerous proposed methods whose means, goals, financial costs, response times, and risks vary widely, and whose boundaries with emissions abatement and adaptation are blurry.[8] Some methods would remove carbon dioxide from the atmosphere (CDR), whereas others would reduce incoming solar radiation (solar radiation management, or SRM) to counterbalance warming. In general, the former would be slower, more expensive, and less risky but address the cause of climate change more closely to its cause, whereas the latter would be faster, less expensive, and riskier, and address only the warming aspect of climate change.[9]

Because arguments against CE arise more often in the context of the riskier methods, we limit our focus in this article to larger-scale SRM methods such as stratospheric aerosol injection and marine cloud brightening. In these cases, models indicate they could counter a significant portion – and perhaps all – of global warming, although the effects would be regionally heterogeneous.[10] Models also point toward potential negative effects of SRM that may be significant but remain partially uncertain. Precipitation patterns will change.[11] The incoming light would be more diffuse while carbon dioxide would remain elevated, increasing plant primary productivity and altering ecosystems.[12] The leading candidate for stratospheric aerosol injection, sulphate particles, could damage the ozone layer.[13] Furthermore, because the current relevant question is whether to proceed with field tests, our discussion focuses on these more immediate steps, not on future potential SRM deployment.

4 Compare Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press, 2006), and Richard S. J. Tol, "The Economic Effects of Climate Change", 23 *Journal of Economic Perspectives* (2009), 29.

5 Kyoto Protocol to the United Nations Framework Convention on Climate Change, Kyoto, 10 December 1997, in force 16 February 2005, 37 *International Legal Materials* (1998), 22; Decision 2/CP.15, Report of the Conference of the Parties on Its Fifteenth Session, Held in Copenhagen from 7 to 19 December 2009. Addendum. Part Two: Action Taken by the Conference of the Parties at Its Fifteenth Session, UN Doc. FCCC/CP/2009/11/Add.1, 30 March 2010; International Energy Agency, *World Energy Outlook 2010* (Paris: International Energy Agency, 2010), at 45.

6 Richard A. Betts et al., "When Could Global Warming Reach 4°C?", 369 *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (2011), 67.

7 United Nations Framework Convention on Climate Change, *Investment and Financial Flows to Address Climate Change* (Bonn: UNFCCC Secretariat, 2007).

8 An accessible review is John Shepherd et al., *Geoengineering the Climate: Science, Governance and Uncertainty* (London: The Royal Society, 2009).

9 Ocean fertilization is an exception, in that it presents much greater environmental risks than other proposed forms of carbon dioxide removal, and indeed our argument could be extended to this method. However, evidence increasingly points toward its limited capacity. Phillip Williamson et al., "Ocean Fertilization for Geoengineering: A Review of Effectiveness, Environmental Impacts and Emerging Governance", 90 *Process Safety and Environmental Protection* (2012), 475.

10 Juan B. Moreno-Cruz, Katharine L. Ricke, and David W. Keith, "A Simple Model to Account for Regional Inequalities in the Effectiveness of Solar Radiation Management", 110 *Climatic Change* (2012), 649.

11 *Ibid*.

12 Julia Pongratz et al., "Crop Yields in a Geoengineered Climate", 2 *Nature Climate Change* (2012), 101.

13 Patricia Heckendorn *et al*., "The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone", 4 *Environmental Research Letters* (2009), 045108.

III. A *Prima Facie* Case for Climate Engineering Deployment

The benefits of research rest on whether SRM deployment may provide net benefits. This case need not be irrefutable. Indeed, too many unknowns remain, and the purpose of research is to reduce these unknowns. Therefore, we need to make only a *prima facie* case, i.e., we ask whether, at first appearance, SRM deployment could provide significant net benefits to humans and the environment under reasonable assumptions about a climate change future.

In short, most studies which use climatic and economic modelling indicate that SRM deployment would be highly beneficial under most circumstances. Early studies compared only the direct (and small) financial costs of SRM with the benefits of reducing climate change, but did not consider negative side effects.[14] More recent papers tried to incorporate such effects, as well as secondary benefits such as increased agricultural productivity due to diffuse light.[15] For example, one paper used the Dynamic Integrated Climate Change Model to consider both the beneficial and damaging effects of SRM. The authors found that when SRM supplements emissions abatement, it passes a cost-benefit test in a large majority, but not all, of the ranges of damages due to SRM, and of the probability that the SRM would be prematurely terminated.[16]

The greatest concern about the environmental effects of SRM is in the context of regional precipitation reductions predicted by some models.[17] The authors of a recent article used a climate model to calculate, for each of 22 terrestrial regions of the planet, damage functions that combined and equally weighed temperature and precipitation changes. The authors examined optimization scenarios under which the regions were alternatively weighted by area, population, and economic activity. The results demonstrated that under both Pareto optimal and potentially Pareto optimal scenarios, all regions benefitted significantly under climate change with SRM relative to climate change alone.[18]

The *capacity* to deploy SRM in an informed manner adds further value, independent of whether it actually is deployed. This is because the probability distribution of climate change damages has a long tail, in which there is a significant but low chance of very high damages. There are three reasons for this, each of which will not be known for decades due to the latency of climate change. First, climate sensitivity (the magnitude of climate change for a given amount of cumulative greenhouse gas emissions) may turn out to be greater than expected.[19] Second, climate change could induce a positive feedback loop, leading to non-linear climatic responses.[20] Third, an optimal abatement strategy may be unattainable due to the political demands of global collective action. Bearing in mind that some proposed SRM techniques may be rapidly effective, they could be deployed in response to learning about or actually experiencing the above possibilities.[21] In other words, the potential to deploy SRM is a form of insurance, and having such capacity would have a high value, especially – as we discuss below – from a precautionary perspective.

From these studies, we conclude that there is a reasonable chance that SRM deployment would significantly reduce the net damage from climate change to humans and the environment, and that

14 See, e.g., William D. Nordhaus, *A Question of Balance: Weighing the Options on Global Warming Policies* (New Haven: Yale University Press, 2008), at 20.

15 Juan B. Moreno-Cruz and Sjak Smulders, "Revisiting the Economics of Climate Change: The Role of Geoengineering", January 2010, available on the Internet at <http://works.bepress.com/morenocruz/4> (last accessed on 17 December 2012); Kjetil Gramstad and Sigve Tjøtta, "Climate Engineering: Cost Benefit and Beyond", 23 September 2010, available on the Internet at <http://mpra.ub.uni-muenchen.de/27302/> (last accessed on 17 December 2012).

16 J. Eric Bickel and Shubham Agrawal, "Reexamining the Economics of Aerosol Geoengineering", 119 *Climatic Change* (2013), 993, at Figure 8.

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

18 Moreno-Cruz et al., "Regional Inequalities", supra, note 10.

19 "[C]limate sensitivity [for a doubling of CO_2] is likely to be in the range of 2 to 4.5 °C with a best estimate of about 3 °C, and is very unlikely to be less than 1.5 °C. Values substantially higher than 4.5 °C cannot be excluded", see Intergovernmental Panel on Climage Change, *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: Intergovernmental Panel on Climage Change, 2007), at 38.

20 Anthony D. Barnosky et al., "Approaching a State Shift in Earth's Biosphere", 486 *Nature* (2012), 52.

21 See Juan B. Moreno-Cruz and David W. Keith, "Climate Policy under Uncertainty: A Case for Solar Geoengineering", 2012, available on the Internet at <http://download.springer.com/static/pdf/547/art%253A10.1007%252Fs10584-012-0487-4.pdf?auth66=1380178945_3768b5c8233ff30fa349a93c91892dbf&ext=.pdf> (last accessed on 15 August 2013).

the capacity to deploy it under low probability, high impact scenarios will have great value.[22]

The costs of SRM research have two components. First, the direct costs of the research are small enough to be negligible relative to forecast climate change damages. Current proposed projects are on the order of hundreds of thousands of USD. Any proposed future budgets are rough conjectures. Nevertheless, one estimate is to increase funding to a magnitude of hundreds of millions USD annually for decades, yielding a total estimate on the order of tens of billions USD total.[23] Calculations of damages to humans and the environment, the second component, are likewise preliminary approximations. The first field tests, such as those now being proposed, pose no risks to humans and the environment. For example, one group of scientists planned on spraying seawater 1 km above the ocean in order to test delivery systems, and another proposes to inject very small amounts of light-scattering aerosols at a high altitude.[24] Clearly, further research would gradually scale up, posing small but increasing risks. Such proposed field projects can and should be carefully evaluated for their potential risks and benefits. Indeed, this may lead to a situation wherein risks outweigh benefits, and such projects should be aborted. The decisions faced now, though, are whether to proceed with small-scale field experiments that cost hundreds of thousands of USD with negligible risks.

Some observers have asserted that "geoengineering cannot be tested without full-scale implementation", however, and this would create unacceptable risks.[25] However, while it is true that moving from the laboratory to the field is a leap, by no means does this imply immediate full-scale deployment. For example, a recent paper described the important early role of analogue experiments and taking advantage of natural phenomena before commencing with experiments that perturb the environment.[26] Beyond that, projects can gradually increase in scale and potential impacts, and can be adaptively managed so that how and whether to proceed with subsequent stages is dependent upon prior results. Specifically, research could engage in "sustained science with small-scale field experiments. Early tests would focus on understanding processes. Later tests potentially could be large enough to produce barely detectable climate effects and reveal unexpected problems, but be small enough to limit risks."[27]

IV. Precaution

Precaution reflects recognition on the part of regulators of special properties of the environment and human health as object of regulation, even if this may result in false negatives. These include, in particular, the irreversible nature of much environmental damage, and the interests of future generations.

Precaution can be seen as a correction to existing legal systems. The principle arose from unease about the difficulty to legally engage threats to the environment or human health for which scientific evidence remained inconclusive, particularly in cases of new technologies or large scale interventions in the environment. In essence, precaution establishes legal competence to act where, if not for precaution, there would be no such competence.[28] Hence, precaution is an *empowering* principle, and may justify public action. Although there are numerous different articulations of the precautionary principle in circulation,[29] they have three elements in common: threats of harm, scientific uncertainty, and a possible precautionary action.

22 Although each of the authors of the above-cited papers made certain assumptions, without which their conclusions may have been different, these assumptions were not unreasonable.

23 Ken Caldeira and David W. Keith, "The Need for Climate Engineering Research", 27 *Issues in Science and Technology* (2010), 57.

24 Daniel Cressey, "Cancelled Project Spurs Debate over Geoengineering Patents", 485 *Nature* (2012), 429; Henry Fountain, "Trial Balloon: A Tiny Geoengineering Experiment", 17 July 2012, available on the Internet at <http://green.blogs.nytimes.com/2012/07/17/trial-balloon-a-tiny-geoengineering-experiment/> (last accessed on 6 March 2013); Lynn M. Russell et al., "E-Peace Eastern Pacific Emitted Aerosol Cloud Experiment", 2011, available on the Internet at <http://aerosols.ucsd.edu/E_PEACE.html> (last accessed on 6 March 2013).

25 Alan Robock et al., "A Test for Geoengineering?", 327 *Science* (2010), 530, at 530.

26 Lynn M. Russell et al., "Ecosystem Impacts of Geoengineering: A Review for Developing a Science Plan", 41 *AMBIO: A Journal of the Human Environment* (2012), 350.

27 Caldeira and Keith, "Climate Engineering Research", supra, note 23, at 62.

28 Han Somsen, "Cloning Trojan Horses: Precautionary Regulation of Reproductive Technologies", in Roger Brownsword and Karen Yeung (eds), *Regulating Technologies: Legal Futures, Regulatory Frames and Technological Fixes* (Oxford: Hart, 2008), 221.

29 Jonathan B. Wiener, "Precaution", in Daniel Bodansky, Jutta Brunnee, and Ellen Hey (eds), *The Oxford Handbook of International Environmental Law* (Oxford: Oxford University Press, 2007), 597.

In international law, the adoption of precaution in the Rio Declaration, and its incorporation in the Convention on Biological Diversity and the UN Convention on Climate Change (UNFCCC) signalled its widespread acceptance as a soft law norm.[30] The principle as such is not legally enforceable, but will typically be embedded in a concrete regulatory context, meaning that precaution often is enforceable. The empowering effect of precaution has been further operationalized through one or more of the constitutive elements of precaution. The totality of these elements instructs regulators to, inter alia:

a. recognize serious or irreversible harm;
b. acknowledge uncertainty;
c. apportion responsibilities to prove safety with regulatees;
d. stimulate public participation and deliberation;
e. consider alternative options;
f. respect the principle of proportionality;
g. ensure the provisional nature of measures;
h. monitor environmental performance.[31]

Precaution has substantially impacted multiple domains of environmental and human health law. Because the precautionary principle addresses risks to only humans and the environment, political and social risks, such as potentially reducing the political willpower toward emissions abatement and adaptation, fall outside the scope of precaution.[32] Although some of these concerns may be legitimate, they are not appropriate for the application of the precautionary principle and instead must be resolved through social, political, and legal pathways.

V. Precaution and Climate Engineering

Precaution has been invoked, both from within and outside academia, as part of a wider debate concerning CE.[33] Here we will discuss two important issues that have dominated this debate. The first is whether precaution could ever help guide CE decisions, considering the critique that the precautionary principle is incoherent since it can sometimes be argued to justify pursuing a particular approach, as well as prohibiting it.[34] In the context of climate engineering, it could simultaneously direct towards the employment and the prohibition of climate engineering, as both responses are characterized by uncertain risks for the environment and human health.

At least for the research phase, this is not the case. Precaution is a tool to deal with uncertain risks, but does not dictate an outcome. Although it is generally associated with banning certain products, activities, or technologies, in reality precautionary action has a variety of implications, potentially including warranting the use of, for example, a new technology to reduce risks.[35] Moreover, the elements noted above, such as proportionality and deliberation, should prevent arbitrary application of the principle.

The second issue concerns what guidance precaution may provide, particularly considering the problems of risk-risk trade-offs and potential catastrophes.[36] Hartzell-Nichols, for example, argues that if climate engineering creates new uncertain, potentially catastrophic risks, then its use – including research – should be rejected:

30 Rio Declaration on Environment and Development, UN Doc. A/CONF.151/26 (Vol. I), Principle 15; Convention on Biological Diversity, Rio de Janeiro, 5 June 1992, in force 29 December 1993, 31 *International Legal Materials* (1992), 818, Preamble, Para. 9; United Nations Framework Convention on Climate Change, Rio de Janeiro, 9 May 1992, in force 21 March 1994, 31 *International Legal Materials* (1992), 849, Art. 3.3.

31 Floor M. Fleurke, "Unpacking Precaution: A Study on the Application of the Precautionary Principle in Europe" (Ph.D. thesis on file at the University of Amsterdam, 2012), at 34 et seq.

32 See, e.g., Benjamin Hale, "The World That Would Have Been: Moral Hazard Arguments against Geoengineering", in Christopher J. Preston (ed.), *Engineering the Climate: The Ethics of Solar Radiation Management* (Lanham, Md.: Rowman and Littlefield, 2012), 113.

33 Bodansky, "May We Engineer the Climate?", supra, note 1; UK House of Commons Science and Technology Committee, *The Regulation of Geoengineering* (London: The Stationery Office, 2010), at 34–35; Kevin Elliott, "Geoengineering and the Precautionary Principle", 24 *International Journal of Applied Philosophy* (2010), 237 et seq.; CBD Decision, *supra* note 2; Jesse Reynolds, "The Regulation of Climate Engineering", 3 *Law, Innovation and Technology* (2011), 113, at 124; Ralph Bodle, "Geoengineering and International Law: The Search for Common Legal Ground", 46 *Tulsa Law Review* (2010), 305, at 309–311; Han Somsen, "When Regulators Mean Business", 40 *Rechtsfilosofie en Rechtstheorie* (2011), 47, at 55–56; Dorothee Amelung et al., "Beyond Calculation: Climate Engineering Risks from a Social Sciences Perspective", available on the Internet at <http://archiv.ub.uni-heidelberg.de/ojs/index.php/forum-mk/article/view/9408> (last accessed on 6 March 2013), at 25–41; Lauren Hartzell-Nichols, "Precaution and Solar Radiation Management", 15 *Ethics, Policy & Environment* (2012), 158 et seq.

34 Cass R. Sunstein, *Laws of Fear: Beyond the Precautionary Principle* (Cambridge: Cambridge University Press, 2005).

35 Imagine a scenario wherein there is a significant but uncertain chance that an asteroid may strike the Earth, with catastrophic results. Precaution would call for proactive steps, such as research into and development of technologies to prevent a disaster. See Richard Posner, *Catastrophe: Risk and Response* (Oxford: Oxford University Press, 2004).

36 Jonathan B. Wiener and John D. Graham (eds.), *Risk vs. Risk: Tradeoffs in Protecting Health and the Environment* (Cambridge, Mass.: Harvard University Press, 1995); Cass R. Sunstein, *Worst-Case Scenarios* (Cambridge, Mass.: Harvard University Press, 2007), at 144.

> [P]recautionary measures themselves prima facie should not pose new or further threats of catastrophe ... [I]f we believe we have moral reasons to avoid the threats of catastrophe posed by climate change we also have reasons to avoid the threats of catastrophe posed by any risky SRM strategies.[37]

Although it may seem to be morally ideal to attempt to avoid all potential catastrophes, this may simply not be the case with climate change given the serious consequences that unabated climate change may pose. Consequently, the above statement leads to paralysis, and likely suboptimal results with significant implications for humans and the environment.

Ideally, when applying precaution, regulators would adhere to a substitution clause that directs them to comparisons. In the case of climate engineering, this means that risks of climate change and risks of climate engineering would be compared with regard to their *relative* magnitude and scientific uncertainty.[38] It does not mean that a strategy that seeks to abate risks should be abandoned solely because it brings new, different risks to the table. Precaution can play a constructive mediating role in this kind of weighing exercise, where it is difficult to balance potential benefits and risks because of scientific uncertainty. Moreover, the presumption that maintaining the status quo takes priority over intentional change is a strong but refutable bias.[39] Notably, exhibiting bias in risk perception is particularly common concerning new technologies that seem beyond individual control and whose effects and not immediately perceptible.[40]

We conclude that a precautionary approach favours SRM research. There is scientific consensus on the risks of climate change: the Intergovernmental Panel on Climate Change Assessment Reports outlines extremely serious potential impacts of climate change. However, it is becoming increasingly clear also that climate policies, at least their current incarnation, will probably be ineffective in significantly reducing these risks.[41] On the other hand, current models indicate that SRM deployment would provide net reduction in both temperature and precipitation changes. Field trials would be smaller in scale and could be monitored for emerging risks, and will reduce uncertainty. The results might indicate lower risks for SRM than previously thought. Such research will not only indicate which climate engineering techniques have potential, but which ones might pose too much risk and should be taken off the table. Furthermore, if there is a feasible future scenario under which SRM will be deployed, research now will improve later decision making. This argument is bolstered by the results of a model of large-scale SRM field tests that indicated trade-offs among duration of the experiment, its intensity, and the certainty of its results.[42] Thus, beginning field research sooner rather than later will have the advantage of requiring less intense interventions in the environment in order to produce a given certainty of results. In addition to the insurance value of SRM knowledge, there is another feasible future scenario under which, for whatever reason, climate change imposes large negative impacts on humans and the environment. Under pressure, political leaders may demand that scientists do whatever they can, including SRM deployment, even if the uncertainties remain great. Precaution would call for those future scientists to know more.

VI. United Nations Framework Convention for Climate Change

Is there support in legally binding treaties for our argument that a precautionary approach favours SRM research? Although the UNFCCC, the most important text in international law concerning climate change, does not directly address CE, it does invoke precaution:

> The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible

37 Hartzell-Nichols, "Precaution and Solar Radiation Management", supra, note 33, at 166.

38 Posner, *Catastrophe*, supra, note 35; Sunstein, *Worst-Case Scenarios*, supra, note 36.

39 Daniel Kahneman, Jack L. Knetsch, and Richard H. Thaler, "The Endowment Effect, Loss Aversion, and Status Quo Bias", 5 *The Journal of Economic Perspectives* (1991), 193; Somsen, "Cloning Trojan Horses", supra, note 28, at 223.

40 Paul Slovic and Elke U. Weber, "Perception of Risk Posed by Extreme Events", Presentation at "Risk Management Strategies in an Uncertain World", Palisades, New York, 12 to 13 April 2002.

41 Intergovernmental Panel on Climage Change, *Fourth Assessment Report*, supra, note 19.

42 Douglas G. MacMynowski et al., "Can We Test Geoengineering?", 4 *Energy & Environmental Science* (2011), 5044.

> damage, lack of full scientific certainty should not be used as a reason for postponing such measures taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.[43]

Although "lack of full scientific certainty" here is aimed at uncertainty related to climate change as such, since the UNFCCC was drafted the uncertainty regarding climate change has been reduced. Meanwhile, the potential effectiveness of a possible set of responses, SRM, remains greatly uncertain. It is reasonable to generalise the purpose of the precautionary principle as it is embodied in the UNFCCC – i.e. for scientific uncertainty to not be a barrier to taking measures – to imply support for at least exploring SRM through research. This reading is bolstered by two other considerations. First, the precautionary passage in the UNFCCC calls for responses to be cost-effective, and both SRM research and deployment appear to be remarkably inexpensive. Second, the UNFCCC calls for the development and diffusion of technology and research.[44] For example:

> All Parties ... shall ... Promote and cooperate in scientific, technological, technical, socio-economic and other research ... intended to further the understanding and to reduce or eliminate the remaining uncertainties regarding ... the economic and social consequences of various response strategies; [and p]romote and cooperate in the full, open and prompt exchange of relevant scientific, technological, [and] technical... information related to ... the economic and social consequences of various response strategies.[45]

VII. Conclusions

We have argued not only that precaution does not condemn SRM research, but that SRM research is in itself a precautionary response to the grave and potentially irreversible risks of climate change. This is not an argument for deployment, a decision that would require information presently unavailable. It is also not an argument to reduce efforts toward emissions abatement and adaptation. It simply means that in the face of potential climatic catastrophe, we should not postpone serious investigation into the capacity of SRM.

However, research itself should be organized and conducted in a precautionary manner. Specifically, this means that the elements noted above that constitute and operationalize precaution should become part of the risk assessment in the research phase.[46] Notably, some CE researchers and other scholars are working to further develop these principles as part of legitimate responsible oversight.[47] This is a crucial first step, as SRM, and CE in general, warrant both further research and appropriate regulation.

43 UNFCCC, supra, note 30, Art. 3.3.

44 Ibid., Art. 4.1, 4.3, 4.7, 4.8, 4.9, and 11.1.

45 Ibid., Art. 4.1(g) and (h). "Response strategies" is undefined, but presumably could include responses other than those encouraged by the UNFCCC.

46 See text to note 31.

47 Margaret S. Leinen, "The Asilomar International Conference on Climate Intervention Technologies: Background and Overview", 4 *Stanford Journal of Law, Science, and Policy* (2011), 1; Bipartisan Policy Center's Task Force on Climate Remediation, *Geoengineering: A National Strategic Plan for Research on the Potential Effectiveness, Feasibility, and Consequences of Climate Remediation Technologies* (Washington, DC: BPC, 2011); Steve Rayner et al., "The Oxford Principles", *Climatic Change* (2013), available on the Internet at <http://download.springer.com/static/pdf/874/art%253A10.1007%252Fs10584-012-0675-2.pdf?auth66=1380180336_dbb6694df2e5d5947c88a6088fe12f3e&ext=.pdf> (last accessed on 15 August 2013).