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A Napoleonic Approach to Climate Change: The Geoengineering Branch

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Have a plan, with branches.
~ Napoleon Bonaparte

Abstract

Climate change is an inevitable consequence of human greenhouse gas emissions. Without substantial changes in anthropogenic causes of climate change, there will be severe negative impacts on our planet. Complete abolition of greenhouse gas emissions, however, is not possible, nor will it necessarily stop the negative impacts of climate change. Therefore, substantial research must be done in geoengineering to understand better how we can positively act to avert significant climate change. Given the practical difficulties and potential effects, there must be comprehensive oversight. Currently, differing national laws makes this difficult. Additionally the United States laws do not properly cover climate engineering. Therefore, the United States should enact a comprehensive legal and regulatory program to develop and grow research in climate engineering. This comprehensive regime should be a model for the rest of the world to follow.

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I. Introduction

Absent substantial reductions in greenhouse gas (GHG) emissions, significant climate change will be unavoidable.[1] Carbon remains in the atmosphere for centuries, and even if carbon emissions were stopped immediately, the planet would continue to warm.[2] Although mitigation of GHG emissions remains the preferred approach, recent estimates predict that it will no longer suffice to avert significant planetary warming.[3] While we should continue to mitigate, we need to develop alternative approaches should mitigation not occur quickly enough or to the degree required to avoid catastrophic climate change.[4]

To minimize the worst effects of climate change, we may need to utilize climate engineering.[5] Climate engineering could help avoid the worst

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1. *See New Study Shows Climate Change Largely Irreversible*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (Jan. 26, 2009) [hereinafter NOAA], http://www.noaanews.noaa.gov/stories2009/20090126_climate.html (concluding that climate change caused by increases in carbon dioxide are irreversible for more than one thousand years after carbon emissions stop completely) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

2. *See id.* (discussing the climatic changes that would continue even after cessation of carbon emissions).

3. *See* Susan Solomon et al., *Irreversible Climate Change Due to Carbon Dioxide Emissions* 106 PROCEED. NAT'L ACAD. SCI. 1704, 1709 (2009), *available at* http://www.pnas.org/content/early/2009/01/28/0812721106.full.pdf ("Irreversible climate changes due to carbon dioxide emissions have already taken place, and future carbon dioxide emissions would imply further irreversible effects on the planet, with attendant long legacies for choices made by contemporary society.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

4. *See* David Bello, *Has the Time Come to Try Geoengineering?*, SCIENTIFIC AMERICAN (Aug. 15, 2012), http://blogs.scientificamerican.com/observations/2012/08/15/has-the-time-come-to-try-geoengineering/ ("If the world collectively fails to restrain pollution, then we might need to deploy geoengineering techniques in a hurry to prevent catastrophic climate change.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

5. In recognition of the common usage of "geoengineering," this paper uses the terms "climate engineering" and "geoengineering" interchangeably to mean "the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change." THE ROYAL SOCIETY, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE, AND UNCERTAINTY 1 (2009) [hereinafter ROYAL SOCIETY], *available at* http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT). For further discussion of these terms, see BART GORDON, ENGINEERING THE CLIMATE: RESEARCH NEEDS AND STRATEGIES FOR INTERNATIONAL COOPERATION 39 (2010), *available at* http://www.washingtonpost.com/wp-srv/nation/pdfs/Geongineeringreport.pdf (arguing that although numerous terms besides "climate engineering" have been used to refer to these activities, including "climate remediation," "climate intervention," and "geoengineering," the Chair of the House Committee on Science and Technology finds that

consequences of planetary warming and reduce atmospheric carbon.[6] The United States should establish a comprehensive scheme to encourage research and regulation of geoengineering, because current environmental laws, targeted to pollution, do not address it.[7] The United States should prohibit the implementation of geoengineering until absolutely necessary, if ever.[8]

Part II of this Article explores the factors that make continued climate change inevitable. It next discusses climate engineering technologies and their anticipated benefits and risks. Part III reviews the domestic and international laws that might control climate engineering research and testing in the United States. Finally, Part IV presents considerations for a regulatory scheme that would foster the research and testing of climate engineering and may serve as a model for an international program.

II. Mitigation Alone Will Not Avert Significant Climate Change

Human-sourced emissions of greenhouse gases are causing significant climate change.[9] We can now anticipate that we will take longer and be less successful in reducing these emissions than will be necessary to avoid significant alteration of the climate.[10] As a result, we will inevitably need to expand the set of tools to which we can turn to combat climate

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"climate engineering" better communicates the concept to policymakers and the public) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

6. *See id.* (addressing the scientific community's concerns regarding climate change and suggesting geoengineering as a potential tool).

7. *See* U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-10-903, CLIMATE CHANGE: A COORDINATED STRATEGY COULD FOCUS FEDERAL GEOENGINEERING RESEARCH AND INFORM GOVERNANCE EFFORTS 26 (2010) [hereinafter GAO], *available at* http://www.gao.gov/assets/320/310105.pdf (explaining that the extent to which existing laws apply to geoengineering is unclear because of the lack of information on geoengineering approaches and effects) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

8. *See generally* Lauren Morello, *At U.N. Convention, Groups Push for Geoengineering Moratorium*, SCIENTIFIC AMERICAN (Oct. 20, 2010), http://www.scientificamerican.com/article.cfm?id=at-un-convention-groups-push (discussing the reticence of European and other nations to use climate engineering until its impacts are better understood) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

9. *See* Solomon et al., *supra* note 3, at 1704 (noting that significant climate change is occurring "due to anthropogenic carbon dioxide already in the atmosphere").

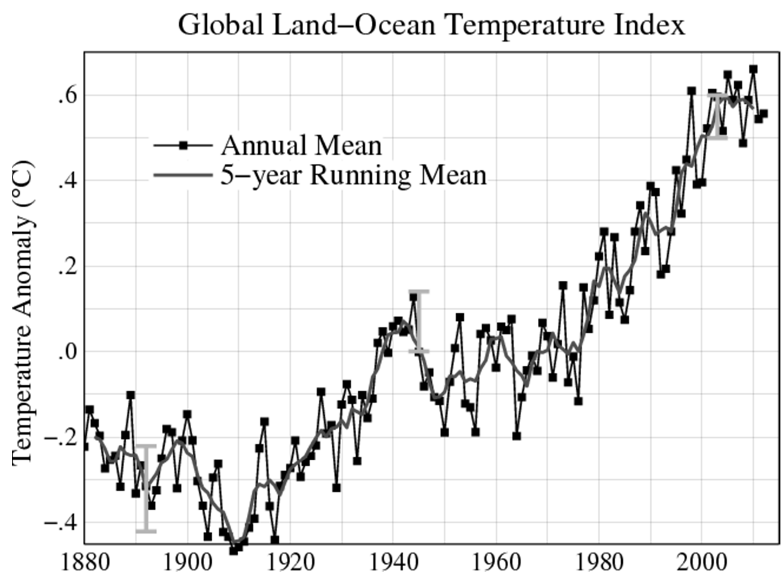
10. *See* ROYAL SOCIETY, *supra* note 5, at 1 (discussing the political, social, and scientific impediments that prevent mitigation from being an effective method of preventing climate change).

change and its consequences.[11] One of the tools that we need to consider more seriously is climate engineering.[12]

A. The Climate Is Changing

The Earth is warming.[13] Figure 1[14] illustrates the rise in annual mean temperatures since the late nineteenth century:

Figure 1



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11. *See id.* at ix ("Unless future efforts to reduce greenhouse gas emissions are much more successful than they have been so far, additional action may be required should it become necessary to cool the Earth this century.").

12. *See id.* at 4 ("Concerns regarding the slow progress on achieving emissions reductions, and uncertainties about climate sensitivity and climate tipping points have led some members of the scientific and political communities to suggest that geoengineering may offer an alternative solution to climate change mitigation.").

13. *See* National Climatic Data Center, *Global Climate Change Indicators*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, http://www.ncdc.noaa.gov/indicators (last visited Sept. 7, 2013) ("This page presents the latest information from several independent measures of observed climate change that illustrate an overwhelmingly compelling story of a planet that is undergoing global warming.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Goddard Institute for Space Studies, *GISS Surface Temperature Analysis*, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION [hereinafter GISS], http://data.giss.nasa.gov/gistemp/graphs_v3 (last visited Sept. 7, 2013) (tracking temperature changes from 1880 to 2010) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

14. *Id.*

The change between any individual year and another, however, may be unclear[15] or misleading,[16] because individual years are subject to the variability of the El Niño-La Niña cycle, volcanic eruptions, or other events.[17] The warming trend over years, particularly recent years, however, is especially meaningful because it shows that the hottest years on record have all occurred recently.[18] Indeed, all twelve years in the twenty-first century rank among the fourteen warmest in the 133-year period of record.[19]

Numerous Earth systems are manifesting the indirect consequences of this warming, such as extreme weather events, increasing ocean

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15. *See* Zeke Hausfather, *Global Temperature in 2010: Is it the Hottest Year on Record, and Does it Matter?*, THE YALE FORUM ON CLIMATE CHANGE AND THE MEDIA (Feb. 1, 2011), http://www.yaleclimatemediaforum.org/2011/02/global-temperature-in-2010-hottest-year (noting the six major institutions that report estimates of global temperature, and explaining that their calculations sometimes vary because of differences in the manner in which they extrapolate temperatures for regions with fewer monitoring stations, such as the poles) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

16. *See* Adam Voiland, *Despite Subtle Differences, Global Temperature Records in Close Agreement*, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (Jan. 13, 2011), http://www.nasa.gov/topics/earth/features/2010-climate-records.html (explaining that subtle differences between numbers fuel misconceptions of global warming, which is demonstrated when one compares 2009, the third warmest year, to 1998, 2002, 2003, 2006, and 2007, with the maximum difference between the years being 0.03 degrees Celsius, that the six years are virtually identical) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

17. *See* Adam Voiland, *2009: Second Warmest Year on Record; End of Warmest Decade*, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (Jan. 21, 2010), http://www.nasa.gov/topics/earth/features/temp-analysis-2009.html (providing examples of different factors, such as El Niño and La Niña weather events, that cause well-known weather fluctuations) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); *see also* CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS 287 (Susan Solomon et al. eds., 2007) [hereinafter IPCC], *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf (providing more information about the effects of El Niño on global temperatures).

18. *See* Hausfather, *supra* note 15 ("Combining both land and ocean temperatures shows that global temperatures over the past decade have been warming slightly faster than would otherwise have been expected given the prior temperature trend.").

19. *See* National Climatic Data Center, *State of the Climate Global Analysis—Annual 2012*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, http://www.ncdc.noaa.gov/sotc/global/2012/13 (last visited Sept. 21, 2013) ("Including 2012, all 12 years to date in the 21st century (2001–2012) rank among the 14 warmest in the 133-year period of record.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

temperatures, changes in precipitation patterns, and rising sea levels.[20] For example, the global mean sea level showed little change between 1 A.D. and 1900,[21] but it has risen since that time, and its rise is accelerating.[22] Scientists recognize two major causes of this rise: thermal expansion of the oceans and melting of land-based ice, such as glaciers.[23] Recession of glaciers is a strong indicator of climate change.[24] Available data, collected since the 1800s, reveals a considerable reduction in glacier size from 1850 until the 1970s, when glacier thickness stabilized.[25] The rate of loss has accelerated since the 1990s.[26]

B. The Rise in the Planet's Temperature Will Continue and Accelerate

Even if we eliminate the anthropogenic sources[27] of global warming immediately and completely, the global temperature will continue

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20. *See* National Climatic Data Center, *supra* note 13 ("The warming trend [is] . . . confirmed by other independent observations, such as the melting of mountain glaciers on every continent, reductions in the extent of snow cover, earlier blooming of plants in spring, a shorter ice season on lakes and rivers, ocean heat content, reduced arctic sea ice, and rising sea levels.").

21. *See id.* ("Global mean sea level has been rising at an average rate of approximately 1.7 mm/year over the past 100 years . . . which is significantly larger than the rate averaged over the last several thousand years."); *see also* IPCC, *supra* note 17, at 409 (tracking global sea level changes starting from the end of the last ice age and offering projections of future sea level changes).

22. *See* IPCC, *supra* note 17, at 409 (explaining past and future increases in global sea level).

23. *See id.* ("The two major causes of global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting.").

24. *See* WORLD GLACIER MONITORING SERVICE & UNITED NATIONS ENVIRONMENT PROGRAMME, GLOBAL GLACIER CHANGES: FACTS AND FIGURES 13 (2008), *available at* http://www.grid.unep.ch/glaciers/pdfs/glaciers.pdf (stating that glacier changes are regarded as a valuable climate indicator and detection tool).

25. *See* IPCC, *supra* note 17, at 357 (following glacier changes starting in the 1800s).

26. *See* M. Zemp, M. Hoelzle & W. Haeberli, *Six Decades of Glacier Mass-Balance Observations: A Review of the Worldwide Monitoring Network*, 50 ANNALS OF GLACIOLOGY 101, 106 (2009) (tracking changes in glacier melt, including the accelerated rate of loss between 1985 and the present).

27. *See* J. Lastovicka et al., *Global Change in the Upper Atmosphere*, 314 SCIENCE 1253, 1254 (2006) (naming the increase in carbon emissions since the start of the Industrial Revolution as the primary instigator of climate change and noting that the upper atmosphere is cooling while the lower atmosphere is warming because carbon in the lower atmosphere creates the "greenhouse effect"); *see also* IPCC, *supra* note 17, at 139 (explaining that carbon emissions from burning fossil fuels include more 12C isotopes than 13C isotopes at a rate that would not otherwise occur in nature, and that the ratio of 12C isotopes to 13C isotopes in the atmosphere has increased at a rate consistent with that of CO_2 emissions from fossil origin); Gerald A. Meehl et al., *Combinations of Natural and Anthropogenic Forcings in Twentieth-Century Climate*, 17 J. CLIMATE 3721, 3723–24 (2004) (stating that the rate and

to rise for decades before it stabilizes.[28] Several factors will cause this continued rise.[29] First, carbon dioxide (CO_2), which remains in the atmosphere for centuries, will continue to trap heat.[30] Second, the thermal inertia of the Earth's oceans means that they absorb heat and radiate it gradually, for hundreds of years.[31] Second, feedbacks increase the rate of global warming.[32]

First, although natural processes, such as photosynthesis and absorption by ocean waters, remove some of the anthropogenic CO_2 that is released into the atmosphere, these processes cannot remove all such CO_2, meaning that CO_2 will continue to accumulate in the atmosphere.[33] Moreover, natural processes become less successful at removing CO_2 as

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extremity of climate change cannot be explained without accounting for anthropogenic influences, as simulations of global temperatures including only natural influences project global temperatures that remain largely flat and only simulations that include human sources track the actual warming that has occurred since the 1970s). This evidence has allowed climate scientists to conclude that climate change is anthropogenic.

28. *See* Solomon et al., *supra* note 3, at 1704 (explaining that even if all emissions ceased, atmospheric temperatures would not drop significantly for at least one-thousand years).

29. *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT 36–38 (2007) [hereinafter CLIMATE CHANGE 2007], *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf (discussing long-lived greenhouse gas emissions and other factors of climate change, such as land cover, solar radiation, and feedbacks).

30. *See* David Archer et al., *Atmospheric Lifetime of Fossil Fuel Carbon Dioxide*, 37 ANN. REV. EARTH PLANET SCI. 117, 131 (2009) ("[T]he ocean will absorb most of [anthropogenic CO_2] on a timescale of 2 to 20 centuries.").

31. *See generally* James Hansen, et al., *Target Atmospheric CO_2: Where Should Humanity Aim?*, 2 OPEN ATMOSPHERIC SCI. J. 217 (discussing the role of the ocean's thermal inertia in earth temperatures as it relates to reductions in GHGs).

32. *See* Daniel A. Lashof, Benjamin J. DeAngelo, Scott R. Saleska & John Harte, *Terrestrial Ecosystem Feedbacks to Global Climate Change*, 22 ANN. REV. ENERGY ENV'T 75, 78–81 (1997) (defining the feedback process as that whereby change in one variable (such as CO_2 concentration) causes change in temperature, which causes change in a third variable (such as water vapor), which in turn causes further change in temperature). Feedbacks can either increase (positive feedback) or reduce (negative feedback) the system's response to outside variables. *Id*. at 1. An example of a negative feedback is the increase in low clouds caused by increased evaporation, which reflect sunlight, mitigating global warming. *Id.*

33. *See* CLIMATE CHANGE 2007, *supra* note 29, at 36–38 ("Warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback leads to larger atmospheric CO_2 increases and greater climate change for a given emissions scenario."); *see also* IPCC, *supra* note 17, at 512 ("Natural processes such as photosynthesis, respiration, decay and sea surface gas exchange lead to . . . a small net uptake of CO_2 . . . , partially offsetting the human-caused emissions.").

emissions increase,[34] and climate change itself suppresses carbon absorption by both land and ocean processes.[35]

Second, because of the thermal inertia of the Earth's oceans, the global temperature will continue to rise, even if carbon emissions were to cease.[36] Thus, the warming currently experienced is only about sixty percent of the warming that would be expected at the atmosphere's current level of CO_2 concentration.[37] For this reason, were society to stop emitting all carbon today, the planet's temperature would not immediately return to pre-industrial levels or even stabilize.[38] Actually, the temperature would continue to increase for a few decades,[39] and only then remain at that new level for at least one thousand years.[40]

Third, not only will global warming continue for several decades, but the rate of warming will increase due to carbon-cycle feedback cycles that accelerate warming.[41] Indeed, models suggest that feedbacks will more

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34. *See* IPCC, *supra* note 17, at 538 ("The CO_2 increase alone will lead to continued uptake by the land and the ocean, although the efficiency of this uptake will decrease through the carbonate buffering mechanism in the ocean, and through saturation of the land carbon sink.").

35. *See id.* ("Climate change alone will tend to suppress both land and ocean carbon uptake, increasing the fraction of anthropogenic CO_2 emissions that remain airborne and producing a positive feedback to climate change.").

36. *See* Solomon et al., *supra* note 3, at 1704 (explaining the effects of existing atmospheric carbon on global temperatures even if emissions cease); *see also* Marten Scheffer, Victor Brovkin & Peter M. Cox, *Positive Feedback Between Global Warming and Atmospheric CO_2 Concentration Inferred from Past Climate Change*, GEOPHYSICAL RES. LETTERS, May 26, 2006, at 1 (illustrating the effects of feedbacks on climate change, and how the release of CO_2 raises global temperatures, which prompts the release of additional greenhouse gases, and thus the rise of CO_2 appears to lag increases in temperature).

37. *See* David Archer & Victor Brovkin, *The Millennial Atmospheric Lifetime of Anthropogenic CO_2*, 90 CLIMATIC CHANGE 283, 289 (2008) ("The warming we have experienced so far today is only about 60% of the equilibrium warming expected at today's atmospheric CO_2 value.").

38. *See* H. Damon Matthews & Ken Caldeira, *Stabilizing Climate Requires Near-Zero Emissions*, GEOPHYSICAL RES. LETTERS, Feb. 27, 2008, at 1 (stating that the warming caused by existing atmospheric carbon will remain for centuries even without further emissions).

39. *See id.* ("Model simulations have demonstrated that global temperatures continue to increase for many centuries beyond the point of CO_2 stabilization."); *see also* IPCC, *supra* note 17, at 822 (providing predictions of future global temperature changes, estimating that if the composition of the atmosphere were to be held constant, the global temperature would still rise by up to 0.9° C by the end of the twenty-first century).

40. *See* Solomon et al., *supra* note 3, at 1704 (claiming that increases in temperature will not drop for at least one thousand years).

41. *See* Peter M. Cox, Richard A. Betts, Chris D. Jones, Steven A. Spall & Ian J. Totterdell, *Acceleration of Global Warming Due to Carbon-Cycle Feedbacks in a Coupled Climate Model*, 408 NATURE 184, 184 (2000) ("[C]arbon-cycle feedbacks could significantly accelerate climate change over the twenty-first century.").

than double the direct effect of increasing CO_2 levels without feedbacks.[42] For example, feedbacks are accelerating the rate at which the Arctic ice cap melts.[43] As the global temperature has warmed, less snow has fallen on the Arctic ice cap.[44] Because snow reflects approximately eighty-five percent of the sunlight that it receives,[45] snow acts as sunscreen for ice. The decline in snowfall has exposed ice to sunlight, which increases melting.[46] As the melting increases, the planetary surface albedo[47] decreases, thus prompting greater melting.[48] Ocean waters absorb almost ten times more solar radiation than does sea ice,[49] thereby increasing temperatures.[50]

Additional feedbacks will accelerate the rate at which the atmosphere warms.[51] Such feedbacks include, among others, the increase of

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42. *See* NAT'L RESEARCH COUNCIL, UNDERSTANDING CLIMATE CHANGE FEEDBACKS 16 (2003) ("Climate models suggest that the temperature change enhancement associated with feedback processes is greater than the temperature change resulting from the direct effect of the carbon dioxide doubling without feedbacks.").

43. *See* Archer & Brovkin, *supra* note 37, at 291 ("There are reasons to believe that real ice sheets might be able to collapse more quickly than our models are able to account for . . . .").

44. *See* U. OF MELBOURNE, *More Rain, Less Snow Leads to Faster Arctic Ice Melt*, MELBOURNE NEWSROOM (July 2, 2011), http://newsroom.melbourne.edu/news/n-572 (last visited Sept. 8, 2013) ("[D]ue to warming temperatures, on more days of the year and in more parts of the polar region, temperatures are becoming too warm for protective snow to form.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

45. *See id.* ("Snow is highly reflective and bounces up to 85 percent of the incoming sunlight back into space." (internal quotations omitted)).

46. *See id.* (discussing snow protection of Artic ice and the increased exposure and melt resulting from decreased snowfall).

47. *See* IPCC, *supra* note 17, at 941 (defining albedo as "the fraction of solar radiation reflected by a surface or object" and noting that snow has a high albedo, while oceans and vegetation-covered surfaces have low albedos).

48. *See* M. Tedesco, et al., *The Role of Albedo and Accumulation in the 2010 Melting Record in Greenland*, 6 ENV'T RES. LETTERS 1, 2 (2011) (linking decreases in surface albedo to increases in ice melt).

49. *See* Alicia Newton, *The Big Melt*, 1 NATURE REPORTS: CLIMATE CHANGE 93, 93 (2007), *available at* http://www.nature.com/climate/2007/0712/pdf/ngeo.2007.31.pdf ("Open ocean waters absorb almost ten times more solar radiation than sea ice—a phenomenon known as the ice-albedo feedback."); s*ee also* James A. Screen & Ian Simmonds, *Declining Summer Snowfall in the Arctic: Causes, Impacts and Feedbacks*, 38 CLIMATE DYNAMICS 1, 1 (2011), *available at* http://www.springerlink.com/content/84078356qupn28g6 (comparing the relationship between the decline of snowfall and the decline of sea ice-cover).

50. *See id.* ("[T]he Arctic is expected to warm particularly strongly, because of the albedo feedback from melting the Arctic ice cap.").

51. *See* Tom Clarke, *Feedback Could Warm Climate Fast*, NATURE (May 23, 2003), http://www.nature.com/news/1998/030519/full/news030519-9.html (naming various feedbacks involving "volcanoes belching out millions of tonnes of carbon dioxide, fluctuations in the Sun's activity as well as changing levels of greenhouse gas and ozone")

water vapor,[52] the weakening of carbon sinks,[53] and the impairment of terrestrial hydrology and its impact on vegetation.[54]

C. Mitigation Alone Is Unlikely to Avert Significant Climate Change

For several reasons, mitigation alone is unlikely to be sufficient to prevent significant climate change. First, international agreements to reduce emissions have had limited success, and are unlikely to be successful in the future.[55] Second, implementation of alternative energy technologies is unlikely to take effect soon enough to avert significant temperature increases.[56] Finally, scientists now believe that initial targets for acceptable warming were too lenient, necessitating a stronger response to climate change than previously anticipated.[57]

To avoid catastrophic climate change, international agreements have set goals to reduce greenhouse gas emissions.[58] The United Nations

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(on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

52. *See* NAT'L RESEARCH COUNCIL, s*upra* note 42, at 2 ("Water vapor feedback is the most important positive feedback in climate models. It is important in itself, and also because it amplifies the effect of every other feedback and uncertainty in the climate system.").

53. *See* H. Damon Matthews & David W. Keith, *Carbon-Cycle Feedbacks Increase the Likelihood of a Warmer Future*, GEOPHYSICAL RES. LETTERS, May 4, 2007, at 1 ("Climate changes will likely weaken carbon sinks, leading to positive carbon-cycle feedbacks . . . .").

54. *See* NAT'L RESEARCH COUNCIL, s*upra* note 42, at 60 (reporting on terrestrial hydrology's role in climate change feedbacks).

55. *See* Kiel Institute, *International Climate Policy*, ACADEMY: THE ENVIRONMENT AND NATURAL RESOURCES, http://www.ifw-kiel.de/academy/the-environment-and-natural-resources/european-and-international-climate-policy (last visited Sept. 9, 2013) (analyzing climate change policies for effectiveness) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

56. *See* Solomon et al., *supra* note 3, at 1704 (explaining that climate changes caused by carbon presently in the atmosphere are irreversible).

57. *See* Bill McKibben, *Global Warming's Terrifying New Math*, ROLLING STONE (July 19, 2012), http://www.rollingstone.com/politics/news/global-warmings-terrifying-new-math-20120719 (discussing the agreed two degree-Celsius limit on global warming as too lenient, as smaller temperature increases have already caused a great deal of damage) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

58. *See* United Nations Framework Convention on Climate Change, *Action on Mitigation: Reducing Emissions and Enhancing Sinks*, FOCUS: MITIGATION, http://unfccc.int/focus/mitigation/items/7171.php (last visited Sept. 8, 2013) (describing international initiatives and agreements focused on mitigation) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); *see also* Kyoto Protocol, *infra* note 61 (citing a treaty in which countries agree to limit greenhouse gas emissions).

Framework Convention on Climate Change (UNFCCC)[59] set an overall framework for intergovernmental efforts to address climate change.[60] In 1997, the parties to the UNFCCC developed the Kyoto Protocol,[61] which committed industrialized nations to achieve reductions in greenhouse gas emissions by 2012.[62] These countries committed themselves to collective reductions averaging more than five percent from 1990 emissions levels.[63] Unfortunately, emissions have continued their upward trajectory.[64] As of 2007, their collective emissions had dropped only 1.4% below their 1990 emissions.[65] At the same time, emissions from the non-industrialized countries had increased by 100.6% over 1990 levels, so that combined

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59. United Nations Framework Convention on Climate Change, May 9, 1992, 1771 U.N.T.S. 107.

60. *See generally Background on the UNFCCC: The International Response to Climate Change*, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, http://unfccc.int/essential_background/items/6031.php (last visited Sept. 9, 2013) ("In 1992, countries joined . . . [the UNFCCC] to cooperatively consider what they could do to limit average global temperature increases and the resulting climate change, and to cope with whatever impacts were, by then, inevitable.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

61. *See* Kyoto Protocol to the United Nations Framework Convention on Climate Change, *opened for signature* Mar. 16, 1998, 2303 U.N.T.S. 162 [hereinafter Kyoto Protocol]; *Background on the UNFCCC: The International Response to Climate Change*, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, http://treaties.un.org/doc/publication/UNTS/Volume%202303/v2303.pdf (last visited Sept. 9, 2013) ("By 1995, countries realized that emission reductions provisions in the Convention were inadequate. They launched negotiations to strengthen the global response to climate change, and, two years later, adopted the Kyoto Protocol.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

62. *See* Kyoto Protocol, *supra* note 61, at art. III, ¶ 1 (stating that the parties shall reduce their "aggregate anthropogenic carbon dioxide equivalent emissions" of greenhouse gases, with a "view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012").

63. *See* United Nations Climate Change Convention Press Release: Industrialized Countries to Cut Greenhouse Gas Emissions by 5.2% (Dec. 11, 1997), http://unfccc.int/cop3/fccc/info/indust.htm ("After 10 days of tough negotiations, ministers and other high-level officials from 160 countries reached agreement this morning on a legally binding Protocol under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2%.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

64. *See* JOS G.J. OLIVIER, GREET JANSSENS-MAENHOUT & JEREON A.H.W. PETERS, TRENDS IN GLOBAL CO_2 EMISSIONS 2012 REPORT 6 (2012) (detailing the increase in global carbon dioxide emissions).

65. *See* Kyoto-Related Fossil-Fuel CO_2 Emission Totals, CARBON DIOXIDE INFORMATION ANALYSIS CTR. (Jan. 16, 2013), http://cdiac.ornl.gov/trends/emis/annex.html (providing measurements of annual emissions produced by countries listed on the Kyoto Protocol Annex B, as well as countries not listed on Annex B, for the years 1990–2009) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

global emissions had increased by 34.7% since 1990.[66] As discussed below in Part IV, similar efforts are likely to be unsuccessful in the future.

Second, even if nations decide to reduce CO_2 emissions, structural aspects of the energy industry, which generates one-quarter of global greenhouse gases,[67] will require decades to convert a significant portion of the industry to clean technologies.[68] Although society adopts certain technologies with lightning rapidity,[69] conversion to new energy technologies occurs much more slowly.[70] Indeed, two "laws" of energy-technology development dictate that the energy industry requires several decades to adopt and implement new technologies.[71] On average, energy

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66. *See id.* (comparing industrialized countries with non-industrialized countries).

67. *See* United Nations Environment Programme, *World Greenhouse Gas Emissions by Sector*, GRID-ARENDAL (Feb. 16, 2012) [hereinafter UNEP], http://maps.grida.no/go/graphic/world-greenhouse-gas-emissions-by-sector (providing a graph illustrating world greenhouse gas emissions by sector) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

68. *See* UNITED NATIONS ENV'T PROGRAMME, EMISSIONS GAP REPORT 2012 4 (2012) (considering the problems shifting the energy industry to less carbon-intensive methods, which is "locked in" in a number of other aspects of society, such as buildings, transportation systems, factories, and other infrastructure); State and Local Climate and Energy Program, *Renewable Energy*, ENVTL. PROT. AGENCY, http://www.epa.gov/statelocalclimate/state/topics/renewable.html (last visited Sept. 9, 2013) (discussing price barriers on renewable energy sources, including unfavorable utility rate structures, lack of interconnection standards, barriers in environmental permitting, and lack of transmission) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

69. *See* Michael DeGusta, *Are Smart Phones Spreading Faster than Any Technology in Human History?*, TECHNOLOGY REVIEW (May 9, 2012), http://www.technologyreview.com/news/427787/are-smart-phones-spreading-faster-than-any/# (providing that landline phones required almost a full century to reach saturation (the point at which demand falls off), whereas mobile phones achieved this level in 20 years, suggesting that smart phones might reach saturation in half that time, and tablet computers even faster) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

70. *See* Michael E. Webber, Roger D. Duncan & Marianne Shivers Gonzales, *Four Technologies and a Conundrum: The Glacial Pace of Energy Innovation*, ISSUES IN SCIENCE AND TECHNOLOGY, http://www.issues.org/29.2/Webber.html (last visited Sept. 9, 2013) (stating that the transition to renewable energy sources will be slow) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

71. *See* Gert Jan Kramer & Martin Haigh, *No Quick Switch to Low-Carbon Energy*, 462 NATURE 568, 568 (2009) (explaining the two laws of energy-technology deployment: (i) new energy technologies expand exponentially for several decades until they become "material," i.e., provide approximately one percent of world energy; (ii) after reaching materiality, growth rates then proceed linearly); *see also* Joseph J. Romm, *The Proposition's Opening Statement*, THE ECONOMIST (Aug. 19, 2008), http://www.economist.com/node/11918864 (discussing the possibility of the commercial introduction of low-carbon energy technologies; average time for an energy technology to reach a one percent share is twenty-five years, which follows a transition from scientific

technologies have required thirty years to advance from being technically available to reaching materiality.[72] This pattern was consistent across all technologies, including nuclear power, natural gas, biofuels, wind, and solar photovoltaic.[73]

Figure 2[74] below illustrates that several energy technologies grew during the last century in accordance with these "laws":

Figure 2

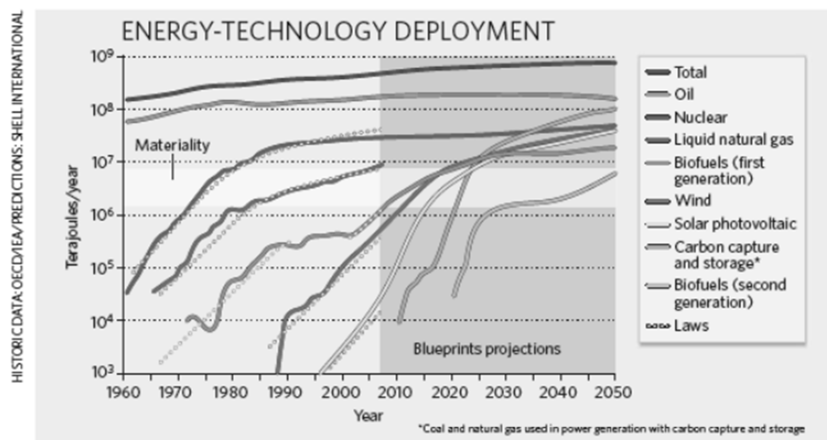

Figure 1 | Global production of primary energy sources. When a technology produces 1,000 terajoules a year (equivalent to 500 barrels of oil a day), the technology is 'available'. It can take 30 years to reach materiality (1% of world energy mix). Projections after 2007 taken from Shell's Blueprints scenario[3].

Adoption of new technologies in the energy field requires significant time because of several inherent characteristics of the power industry. First, historical patterns show that the industry needs almost a full decade to build and test new technologies: three years to build a demonstration plant, one year to commence operations, and two to five

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breakthrough to commercial introduction that may take decades) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

72. *See* Kramer & Haigh, *supra* note 71, at 568 ("In the twentieth century, it took 30 years for energy technologies that were available in principle to grow exponentially and become widely available.").

73. *See id.* (stating that the pattern of slow commercial availability of energy technologies was remarkably consistent across all technologies); *id.* at 569 ("The challenge in the decades ahead is to match, perhaps even outperform, the historic 'laws' by designing energy policies directed at decarbonizing the energy industry."); *see also* Peter Lund, *Market Penetration Rates of New Energy Technologies*, 34 ENERGY POL'Y 3317, 3321–22 (2006) (providing a separate analysis projecting that the time for solar photovoltaic and wind energy sources to grow from providing one percent of their total energy potential to fifty percent will be nearly thirty years).

74. Kramer & Haigh, *supra* note 71, at 569.

years to identify problems and reach satisfactory operability.[75] Second, massive amounts of capital must be invested to alter significantly the mix of energy sources,[76] amounts that dwarf the scale of the industry.[77] Third, once a technology reaches materiality, growth rates flatten (see Figure 3).[78] This growth trend results in part from the nature of energy infrastructure. Power plants have average lives of twenty-five to fifty years, though some have operational lives of up to 100 years.[79] Consequently, only two to four percent of existing sources require replacement in a given year.[80] Besides replacing power plants, conversion to renewable energy systems will often require other developments, such as land acquisitions, different transmission methods, enabling technologies, market systems, and other changes, which may not yet be foreseeable.[81]

Royal Dutch Shell projected that renewable sources of energy could reach materiality by 2030, sooner than others have forecast.[82] Royal Dutch Shell further projected that by 2050 total energy demand would be

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75. *See id.* at 568 (explaining that energy technology relies on conversion processes and that the wind power required decades to develop, produce, purchase, and deploy the new turbines at the scale required to generate one percent of the country's energy).

76. *See id.* (stating that it takes a few hundred billion dollars to bring a new technology to materiality).

77. *See id.* ("You cannot just spend $1 trillion overnight in a $30-billion industry.").

78. *See id.* ("After reaching materiality, growth curves have historically leveled off.").

79. *See id.* ("Unlike consumer goods that may become obsolete in a few years, the capital goods of the energy system have a lifetime of 25–50 years.").

80. *See id.* ("[T]he capital goods of the energy system have a lifetime of 25–50 years. That means only 2–4% of existing technology needs replacing in a given year."); Bryan K. Mignone, Robert H. Socolow, Jorge L. Sarmiento & Michael Oppenheimer, *Atmosphere Stabilization and the Timing of Carbon Mitigation*, 88 CLIMATIC CHANGE 252, 255 (2008) (explaining that development of new technology provides another incentive to plant owners to defer early retirement and subsequent construction of new plants; technological advancements discourage plant owners from committing themselves to current technologies and running the risk of locking themselves into expensive, yet soon-to-be-outdated, methods); *see also id.* at 252 n.3 (describing how the tendency toward economic postponement are somewhat mitigated by how quickly expensive technology is advancing).

81. *See* Karsten Neuhoff, *Large Scale Deployment of Renewables for Electricity Generation*, 21 OXFORD REV. ECON. POL'Y 7–9 (2005) (detailing the marketplace and non-marketplace barriers to conversion to renewable energy); Mark A. Delucchi & Mark Z. Jacobson, *Providing All Global Energy with Wind, Water, and Solar Power, Part II: Reliability, System and Transmission Costs, and Policies*, 39 ENERGY POL'Y 1170, 1171 (2011) (offering various developments that could enable renewable energy to be a viable source of power).

82. *See* SHELL INT'L BV, SIGNALS AND SIGNPOSTS: SHELL ENERGY SCENARIOS TO 2050 [hereinafter SHELL INT'L] 57 chart 8 (2011) (depicting the anticipated date different energy sources will reach maturity) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

one-third lower than a business-as-usual scenario.[83] Even if these projections are correct, CO_2 concentrations would not stabilize until they reached 550 ppm.[84]

Not only are we unlikely to meet current emissions targets, but scientists now believe that even these targets are not stringent enough.[85] Despite mitigation efforts during the past three decades, atmospheric CO_2 concentrations have risen steadily.[86] Figure 3[87] presents the atmospheric concentration of CO_2 since 1980:

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83. *See* Kramer & Haigh, *supra* note 71, at 569 (hypothesizing that by 2050 total energy demand will be a third lower than business-as-usual projections, mostly because of enhanced efficiency and electric vehicles).

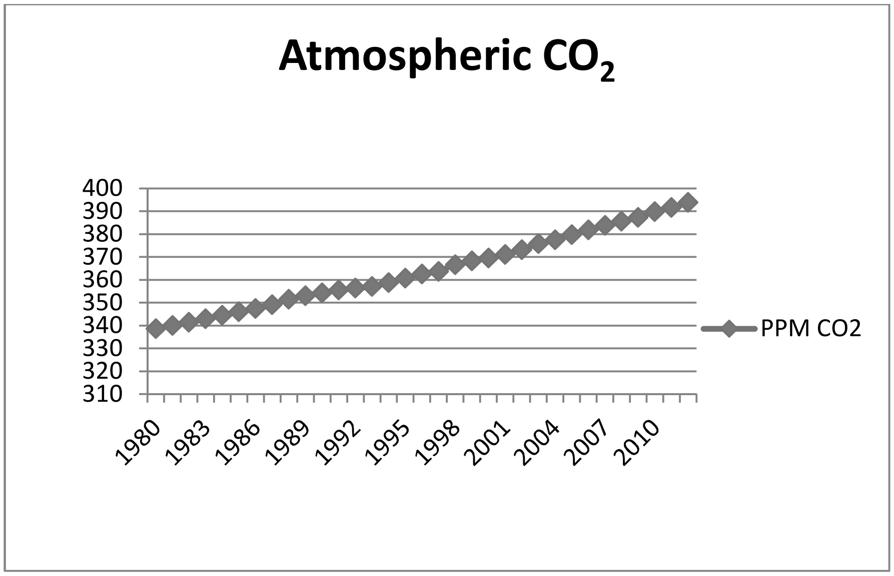
84. *See id.* ("We believe that the Blueprints scenario is the best we can reasonably hope to achieve for new energy deployment, yet in it, by 2050 two-thirds of the world energy supply still comes from fossil fuels and CO_2 concentrations stabilize at around 550 p.m."); *see also* Ailun Yang & Yiyun Cui, *Global Coal Risk Assessment: Data Analysis and Market Research* 5, tbl. I.i (World Resources Inst. Working Paper, Nov. 2012) (explaining that increased emissions are foreseeable in part because nearly 1,200 coal-fired power plants (including 360 in China and 450 in India) have been proposed to be built) (on file with the Washington and Lee Journal of Energy, Climate, and the Environment).

85. *See* Marco Steinacher, Fortunat Joos & Thomas F. Stocker, *Allowable Carbon Emissions Lowered by Multiple Climate Targets*, 499 Nature 197, 197 (2013) (stating that the climate targets are unable to limit the risks from anthropogenic emissions sufficiently).

86. *See Greenhouse Gas Index Continues Climbing*, National Oceanic and Atmospheric Administration (Nov. 9, 2011), http://www.noaanews.noaa.gov/stories2011/20111109_greenhousegasindex.html (detailing increases in greenhouse gases) (on file with the Washington and Lee Journal of Energy, Climate, and the Environment).

87. *See ESRL Data*, National Oceanic and Atmospheric Administration, ftp://ftp.cmdl.noaa.gov/ccg/co2/trends/co2_annmean_mlo.txt (last visited Dec. 30, 2013) [hereinafter ESRL Data] (compiling measurements of CO_2 expressed as a mole fraction in dry air for the period 1959–2012) (on file with the Washington and Lee Journal of Energy, Climate, and the Environment).

Figure 3



During this period, atmospheric CO_2 increased from 338.7 ppm to 393.8 ppm, a rise of 16.3%.[88] Atmospheric CO_2 increased every year.[89] Furthermore, the annual increase in CO_2 is actually rising.[90] Since 2002, annual CO_2 concentrations have increased on average by 2 ppm per year.[91]

Thus, not only are targets in international agreements too difficult to achieve,[92] they may also be too lenient.[93] The following example

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88. *See Trends in Atmospheric Carbon Dioxides*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, http://www.esrl.noaa.gov/gmd/ccgg/trends/ (last visited Oct. 20, 2013) (describing calculation of mean growth rates) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

89. ESRL Data, *supra* note 87.

90. *See* Lee R. Kump, *The Last Great Global Warming*, SCIENTIFIC AMERICAN, July 2011, at 57, 60, *available at* http://physics.ucf.edu/~britt/Climate/Reading1-Last%20great%20warming.pdf (explaining that scientists calculate this rate of atmospheric carbon dioxide increase as possibly ten times faster than carbon dioxide rose leading up to the Paleocene-Eocene Thermal Maximum, the last major planetary warming, when temperatures rose by five degrees Celsius).

91. *See Annual Data: Atmospheric CO_2*, CO_2 NOW, http://co2now.org/current-co2/co2-now/annual-co2.html (last visited Sept. 9, 2013) ("For the past decade (2003–2012) the average annual increase is 2.1 ppm per year.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

92. *See* SHELL INT'L, *supra* note 82, at 66 (discussing the probable difficulty in nations with such varied background and goals agreeing on a plan to control climate change).

illustrates the obstacles that prevent abatement of atmospheric levels of CO_2. At the 2010 UN Climate Change Summit in Cancun, the delegates agreed to limit warming to a global mean temperature increase of two degrees Celsius,[94] which requires an atmospheric content of 450 ppm of CO_2.[95] To achieve this target, global emissions immediately need to begin declining by more than one percent per year,[96] in contrast to the annual global increase.[97] Small delays in emissions cuts, moreover, necessitate much larger reductions in future emissions.[98] Delay causes the atmospheric CO_2 to peak higher and later, thus necessitating much sharper cuts to attain the same level.[99] For this reason, stabilization at 450 ppm appears to be "virtually impossible even if aggressive mitigation were to begin today."[100]

Thus, not only are targets in international agreements too difficult to achieve,[101] these targets may also be too lenient.[102] Scientists have set a rise of two degrees Celsius as a target to avert catastrophic consequences.[103]

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93. *See id.* (arguing that the Copenhagen Accord failed to set effective targets).

94. *See* The Cancun Agreements, UNFCCC (Dec. 11, 2010), http://cancun.unfccc.int/cancun-agreements/main-objectives-of-the-agreements/#c33) (last visited Oct. 4, 2013) (stating that a main objective is to keep global average temperature rise below two degrees) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

95. *See* IPCC, *supra* note 17, at 826 (explaining that the best calculation for atmospheric content of 450 ppm would be a temperature increase of no more than two degrees).

96. *See* Mignone et al., *supra* note 80, at 251 (projecting that a decline in emissions by one percent would achieve a 475 ppm CO_2 level).

97. *See* UNEP, *supra* note 67, at 3 (indicating that global emissions must peak before 2020 to have a "likely" chance of staying within the two degrees Celsius target and describing the two degrees Celsius target as "highly unrealistic"); s*ee also Current Rates of Decarbonisation Pointing to 6°C of Warming*, PRICEWATERHOUSECOOPERS (Nov. 5, 2012) http://press.pwc.com/GLOBAL/News-releases/current-rates-of-decarbonisation-pointing-to-6oc-of-warming/s/47302a6d-efb5-478f-b0e4-19d8801da855) (stating that current rates of decarbonization point to six degrees Celsius of warming) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

98. *See* Mignone et al., *supra* note 80, at 253 ("We find that the marginal rate of substitution between future and present mitigation . . . becomes quite large when the decline rate increases beyond 1 or 2% per year, meaning that small increases in delay necessitate very large increases in the intensity of future mitigation.").

99. *See id.* at 256 ("[T]he peak atmospheric concentration would increase by 6.6 ppm if mitigation were delayed 1 year.").

100. *Id.*; *see also* SHELL INT'L, NEW LENS SCENARIOS: A SHIFT IN PERSPECTIVE FOR A WORLD IN TRANSITION (2013) (finding that Shell's most recent estimate projects that we will "overshoot" the 2° C goal) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

101. *See* SHELL INT'L, *supra* note 82, at 66 (discussing the probable difficulty in nations with such varied background and goals agreeing on a plan to control climate change).

102. *See id.* (arguing that the Copenhagen Accord failed to set effective targets).

103. *See* IPCC, *supra* note 17, at 826 (discussing the benefits of staying within a two degree global temperature increase).

Recent analyses, however, suggest that this rise would be too high.[104] Comparison to prehistoric records indicate that the current level of CO_2 (approximately 394 ppm) is already too high to maintain current planetary conditions.[105] Indeed, current analyses suggest that 2° C warming may cause significant sea-level rises, storms, floods, droughts, and heat waves.[106] Maintaining climate conditions comparable to those of the Holocene Era, during which civilization developed, requires reducing the atmospheric CO_2 level to 350 ppm.[107]

Thus, the solution required must not merely *cut* emissions, but also *reduce* atmospheric carbon.

D. Climate Engineering: What It Is, and How It Can Help

The realities of climate change highlight two key considerations. First, significant climate disruption is foreseeable, regardless of future emission levels.[108] Second, mitigation alone cannot return the climate to its preindustrial state.[109] To avoid severe climate disruption, we need to explore a broad range of alternatives.[110] These alternatives should include climate engineering.

Climate engineering refers to efforts to intervene in the Earth's climate system to reduce temperature and to stabilize it at a lower level than would be obtained without intervention; it requires deliberate efforts and has global impacts.[111] Thus, it involves both deliberate efforts and global impacts to be effective.

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104. *See* Hansen et al., *supra* note 31, at 217 (arguing that a limitation of one degree Celsius, as opposed to the two degree goal, could prevent irreparable species and ice sheet loss) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

105. *See id.* at 218 (calculating that even at the current level of atmospheric CO_2, additional warming is already "in the pipeline" because of planetary feedbacks, and estimating that the planet is committed to an additional 1.4° C of warming, a total increase of 2° C from preindustrial levels).

106. *See id.* at 225 (stating that even a small change in surface temperature could spur extreme environmental responses).

107. *See id.* at 229 (suggesting an initial goal of 350 ppm to return planetary balance).

108. *See* ROYAL SOCIETY, *supra* note 5, at ix (stating that emissions changes alone have not been successful in providing a solution to the global warming issue).

109. *See id.* (arguing that mitigation efforts will not be implemented quickly enough to make necessary changes needed to stunt global warming).

110. *See id.* ("Unless future efforts to reduce greenhouse gas emissions are much more successful then they have been so far, additional action may be required should it become necessary to cool the Earth this century.").

111. *See id.* (defining geoengineering as the "deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming").

Climate engineering techniques fall into two broad categories. The first, solar radiation management (SRM), would reduce the amount of solar radiation available to heat the planet.[112] The second, carbon dioxide removal (CDR), would remove CO_2 from the atmosphere.[113] Within these two categories, climate engineering techniques may be further classified. First, they may be grouped according to the length of their life cycles: the effects of some would be short-lived and could be "shut off" almost immediately;[114]whereas the effects of other techniques might last for decades or even centuries.[115] Second, techniques vary by their means of intervention. Some methods require small-scale changes (painting roofs to reflect more sunlight, for example), whereas others involve the manipulation or enhancement of biological processes.[116] Finally, methods may be grouped according to the amount of time required before they take effect; certain types can begin to cool the planet within months, whereas others require decades.[117]

SRM techniques reflect the sun's inbound light and heat back into space.[118] They include a broad range of methods and costs; some SRM techniques are simplistic while others are technologically complex and

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112. *See id.* at 1 ("[SRM] methods: which reduce the net incoming . . . solar radiation received, by deflecting sunlight, or by increasing the reflectivity (albedo) of the atmosphere, clouds or the Earth's surface.").

113. *See id.* ("[CDR] methods: which reduce the levels of carbon dioxide (CO2) in the atmosphere, allowing outgoing long-wave (thermal infra-red) heat radiation to escape more easily.").

114. *See generally id.* (evaluating various geoengineering methods for "timeliness," which includes "the state of readiness for implementation . . . and the speed with which the intended effect (on climate change) would occur").

115. *See* Mark Williams, *Cooling the Planet*, M.I.T. TECH. REV. (Feb. 13, 2007), http://www.technologyreview.com/news/407306/cooling-the-planet/ (stating that the cost of climate engineering techniques would vary dramatically, with some, such as stratospheric aerosols, costing a few billion dollars, and others, such as space-based mirrors, requiring trillions of dollars) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); *see also* Virgoe, *infra* note, 146, at 108 (arguing that methods will also vary in their need for ongoing maintenance, some lasting a long time (painted roofs), and others requiring repetition (aerosols) or maintenance (space mirrors) on a regular basis).

116. *See* ROYAL SOCIETY, *supra* note 5, at 47 (stating that some improvements will be more simplistic in nature, while others will require industrial-scale developments).

117. *See* Peter Davidson, Chris Burgoyne, Hugh Hunt & Matt Causier, *Lifting Options for Stratospheric Aerosol Engineering: Advantages of Tethered Balloon Systems*, 370 PHIL. TRANS. R. SOC. A 4263, 4264 (2012) (stating the importance of analysis of anticipated timetables for different methods because some methods, such as CDR, might require up to fifty years to have an impact, whereas others, such as SRM techniques, could take effect within a few years).

118. *See* ROYAL SOCIETY, *supra* note 5, at 1 (explaining that SRM techniques work by deflecting sunlight or making the atmosphere more reflective).

prohibitively expensive.[119] They also vary as to the part of the environment which they affect—the earth's surface, its atmosphere, or outer space.[120] Surface-based techniques include painting roofs white, planting more reflective crops, or covering desert or ocean surfaces with reflective materials.[121] Atmospheric methods increase the reflectivity of clouds[122] or mimic the temporary, global cooling that results from the ejection of sulfur particles from volcanic eruptions[123] by injecting aerosol particles into the atmosphere.[124]

A major advantage of some SRM techniques is that they may be the only means to reduce the global temperature almost immediately, should that become necessary,[125] because they could take effect within a matter of months.[126] SRM, however, does not remove CO_2 from the atmosphere; it merely compensates for the increased levels of CO_2.[127] As a result, scientists anticipate SRM could have unintended consequences.[128] Scientists also believe that, once started, some SRM methods must be used

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119. *See* Roger Angel, *Feasibility of Cooling the Earth with a Cloud of Small Spacecraft near the Inner Lagrange Point (L1)*, 103 PROC. NATL. ACAD. SCI. 17184, 17188 (2006) (explaining that some space-based reflective mirrors, for instance, could require several decades and trillions of dollars to put into place).

120. *See* Peter J. Irvine, Andy Ridgwell & Daniel J. Lunt, *Climatic Effects of Surface Albedo Geoengineering*, J. GEOPHYSICAL RES., Dec. 22, 2011 at 2 (discussing how different geoengineering techniques affect different aspects of the environment).

121. *See id.* at 2 (summarizing crop, desert, and urban albedo geoengineering techniques).

122. *See* Angel, *supra* note 119, at 17185 (detailing the addition of particles of various materials, such as sea salt, to whiten clouds).

123. *See id.* at 17188 ("One way known to reduce heat input, observed after volcanic eruptions, is to increase aerosol scattering in the stratosphere.").

124. *See* David W. Keith, Edward Parson & M. Granger Morgan, *Research on Global Sun Block Needed Now*, 463 NATURE 426, 426 (2010), *available at* http://www.nature.com/nature/journal/v463/n7280/full/463426a.html ("SRM could alter the global climate within months—as suggested by the 1991 eruption of Mount Pinatubo, which cooled the globe about 0.5° C in less than a year by injecting sulphur dioxide into the stratosphere.").

125. *See* ROYAL SOCIETY, *supra* note 5, at 47 ("SRM methods are the only way in which global temperatures could be reduced at short notice, should this become necessary.").

126. *See* Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. & RES. ECON. 45, 47 (2008) (stating the albedo enhancement technique could lead to climate response in a matter of months).

127. *See id.* ("Geoengineering is a stopgap measure, a 'quick fix,' a 'Band-Aid.'").

128. *See* ROYAL SOCIETY, *supra* note 5, at 50 (explaining the varied responses of different aspects of climate; precipitation is sensitive to specific aspects of climate, while other natural systems are likely to have unforeseen reactions to decreased temperatures in high-CO_2 conditions).

continuously, or warming will return immediately and at a rate too fast for humans and animals to adapt.[129]

In contrast to SRM, CDR can reverse warming, since it reduces the atmosphere's CO_2 content.[130] However, reversal requires the reduction of a significant fraction of CO_2 before it alters the atmospheric balance.[131] Thus, in contrast to SRM, CDR may require several decades before it can have a discernible effect on the environment.[132] On the other hand, its ability to lower the CO_2 content of the atmosphere may become critical if significant mitigation efforts come too late to avoid dangerous warming.[133] Furthermore, CDR involves fewer environmental risks.[134] This contrasts with SRM, which, besides several possible adverse consequences, would only create an artificial and approximate balance between increased atmospheric gas concentrations and sunlight levels.[135]

CDR techniques involve the storage of CO_2 in the ocean or in the ground.[136] Ocean-based methods include ocean fertilization (promoting the

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129. *See* Alan Robock, Martin Bunzl, Ben Kravitz & Georgiy Stenchikov, *A Test for Geoengineering?*, 327 SCIENCE 530, 531 (Jan. 2010), *available at* http://www.sciencemag.org/content/327/5965/530.short (stating that when geoengineering is started and then stopped, climate change may occur more rapidly than if geoengineering was never attempted) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT). *See generally* Robert L. Olson, *Soft Geoengineering: A Gentler Approach to Addressing Climate Change*, ENV'T MAG., Sept./Oct. 2012, *available at* http://www.see.ed.ac.uk/~shs/Climate%20change/Geo-politics/Bright%20water.pdf (explaining that as a response to these objections, scientists have begun to explore "soft geoengineering" techniques, and, further, characteristics of these methods include multiple benefits beyond climate impact, low or no anticipated negative ecosystem effects, and rapid reversibility) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

130. *See* ROYAL SOCIETY, *supra* note 5, at ix ("Carbon dioxide removal techniques address the root cause of climate change by removing greenhouse gases from the atmosphere.").

131. *See id.* at x (explaining that the scale is an important component to the effectiveness of CDR methods).

132. *See id.* (stating that the effects of CDR methods will be felt long-term, without direct short-term benefits).

133. *See* UNEP, *supra* note 67, at 3 (calculating that forty percent of scenarios with a "likely" chance of meeting the two degree Celsius target have net negative total greenhouse emissions; these scenarios assume utilization of carbon capture and storage, a CDR technology).

134. *See* ROYAL SOCIETY, *supra* note 5, at x (explaining that the environmental effects of SRM methods are mostly unknown, leading to greater risk than CDR techniques).

135. *See* IPCC, *supra* note 17, at 4 (contrasting CDR and SRM techniques, particularly the potential negative effects of SRM, specifically that SRM would require long-term maintenance).

136. *See* ROYAL SOCIETY, *supra* note 5, at 9 ("A number of methods aimed at the direct removal of CO_2 from the atmosphere have been proposed, including . . . either chemical or

growth of carbon-consuming phytoplankton) and enhanced upwelling/downwelling (altering ocean circulation to increase the availability of nutrients to enhance phytoplankton growth (upwelling) while accelerating the return of CO_2-concentrated surface water to the deep sea (downwelling)).[137] Land-based techniques include direct air capture and sequestration, use of biomass and sequestration, and afforestation.[138]

Whether SRM or CDR, several aspects of climate engineering make it a compelling option: climate engineering is easier than mitigation to implement; it produces benefits sooner than other approaches, it is more politically viable, and it can reduce, rather than just stabilize, CO_2 levels.[139] For these reasons we should anticipate that one or more nations—or even private parties—will seriously consider implementing climate engineering methods.[140]

A key advantage of climate engineering over mitigation is that climate engineering would be much easier to institute effectively. Mitigation requires billions of consumers to change energy-consumption habits, as well as unprecedented international cooperation.[141] Climate engineering, on the other hand, could be implemented by a single state, or even by a single—albeit well-financed—individual.[142] For instance, at least two methods, stratospheric aerosols and cloud whitening, could cost less than $10 billion per year, each.[143] When compared to the trillions of dollars

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physical processes to remove the greenhouse gas, and biologically based methods . . . to simulate or enhance natural carbon storage processes.”).

137. *See* GAO, *supra* note 7, at 7 (“Enhanced upwelling/downwelling—altering ocean circulation patterns to bring deep, nutrient-rich water to the ocean’s surface (upwelling), to promote phytoplankton growth—which removes CO_2 from the atmosphere, as described below—and accelerating the transfer of CO_2 -rich water from the surface of the ocean to the deep-sea (downwelling).”).

138. *See* ROYAL SOCIETY, *supra* note 5, at 10 (describing land-based CDR methods).

139. *See* Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. & RES. ECON. 45, 45 (2008) (discussing how geoengineering is both politically and economically more feasible and could possibly reduce, rather than just prevent, climate change).

140. *See* ROYAL SOCIETY, *supra* note 5, at 42–43 (describing the involvement of private parties in the implementation of geoengineering techniques).

141. *See* Barrett, *supra* note 139, at 50 (“Theory points to the difficulty in achieving substantial and wide scale cooperation for this problem, and the record to date sadly supports this prediction.”); *id.* at 49 (explaining that stabilization of CO_2 levels would require cutting emissions by sixty to eighty percent, yet emissions have risen approximately twenty percent since the adoption of the Framework Convention on Climate Change).

142. *See* William C.G. Burns, *Climate Geoengineering: Solar Radiation Management and Its Implications for Intergenerational Equity*, 4 STANFORD J. LAW, SCI. & POL’Y 46, 46 n.50 (2011) (arguing that the cost of many geoengineering options might be “well within the budget of almost all nations,” as well as a handful of wealthy individuals, potentially allowing a rogue nation or individual to engage in climate engineering unilaterally).

143. *See* Barrett, *supra* note 139, at 49 (establishing that geoengineering techniques are relatively low-cost when compared with the costs of mitigation, as seen in the Panel on

that mitigation is anticipated to cost annually,[144] such an alternative is essentially "costless."[145]

Besides its lower financial costs, geoengineering will likely require less political capital.[146] As mentioned, mitigation requires consumers to conserve, change habits, or both.[147] Businesses must modify their products or, in some cases, face extinction. Thus, mitigation requires the cooperation of billions. Because of the inconvenience and disruption associated with mitigation, most governments have been unwilling to require the reductions necessary to curtail the use of fossil fuels significantly.[148] Most climate engineering proposals, on the other hand, require no such sacrifices. Although geoengineering may have its own negative consequences, in many instances it will not require the unpopular changes in lifestyle or

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Policy Implications of Greenhouse Warming calculation that adding aerosol dust to the stratosphere would cost just pennies per ton of CO_2 mitigated); *see also* James Temple, *Cloud Brightening: Theory to Prototype*, SAN FRANCISCO CHRON. (Jan. 5, 2013), *available at* http://www.sfgate.com/science/article/Cloud-brightening-theory-to-prototype-4170478.php (noting that cloud brightening using seawater was projected to cost as little as $2.5 billion annually) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Barrett, *supra* note 139, at 49 (stating even persons skeptical of such calculations have acknowledged that the costs of such systems would be "trivial" compared to mitigation approaches).

144. *See* Justin McClellan, David W. Keith & Jay Apt, *Cost Analysis of Stratospheric Albedo Modification Delivery Systems*, ENVIRON. RES. LETT., Aug. 30, 2012 at 6, *available at* http://iopscience.iop.org/1748-9326/7/3/034019/pdf/1748-9326_7_3_034019.pdf (estimating that by 2030 the annual cost of mitigation will range from $200 billion to $2 trillion) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

145. *See* Barrett, *supra* note 139, at 49 (estimating SRM would have a marginal cost of approximately 1/10,000th of the cost of mitigation); *see also* Alan Carlin, *Why a Different Approach Is Required If Global Climate Change Is to Be Controlled Efficiently or Even at All*, 32 WM & MARY ENVTL. L & POL'Y REV. 685, 739 (2008) ("SRM is estimated to have a marginal cost about 1/10,000th as expensive as ERD [exclusive regulatory de-carbonization, the mitigation strategy of exclusively reducing carbon output] per equivalent ton of carbon reduced to limit global temperature increases to 2° C above pre-industrial levels using current assumptions concerning climate sensitivity.").

146. *See* John Virgoe, *International Governance of a Possible Geoengineering Intervention to Combat Climate Change*, 95 CLIMATIC CHANGE 103, 107 (2009) (explaining the differences in terms of participation geoengineering requires as opposed to mitigation or other CO_2 reduction methods).

147. *See* Carlin, *supra* note 145, at 721 ("It is difficult to see . . . why many constituents would not pursue every available loophole rather than reduce their welfare and freedom of choice.").

148. *See id*. at 720–21 ("[P]oliticians would be required to maintain unusually strong resolve as the population learns what would be the real effects of the [mitigation] measures. . . . It is difficult to see why politicians would be willing to force their constituents to adopt unpopular and expensive constraints on their activities. . . ."); ROYAL SOCIETY, *supra* note 5, at 4 (arguing that because of the many unknown factors, political communities may lean away from mitigation toward an alternative, such as geoengineering).

business models necessitated by mitigation.[149] When combined with its lower costs, climate engineering may be less disruptive and thus more palatable.[150]

Absent utilization of geoengineering, global warming will not reverse until atmospheric CO_2 declines through natural processes.[151] Thus, to produce a rapid reduction in the amount of atmospheric carbon and its consequences, climate engineering is the only choice.[152]

E. Climate Engineering: Objections and Responses

Despite the advantages of climate engineering, critics raise many legitimate concerns regarding the moral hazard presented by climate engineering, the risk of unforeseen or uneven consequences, and the potential for misuse or irresponsible implementation.[153]

The primary objection to pursuing climate engineering is that it will give rise to a moral hazard and will remove the incentive to reduce fossil fuel use.[154] Essentially, if society can avert the worst consequences of climate change through geoengineering, then it will not undertake the

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149. *See* Virgoe, *supra* note 146, at 106–07 (describing the socio-political characteristics of geoengineering).

150. *See* Carlin, *supra* note 145, at 721 ("Global warming has all the psychological characteristics—a long time horizon, uncertainty, and few readily apparent effects to remind people that there is a problem in their everyday lives—needed to keep it at a modest level of priority.").

151. *See* Samuel Thernstrom, *What Role for Geoengineering?*, AMERICAN (Mar. 2, 2010), *available at* http://www.american.com/archive/2010/march/what-role-for-geoengineering ("[B]y the time the atmospheric concentration of carbon dioxide peaks, whatever amount of warming it will cause will be locked in, and it will take centuries for the amount of CO_2 in the atmosphere to decline significantly through natural processes.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

152. *See* Barrett, *supra* note 139, at 47–49 (explaining climate engineering's usefulness as a short-term solution).

153. *See generally* ROYAL SOCIETY, *supra* note 5 (discussing various concerns associated with geoengineering).

154. *See* William Daniel Davis, *What Does "Green" Mean: Anthropogenic Climate Change, Geoengineering, and International Environmental Law*, 43 GEO. L. REV. 901, 946–47 (2009) ("One of the most commonly voiced objections to geoengineering is that it would create a moral hazard by reducing the political will to adopt stringent mitigation policies that would reduce GHG emissions and attack anthropogenic climate change at the source."); *see also Use of Geoengineering to Curb Warming Is 'Moral Corruption,' says Ethicist*, CLIMATE SPECTATOR (Aug. 23, 2011), http://www.climatespectator.com.au/news/use-geoengineering-curb-warming-moral-corruption-says-ethicist ("Geoengineering, or deliberate alteration of the Earth's environment by humans in the name of climate adaptation, could be considered a form of 'moral corruption,' says a leading Australian ethicist.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

societal and lifestyle changes required for effective mitigation.[155] Thus, society will continue with business as usual (either maintaining or increasing levels of fossil fuel use), relying upon climate engineering to avoid the worst effects of climate change.[156]

There are several responses to the moral hazard objection to geoengineering. Although the pursuit of climate engineering may create a moral hazard, any moral hazard may be an acceptable risk or may be offset by greater concerns, such as an anticipated global catastrophe.[157] Second, geoengineering may actually encourage mitigation.[158] According to this theory, the radical nature of climate engineering and its potential risks may inspire society to pursue mitigation more seriously.[159]

Critics make a second objection to climate engineering—they argue that the dangers of climate engineering could outweigh its benefits. For example, spraying sulfate particles into the atmosphere could trigger acid rain[160] and deplete the ozone layer;[161] albedo modification may impair

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155. *See* Stephen M. Gardiner, *Some Early Ethics of Geoengineering the Climate: A Commentary on the Values of the Royal Society Report*, 20 ENVTL. VALUES 163, 166 (2011) ("In the current context, the worry is that 'major efforts in geoengineering may lead to a reduction of effort in mitigation and/or adaptation because of a premature conviction that geoengineering has provided "insurance" against climate change.'").

156. *See* Russell Powell et al., *The Ethics of Geoengineering* 2 (James Martin Geoeng'g Ethics Working Grp. Working Draft), *available at* http://www.practicalethics.ox.ac.uk/__data/assets/pdf_file/0013/21325/Ethics_of_Geoengineering_Working_Draft.pdf ("[T]he fear is that polluters, policymakers or society at large will have weaker incentives to reduce carbon emissions if they know that geoengineering methods can and likely will be used to offset these emissions. This will lead to greater carbon emissions.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

157. *See* Gardiner, *supra* note 155, at 167 ("[I]f at this point the odds of eventual global catastrophe are high, perhaps society should pursue geoengineering even if doing so makes progress on conventional responses (even) less likely.").

158. *See* Davis, *supra* note 154, at 947 ("[T]he prospect of actual implementation of geoengineering programs, given their radical nature and frightening potential side effects, might generate, rather than reduce, the political will necessary to implement more aggressive mitigation policies.").

159. *See id.* (stating that the radical nature and negative side effects of geoengineering may increase the likelihood that society will pursue mitigation policies).

160. *See* Ben Kravitz, et al., *Sulfuric Acid Deposition From Stratospheric Geoengineering with Sulfate Aerosols*, J. GEOPHYSICAL RES., Jul. 28, 2009, at 1, 4, *available at* http://onlinelibrary.wiley.com/doi/10.1029/2009JD011918/abstract (discussing the potential problems that an increase in sulfur deposition will have on ecosystems) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND ENVIRONMENT).

161. *See* Simone Tilmes, et al., *Impact of Geoengineered Aerosols on the Troposphere and Stratosphere*, J. GEOPHYSICAL RES., Jun. 27, 2009, at 1, 2 ("Enhanced stratospheric aerosol levels after a volcanic eruption, would disturb ozone photochemistry in midlatitudes, because of the suppression of stratospheric NO_x, leading to enhanced halogen catalyzed

ecosystem productivity by reduced photosynthesis;[162] ocean fertilization may undermine biological productivity in non-fertilized areas, cause widespread eutrophication and anoxia, and stimulate toxic algal blooms;[163] sequestered carbon could escape and reenter the atmosphere.[164] Without further study of climate engineering and its effects, analyses of climate engineering's benefits and costs are too uncertain to be valuable.

Alternatively, critics object that the dangers imposed by geoengineering could disproportionately affect certain regions or populations.[165] Lower precipitation may particularly impact East and Southeast Asia, Africa, and the Amazon and Congo valleys.[166] This may undermine the food security of two billion people.[167] Thus, climate engineering will create its own winners and losers, as will climate change.[168] While most nations may benefit from reduced global temperatures, others will suffer from changed atmospheric conditions.[169]

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ozone depletion.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

162. *See* Davis, *supra* note 154, at 924 ("Albedo modification schemes pose a variety of frightening side effects, such as impaired ecosystem productivity from reduced photosynthesis.").

163. *See* Burns, *supra* note 142, at 40–41 ("Several studies have also indicated that ocean iron fertilization, a CDR approach, could undermine biological productivity in non-fertilized regions, cause widespread eutrophication and anoxia, and stimulate toxic algal blooms.").

164. *See* Bob van der Zwaan & Koen Smekens, *CO_2 Capture and Storage with Leakage in an Energy-Climate Model*, 14 ENVTL. MODEL. & ASSESS. 135, 135 (2009) ("The leakage time frame that characterises [carbon sequestration], and the compatibility of that time frame with climate change policy and targets as well as features of the carbon cycle, is determinant for [sequestration]'s suitability to mitigate, postpone, or preclude climate change.").

165. *See* KELSI BRACMORT & RICHARD K. LATTANZIO, CONG. RESEARCH SERV., R41371, GEOENGINEERING: GOVERNANCE AND TECHNOLOGY POLICY, 21 (2013), *available at* http://www.fas.org/sgp/crs/misc/R41371.pdf ("[T]he global impacts of geoengineering activities—both its benefits and risks—may be unevenly distributed across stakeholders.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

166. *See* Burns, *supra* note 142, at 40 ("Stratospheric sulfate aerosol injection . . . could lead to a substantial reduction in precipitation in monsoon regions in East and South-East Asia and Africa . . . Diebacks of tropics forests could also be triggered by substantial precipitation declines in the Amazon and Congo valleys.").

167. *See id.* ("The severe reduction in monsoonal intensity that will result from the reduction in precipitation could potentially undermine the food security of 2 billion people in the region.").

168. *See* Davis, *supra* note 154, at 929 (stating that the impact of climate change will not be uniformly negative as higher latitude countries, particularly Canada and Russia, may benefit from warmer global temperatures, but that there would be disparities in regional meteorological effects of geoengineering as well).

169. *See id.* ("[I]n general, industrialized countries may benefit relative to less industrialized countries due to their comparatively greater ability to adapt to the consequences of climate change.").

Critics also voice concerns about the possibility of geoengineering's misuse.[170] A rogue nation or entity could decide unilaterally to implement geoengineering over the objection of the world community.[171] Second, governments may use climate engineering technologies either for their own benefit or as a weapon against enemies.[172] Third, private interests may promote geoengineering for their own profit.[173]

The reality is that a single nation, corporation, or individual is capable of undertaking climate engineering.[174] This fact may actually support responsible research and testing of geoengineering.[175] First, an open research program will reduce the perceived need by a rogue country or group to develop its own program.[176] Second, a thorough knowledge of these methods will better enable the world community to recognize the

170. *See* U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-11-71, CLIMATE ENGINEERING: TECHNICAL STATUS, FUTURE DIRECTIONS, AND POTENTIAL RESPONSES, at i (2011), *available at* http://www.gao.gov/new.items/d1171.pdf (stating that experts who advocate research to develop geoengineering use caution against the misuse the research could bring) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

171. *See* Barrett, *supra* note 139, at 46 (discussing the likelihood that countries may unilaterally develop and deploy geoengineering because "incentives for countries to reduce emissions on a substantial scale are too weak, and incentives for them to develop geoengineering are too strong" for a commitment to abstain from experimenting with geoengineering to be a realistic prospect).

172. *See* James R. Fleming, *The Climate Engineers*, WILSON Q., Spring 2007, at 1, 8 (discussing the possibility of weaponized weather manipulation) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

173. *See* John Vidal, *Bill Gates Backs Climate Scientists Lobbying for Large-Scale Geoengineering*, THE GUARDIAN (Feb. 5, 2012), http://www.guardian.co.uk/environment/2012/feb/06/bill-gates-climate-scientists-geoengineering (discussing the conflict of interest that may arise from wealthy individuals financially supporting geoengineering research) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

174. *See* Memorandum from the Action Group on Erosion, Technology and Concentration to the U.K. House of Commons ¶ 16 (Dec. 2009) [hereinafter ETC Group Memorandum], *available at* http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/10011318.htm ("The technical capacity to attempt large-scale climate interventions could be in some hands of individuals, corporations, states within the next ten years.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

175. *See* ROYAL SOCIETY, *supra* note 5, at 37 (stating that in order to deal with irresponsible parties dangerously experimenting with geoengineering, "many commentators have suggested forming an international consortium to explore the safest and more effective options, while also building a community of responsible geoengineering researchers").

176. *See* David G. Victor, et al., *The Geoengineering Option*, FOREIGN AFFAIRS (Mar./Apr. 2009), http://www.foreignaffairs.com/articles/64829/david-g-victor-m-granger-morgan-jay-apt-john-steinbruner-and-kat/the-geoengineering-option (discussing the need for a cooperative, international research agenda in order to avoid independent countries or organizations deploying their own geoengineering schemes) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

effects of a rogue entity that attempts to geoengineer.[177] Finally, since private entities might emerge as interest groups advocating for the deployment of one or more methods,[178] an open research program will reduce their influence and ensure that the results and analyses are unbiased by any outside circumstances.[179] An open research program would also minimize the risks that testing is rushed or that it or its results are skewed to reach particular results.[180]

Another concern is that the related research could foster "technological momentum" in support of geoengineering.[181] This refers to the tendency of research programs to create a body of researchers vested in the development of the technology they are researching.[182] This tendency has arisen in a number of contexts, notably medical technology and weapons systems.[183] In part because of the disparity in expertise, policymakers are reluctant to oppose the recommendations of these groups for further development and deployment of new technologies.[184]

While the risk of such technological momentum is real, several checks should work to minimize this concern. Ideally, any decision to utilize climate engineering should be made at a global level, thereby

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177. *See* Mark G. Lawrence, *The Geoengineering Dilemma: To Speak or Not to Speak*, 77 CLIMATIC CHANGE 245, 246 (2006) ("[W]ithout a good overview of potential geoengineering efforts which might eventually be undertaken, it would be difficult to monitor for the possibility of 'covert' geoengineering.").

178. *See* Victor et al., *supra* note 176 ("[S]ome geoengineering options are cheap enough to be deployed by wealthy and capable individuals or corporations.").

179. *See id.* (stating that a cooperative, international research agenda is necessary in order to establish rules that govern the use of geoengineering technology for the good of the entire planet).

180. *See id.* (discussing the risk that geoengineering might be undertaken by a state without appropriate concern for harms elsewhere).

181. *See* Davis, *supra* note 154, at 948 ("Another potential objection to a geoengineering research program is that it would generate 'technological momentum,' so that if it was determined that geoengineering was possible, even if likely to generate side effects, the result would be development and eventual deployment."); *see also* U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-11-71, CLIMATE ENGINEERING: TECHNICAL STATUS, FUTURE DIRECTIONS, AND POTENTIAL RESPONSES, i (2011), *available at* http://www.gao.gov/new.items/d1171.pdf (stating that advocates of geoengineering research caution against the misuse the research could bring) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

182. *See* Davis, *supra* note 154, at 948 (indicating "technological momentum" occurs when "research programs create a community of researchers that functions as an interest group promoting the development of the technology that they are investigating").

183. *See id.* at 949 (providing the fields of medical technology and weapons systems as two examples of areas in which "technological momentum" has been observed).

184. *See id.* ("Given [researchers'] comparative level of expertise, policymakers may have a difficult time resisting calls for development and deployment of geoengineering technologies.").

minimizing the influence of interest groups.[185] Second, any research program should be open and transparent.[186] Besides reducing the likelihood that a rogue entity would be able to implement a method undetected, an open research program would also provide accurate and unbiased data, thereby reducing the risk that a vested interest could unduly influence research.[187]

The risks cited by critics are serious, but the true extent of these risks is still unknown,[188] and we are uncertain that we can predict all of the possible risks.[189] That is part of the point of this paper. Because of the potential benefits and possible need for climate engineering, we should create a legal regime that facilitates research into geoengineering and its consequences, rather than one that prohibits or discourages investigation into these methods *ab initio*.[190] Early exploration of these technologies has another critical advantage: it makes it more likely that we will know of benefits and risks before a climate emergency actually arises.[191]

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185. *See infra* Part IV.D (discussing the importance of a moratorium on deployment in order to ensure that research programs are primarily used for research and not implementation).

186. *See infra* Part IV.C (arguing for the benefits of transparency in a domestic research program).

187. *See* Davis, *supra* note 154, at 934 (stating that a transparent research program will lessen the likelihood that a state or "rogue billionaire" will unilaterally implement a geoengineering program).

188. *See* Douglas G. MacMartin, David W. Keith, Ben Kravitz & Ken Caldeira, *Management of Trade-Offs in Geoengineering Through Optimal Choice of Non-Uniform Radiative Forcing*, 3 NATURE CLIMATE CHANGE LETTERS 365, 365 (2013) (stating that recent analysis suggests desired climate moderation may be achieved with thirty percent less solar insulation than previously anticipated, thus reducing the potential side effects of SRM, demonstrating the uncertainty that these risks will be as great as projected).

189. *See* Alan Robock, *20 Reasons Why Geoengineering May Be a Bad Idea*, BULL. ATOMIC SCIENTISTS, May/June 2008, at 14, 17 (discussing the uncertainty in predicting the outcome of geoengineering efforts) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

190. *See generally infra* Part IV.E (arguing that the United States should use NEPA and financial incentives to conduct geoengineering research and testing).

191. *See* Gareth Davies, *Framing the Social, Political, and Environmental Risks and Benefits of Geoengineering*, 46 TULSA L. REV. 261, 270 (2010) (explaining that the "moral hazard" argument against geoengineering presents a real danger if global warming reaches a point where geoengineering is clearly desirable, because the political and research base will not be there).

F. Climate Engineering: The Need to Accelerate Research Now

Little research has been conducted on any method of climate engineering;[192] only the United Kingdom and a project jointly supported by France, Germany, and Norway have begun concerted research efforts regarding climate engineering.[193] Years of research and testing must be conducted before such technologies can be utilized responsibly.[194] After completion of initial research, extensive modeling would be conducted of various approaches and their consequences.[195] After these laboratory analyses were completed, scientists would perform limited field testing.[196] Some experts project that, combined, these steps might require a decade or longer.[197] Accordingly, a research program focused on geoengineering technologies should commence as soon as possible, so that the risks are understood before the onset of catastrophic climate change.[198]

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192. *See The Principles*, OXFORD GEOENGINEERING PROGRAMME, *available at* http://www.geoengineering.ox.ac.uk/oxford-principles/principles/? (last visited Sept. 8, 2013) [hereinafter The Principles] ("Research into geoengineering is at a very early stage . . . .") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); *see also* ROYAL SOCIETY, *supra* note 5, at 52 ("[L]ittle research has actually so far been undertaken on most of the methods considered, despite a great deal of interest in recent years from the scientific and engineering community, from concerned citizens . . . and the media.").

193. *See* Announcement: Oxford to Lead £1.3m Research Project on Geoengineering Governance, OXFORD GEOENGINEERING PROGRAM, http://www.geoengineering.ox.ac.uk/events/upcoming/?id=16 (last visited Sept. 8, 2013) (discussing University of Oxford's research project on geoengineering governance) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Implications and Risks of Engineering Solar Radiation to Limit Climate Change, IMPLICC, http://implicc.zmaw.de/Home.551.0.html (last visited Sept. 8, 2013) (stating that the joint European program studied "novel options to limit climate change" from July 2009 to September 2012 and involved research institutions from France, Germany, and Norway) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

194. *See* ROYAL SOCIETY, *supra* note 5, at 52 ("Much more research on the feasibility, effectiveness, cost, environmental impact and potential unintended consequences of most methods would be required before they can be properly evaluated.").

195. *See id.* at xii ("The principal research and development requirements in the short term are for much improved modeling studies and small/medium scale experiments (e.g. laboratory experiments and field trials).").

196. *See id.* at 41 (cautioning that although there is a need for field trials to further geoengineering research, there is also a clear need for governance of large-scale field testing of some geoengineering techniques).

197. *See* Rob Swart & Natasha Marinova, *Policy Options in a Worst Case Climate Change World*, 15 MITIG. ADAPT. STRATEG. GLOB. CHANGE 531, 542 (2010) (predicting that SRM methods will likely require at least two decades from the commencement of research until they can achieve the desired effect).

198. *See* Davidson, *supra* note 117, at 4294–95 (stating that despite arguments against geoengineering, developing emergency mechanisms now is important to ensure they can be tested before they are actually needed).

Finally, a clarification: while this paper supports the immediate and extensive research and testing of climate engineering methodologies, this paper does not intend to suggest that geoengineering can, or should be, the sole solution to society's climate change problems. We must mitigate. Nevertheless, barring an immediate commitment to a reduction in carbon emissions to nearly zero, we will not avoid a significant increase in global temperatures.[199] Thus, at the very least, we should fully understand the implications of climate engineering should we need to reduce global temperatures immediately to avert a catastrophe.[200]

III. International and Domestic Laws Do Not Provide a Uniform and Concerted Policy for the Regulation of Climate Engineering

Neither domestic nor international law comprehensively governs climate engineering.[201] Because existing environmental laws were drafted in a very different context in response to very different problems, at best they haphazardly address aspects of some climate engineering methods.[202] Moreover, several geoengineering methods fall completely outside of the contemplation of any of these provisions.[203] Ultimately, this inconsistent coverage will complicate both the pursuit and regulation of climate engineering research.

A. Domestic Environmental Laws

In the United States, Congress passed environmental laws to address particular problems, such as polluted air and water, the cleanup of

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199. *See* Matthews & Caldeira, *supra* note 38, at 1 ("[T]o achieve atmospheric carbon dioxide levels that lead to climate stabilization, the net addition of CO_2 to the atmosphere from human activities must be decreased to nearly zero.").

200. *See* Albert C. Lin, *Balancing the Risks: Managing Technology and Dangerous Climate Change*, 8 ISSUES IN LEGAL SCHOLARSHIP 1, 12 (2009) (cautioning that, although climate engineering may allow society to "buy time for more gradual emissions reductions to be put in place and to take effect," climate engineering's adverse effects may not be immediately apparent) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, THE CLIMATE, AND THE ENVIRONMENT).

201. *See* BRACMORT & LATTANZIO, *supra* note 165, at 39 (stating that there is limited domestic oversight of and few international agreements governing geoengineering).

202. *See id.* at 24 (arguing that "some legal instruments may currently apply to domestic geoengineering practices," but "the federal government could expand these existing laws to specifically address geoengineering activities or develop new laws").

203. *See id.* at ii ("[P]olicymakers will also need to consider whether geoengineering can be effectively addressed by amendments to existing laws and international agreements or, alternatively, whether new laws and international treaties would need to be developed.").

toxic chemicals, and the treatment of hazardous waste.[204] These laws, passed in the 1970s and 1980s, predate most consideration of climate change, and, thus, precede any contemplation of climate engineering as a response.[205] In some instances, these laws regulate aspects of particular climate engineering methods, but they do not provide a comprehensive scheme for the regulation of geoengineering research, testing, or deployment.[206] Thus, most research and testing of geoengineering can proceed unregulated in the United States. However, a comprehensive scheme should be developed to promote their research and to regulate these efforts.

The following discussion reviews the federal laws that might regulate climate engineering research and development.

1. Safe Drinking Water Act

The Safe Drinking Water Act (SDWA)[207] ensures the quality of the nation's drinking water by authorizing the EPA to set drinking water quality standards and to oversee local authorities that implement those standards.[208] Pursuant to its authority to protect underground water sources under the SDWA,[209] the EPA regulates the geological sequestration of CO_2.[210] The SDWA authorizes the EPA to establish minimum standards for state underground injection control programs.[211] In December 2010, the

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204. *See Laws and Executive Orders*, ENVTL. PROT. AGENCY, http://www2.epa.gov/laws-regulations/laws-and-executive-orders (last visited Sept. 9, 2013) (providing a summary of environmental laws) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

205. *See generally* Richard J. Lazarus, *The Greening of America and the Graying United States Environmental Laws: Reflections on Environmental Law's First Three Decades in the United States*, 20 VA. ENVTL. L.J., 75 (2001) (discussing the evolution of environmental law in the United States, its origin during the 1970s and development during the 1980s).

206. *See* BRACMORT & LATTANZIO, *supra* note 165, at 25 (discussing federal agencies' minimal efforts and funding with respect to the development and implementation of national geoengineering policies).

207. Safe Drinking Water Act, 42 U.S.C. § 300f (2012).

208. *See id.* § 300g-2 (explaining the roles of the EPA and state regulators).

209. *See id.* § 300h-2 (authorizing the EPA to enforce regulations that protect underground sources of water).

210. *See* Federal Requirements Under the Unground Injection Control Program for Carbon Dioxide Geological Sequestration Wells, 75 Fed. Reg. 77,230, 77,235 (Dec. 10, 2010) [hereinafter Class VI Rule] (to be codified at 44 C.F.R pts. 124, 144, 145, 146, and 147) ("Part C of the SDWA requires EPA to establish minimum requirements for State UIC programs that regulate the subsurface injection of fluids onshore and offshore under submerged lands within the territorial jurisdiction of States.").

211. *See id.* at 77,235 ("Part C of the SDWA requires EPA to establish minimum requirements for state UIC programs that regulate the subsurface injection on fluids onshore

EPA promulgated rules under the Underground Injection Control Program (UIC) of the SDWA.[212] The 2010 rules provide for the development of a new class of wells, Class VI.[213] This class builds upon existing UIC requirements with standards tailored to CO_2 injection for long-term storage.[214] Operators of Class VI wells must prepare assessments of the appropriateness of the location for CO_2 sequestration,[215] must follow certain well construction[216] and operating requirements,[217] must comply with testing and monitoring obligations to ensure the effectiveness of sequestration,[218] must follow post-injection closure procedures,[219] and must provide financial assurance for closing and remediating activities.[220] Carbon dioxide itself is not a drinking water contaminant, but its presence in water

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and offshore under submerged land within the territorial jurisdiction of the state."); *see also* 42 U.S.C. § 330h-1(b)(3) (stating that under the program, the EPA serves as the permitting authority until such time as a state applies for and is accepted for the role).

212. *See id.* at 77,230 (stating that the regulation would become effective on January 10, 2011, one month after the EPA issued the regulation, on December 10, 2010).

213. *See id.* at 77,240 (discussing the proposal for a new class of injection wells, Class VI, as well as the technical criteria for permitting Class VI wells).

214. *See* Geologic Sequestration of Carbon Dioxide, ENVTL. PROT. AGENCY, http://water.epa.gov/type/groundwater/uic/wells_sequestration.cfm (last visited Oct. 15, 2013) ("The Class VI rule builds on existing UIC Program requirements, with extensive tailored requirements that address carbon dioxide injection for long-term storage to ensure that wells used for geologic sequestration are appropriately sited, constructed, tested, monitored, funded, and closed.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

215. *See* Class VI Rule, *supra* note 210, at 77,247 ("Today's final action requires owners or operators of Class VI wells to perform a detailed assessment of the geologic, hydrogeologic, geochemical, and geomechanical properties of the proposed GS [Geologic Sequestration] site to ensure that GS wells are sited in appropriate locations and inject into suitable formations.").

216. *See id.* at 77,250 ("Today's final approach is based on existing construction requirements . . . for Class I hazardous waste injection wells, with modifications to address the unique physical characteristics of CO_2.").

217. *See id.* at 77,257 ("The requirements for operation of Class VI injection wells are based on the existing requirements for Class I wells, with enhancements to account for the unique conditions that will occur during GS including buoyancy, corrosivity, and higher sustained pressures over a longer period of operation.").

218. *See id.* at 77,259 ("Today's final rule . . . requires owners or operators of Class VI wells to develop and implement a comprehensive testing and monitoring plan . . . that includes injectate monitoring, corrosion monitoring of the well's tubular, mechanical, and cement components, pressure fall-off testing, ground water quality monitoring . . . .").

219. *See id.* at 77,266 (discussing the care required during the post-injection site period, in which the owner or operator of the Class VI well must continue monitoring to ensure the protection of underground sources of drinking water).

220. *See id.* at 77,268 (noting that owners or operators of Class VI wells must "demonstrate and maintain financial responsibility as approved by the Director for performing corrective action on wells . . . injection well plugging, PISC and site closure, and emergency and remedial response.").

forms carbonic acid, which can cause metals or other contaminants to leach into ground water as a result of sequestration.[221] The EPA deemed regulation appropriate also because of the large volumes of CO_2 that may be injected, the mobility of CO_2 within geologic formations, and potential impurities in the CO_2 stream.[222]

2. Clean Air Act

Under the Clean Air Act (CAA),[223] the EPA establishes primary and secondary standards for ambient air quality.[224] The EPA sets the primary ambient air quality standards at a level to protect the public health;[225] it sets the secondary standards to protect the public welfare.[226] Pursuant to this authority, the EPA identifies pollutants that can be reasonably expected to harm public health or welfare, and prescribes regulations to limit such pollutants accordingly.[227] Through this authority, the CAA might affect climate engineering because the EPA has identified sulfur oxides as one such pollutant.[228] As described previously, sulfur particles are the material of choice for SRM methods that propose to eject

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221. *See id.* ("While CO_2 itself is not a drinking water contaminant, CO_2 in the presence of water forms a weak acid, known as carbonic acid, that, in some instances, could cause leaching and mobilization of naturally-occurring metals or other contaminants from geologic formations into ground water.").

222. *See id.* at 77,233 ("Due to the large CO_2 injection volumes anticipated at GS projects, the relative buoyancy of CO_2, its mobility within subsurface geologic formations, its corrosivity in the presence of water, and the potential presence of impurities in the captured CO_2 stream, the Agency has determined that tailored requirements, modeled on the existing UIC regulatory framework, are necessary to manage the unique nature of CO_2 injection for GS.").

223. Clean Air Act, 42 U.S.C. § 7401 (2012).

224. *See id.* § 7409(a)(1) (authorizing the EPA to establish a national primary ambient air quality standard and a national secondary ambient air quality standard).

225. *See id.* § 7409(b)(1) ("National primary ambient air quality standards . . . shall be ambient air quality standards the attainment and maintenance of which . . . are requisite to protect the public health.").

226. *See id.* § 7409(b)(2) ("Any national secondary ambient air quality standard . . . shall specify a level of air quality the attainment and maintenance of which . . . is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air.").

227. *See id.* § 7408(a) (directing the EPA to identify pollutants which "may reasonably be anticipated to endanger public health or welfare" and to issue air quality criteria accordingly).

228. *See* Keith, Parson & Morgan, *supra* note 124, at 427 ("At one extreme, a state might decide that avoiding the effects of climate change on its people takes precedence over the environmental concerns of SRM and begin injecting sulphur into the stratosphere, with no prior risk assessment or international consultation.").

these sulfur particles into the atmosphere[229] because they mimic volcanic emissions of sulfur.[230] Some analysts suggest, however, that particles other than those made of sulfur, such as titanium dioxide, may provide similar or better results.[231] If titanium dioxide were used, this method would probably not trigger protections under the CAA, because the EPA has not identified titanium dioxide as a pollutant that threatens public health or welfare.[232]

Carbon sequestration also implicates protections of the CAA: pursuant to its authority under the CAA, the EPA has promulgated reporting requirements concerning the release of CO_2 from underground injection facilities established under the SDWA.[233] The EPA promulgated these rules to enable it to monitor the growth and efficacy of geologic sequestration and to evaluate policy options.[234] Pursuant to these regulations, facilities must prepare reports on the amounts of CO_2 received, injected, and sequestered, and whether any CO_2 has escaped through leakage.[235] The EPA also requires that facilities develop and submit for its approval a monitoring, reporting, and verification plan.[236]

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229. *See id.* (discussing the use of sulfur particles in SRM).

230. *See* Davidson et al., *supra* note 117, at 4265 ("The choice of particle is receiving close attention; hitherto, it had been assumed that aerosols would be sulphuric acid mists similar to those produced by volcanoes.").

231. *See id.* at 4266 ("If other particles are to be designed and manufactured . . . , they will need particular properties to be attractive alternatives to the use of a sulphuric acid aerosol. . . . Various high refractive index particle systems could be considered but titanium dioxide (TiO_2) is a promising candidate.").

232. *See generally* 40 C.F.R. pt. 50 (2013) (lacking a section that regulates titanium dioxide); *see also What Are the Six Common Air Pollutants?*, ENVTL. PROT. AGENCY, http://www.epa.gov/air/urbanair/ (last visited Oct. 15, 2013) (naming air pollutants that pose a risk to public health and welfare).

233. *See generally* 40 C.F.R. §§ 98.440–98.449 (establishing reporting requirements); *see also* Mandatory Reporting of Greenhouse Gases: Injection and Geologic Sequestration of Carbon Dioxide, 75 Fed. Reg. 75,060, 75,062 (Dec. 1, 2010) ("CAA section 114 provides EPA with the authority to require the information mandated by this rule because such data will inform and are relevant to EPA's implementation of a wide variety of CAA provisions.").

234. *See* Mandatory Reporting of Greenhouse Gases: Injection and Geologic Sequestration of Carbon Dioxide, 75 Fed. Reg. 75,060, 75,062 (Dec. 1, 2010) (noting that the data collected "will, among other things, inform Agency decisions under the CAA related to the use of carbon dioxide capture and geologic sequestration (CCS) for mitigating GHG emissions.").

235. *See generally* 40 C.F.R. § 98.442 (2013) ("You must report: (a) Mass of CO_2 received[,] . . . injected into the subsurface[,] . . . produced[, and] . . . [m]ass of CO_2 emitted by surface leakage[,] . . . equipment leaks[,] and vented emissions of CO_2 from surface equipment located between the injection flow meter and the injection wellhead . . . [and] between the production flow meter and the production wellhead.").

236. *See* 40 C.F.R. § 98.448 (2013) (mandating the submission and enumerating the requirements of a monitoring, reporting, and verification plan).

3. Comprehensive Environmental Response, Compensation, and Liability Act

Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[237] to provide broad federal authority to compel the cleanup of hazardous substances that may endanger human health or the environment[238] and to ensure that responsible parties bear the costs.[239] CERCLA defines "hazardous substance" to include any substance designated as such by the EPA, not only under CERCLA, but also under other environmental legislation.[240]

In theory, CERCLA could apply to climate engineering through regulation of carbon sequestration.[241] In practice, however, CERCLA is unlikely to have a direct effect on carbon sequestration.[242] Even though CO_2 is not identified as a hazardous substance under CERCLA,[243] the statute's protections may be triggered if a CO_2 stream contains a hazardous substance or reacts with ground water to produce a hazardous substance.[244]

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237. Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. §§ 9601–9675 (2012).

238. *See* H.R. REP. NO. 1016(I), at 6119 (1980), *reprinted in* 1980 U.S.C.C.A.N. 6119, 6119 ("The bill would . . . provide for a national inventory of inactive hazardous waste sites and . . . [would] establish a program for appropriate environmental response action to protect public health and the environment from the dangers posed by such sites.").

239. *See id.* at 6120 ("[CERCLA] would also establish a federal cause of action in strict liability to enable the Administrator to pursue rapid recovery . . . from persons liable therefor and to induce such persons voluntarily to pursue appropriate environmental response actions with respect to inactive hazardous waste sites.").

240. *See* 42 U.S.C. § 9601(14) (defining the term "hazardous substance" as it is defined by the EPA under CERCLA and other acts, such as the Federal Water Pollution Control Act, the Toxic Substances Control Act, among others).

241. *See* Alexandra B. Klass & Elizabeth J. Wilson, *Climate Change and Carbon Sequestration: Assessing a Liability Regime for Long-Term Storage of Carbon Dioxide*, 58 EMORY L.J. 103, 128–32 (2008) (discussing CERCLA's potential application to carbon sequestration).

242. *See id.* at 130 ("Because CO_2 is nontoxic at low concentrations and is not a listed waste, CERCLA likely does not apply to current CO_2 injection activities unless recognized hazardous substances are present.").

243. *See* 42 U.S.C. § 9601(14) (defining hazardous substance); *see also* Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells, 75 Fed. Reg. 77,230, 77,260 (Dec. 1, 2010) ("CO_2 itself is not listed as a hazardous substance under CERCLA.").

244. *See* Federal Requirements Under the Underground Injection Control Program, *supra* note 244 (stating that CO_2 could contain a hazardous substance or react with ground water and produce a hazardous substance).

4. Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA)[245] provides "a comprehensive 'cradle to grave' regulatory system for identifying, listing, and tracking hazardous wastes; setting standards for the generation, handling, storage, and disposal of hazardous wastes . . . ."[246] RCRA applies only to "solid wastes" that are also "hazardous wastes,"[247] when considered in light of certain qualifying criteria.[248] A solid waste is a hazardous waste if it exhibits one of these characteristics: ignitability, corrosivity, reactivity, and toxicity.[249]

RCRA's application to carbon sequestration would depend upon the presence of hazardous materials in CO_2 streams,[250] because CO_2 is not a hazardous waste under RCRA.[251] In most instances, however, the captured CO_2 would contain some impurities.[252] Although concentrations of these impurities would likely be very low,[253] there would be a risk of contaminating underground sources of drinking water given the volume of CO_2.[254] Furthermore, the types and concentrations of impurities would vary by characteristics of the original source of the captured CO_2, such as the nature of the facility, composition of the underlying material (coal, for example), plant operating conditions, and pollution removal technologies.[255] Thus, operators would need to determine whether the CO_2 contains a hazardous material, and, if it did, they would need to inject the

245. Resource Conservation and Recovery Act, 42 U.S.C. §§ 6901–6992k (2012).

246. Klass & Wilson, *supra* note 241, at 125.

247. *See* 40 C.F.R. § 261.3 (2013) (defining hazardous waste).

248. *See id.* § 261.11 (listing the criteria used to classify solid waste as hazardous).

249. *See id.* §§ 261.20–24 (describing the characteristics of ignitability, corrosivity, reactivity, and toxicity).

250. *See* Klass & Wilson, *supra* note 241, at 127 ("CO_2 is not a listed hazardous waste, and it seems unlikely that CO_2 alone would be considered a hazardous waste, although co-injection with other waste stream constituents (e.g., hydrogen sulfide (H_2S)) could cause it to be defined so.").

251. *See id.* (stating that CO_2 is not listed as a hazardous material).

252. *See* Federal Requirements Under the Underground Injection Control Program for Carbon Dioxide Geologic Sequestration Wells, 73 Fed. Reg. 43,492, 43,511 (July 25, 2008) (to be codified at 40 C.F.R. pts. 144, 146) ("Another concern for [underground sources of drinking water] is the presence of impurities in the CO_2 stream.").

253. *See id*. (anticipating that any impurities would only be present in small amounts).

254. *See id.* ("Because of the volume of CO_2 that could be injected, there may be a risk that co-contaminants in the CO_2 stream could endanger [drinking water] . . . .").

255. *See id.* at 43,503 ("[T]he types of impurities and their concentrations in the CO_2 stream are likely to vary by facility, coal composition, plant operating conditions, and pollution removal technologies . . . .").

stream into Class I wells,[256] as RCRA prohibits the injection of CO_2 streams containing hazardous wastes into Class VI wells.[257]

5. Marine Protection, Research, and Sanctuaries Act

The Marine Protection, Research, and Sanctuaries Act (MPRSA)[258] implements the obligations of the United States under the 1972 London Convention.[259] The MPRSA prohibits the transportation of any material for the purpose of dumping it[260] into ocean waters "in the territorial sea or the contiguous zone of the United States."[261] The Act defines "material" to include solid, industrial, and other waste.[262] Even then, a party may receive a permit from the EPA to dispose of materials other than dredged matter, radiological, chemical and biological warfare agents, or high-level radioactive or medical waste.[263] The MPRSA applies to vessels carrying materials out of the United States, as well as vessels entering the territorial sea or the contiguous zone of the United States.[264]

Besides regulating ocean dumping, the MPRSA also establishes a research program.[265] Specifically, it establishes a monitoring and research program concerning the long-range effects of ocean dumping, pollution, and man-induced changes of ocean ecosystems.[266] The MPRSA may

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256. *See* 40 C.F.R. § 262.11 (stating that an operator must determine if its solid waste is hazardous, and prescribing the process for making this determination); *see generally* 40 C.F.R. § 146.5 (describing the purposes and uses of the different classes of wells).

257. *See* Federal Requirements Under the Underground Injection Control Program, *supra* note 244, at 43,503 (July 25, 2008) (indicating that the rule would preclude injecting hazardous waste into class VI wells).

258. Marine Protection, Research, and Sanctuaries Act, 33 U.S.C. §§ 1401–45 (2012).

259. *See* Tracy D. Hester, *Remaking the World to Save It: Applying U.S. Environmental Laws to Climate Engineering Projects*, 38 ECOLOGY L.Q. 851, 886 (2011) ("The MPRSA implements the United States' obligations under the London Convention . . . .").

260. *See* 33 U.S.C. § 1411(a) (prohibiting vessels and aircraft from transporting material to dump it in ocean water).

261. *Id.* § 1401(c).

262. *See id.* § 1402(c) ("'Material' means . . . solid waste . . . industrial . . . and other waste.").

263. *See id.* § 1412(a) (stating that no permit will be issued for "dredged material . . . radiological, chemical, and biological warfare agents, high-level radioactive, and medical waste").

264. *See id.* § 1401(c) (stating that the act regulates both dumping materials taken out of the United States and materials brought into "the territorial sea or the contiguous zone of the United States").

265. *See id.* § 1441 (stating that the Secretary of Commerce will establish a research program).

266. *See id.* §§ 1441–42 (stating that the Secretary of Commerce will create a research program to monitor "long-range effects of pollution, overfishing, and man-induced changes of ocean ecosystems").

regulate climate engineering because fertilization of the ocean with iron could fall within its jurisdiction.[267] A 2007 case regarding a company, Planktos, that planned to conduct an iron fertilization experiment, is illustrative.[268] The EPA wrote to Planktos, informing it that if Planktos used a vessel flying an American flag, then the EPA might require a permit under the MPRSA for ocean dumping.[269] Ocean fertilization techniques require adding only a very small amount of iron to the ocean.[270] The statute prohibits the act of "dumping . . . into ocean waters."[271] The parties did not definitively resolve this issue, however, because Planktos decided to use another vessel, thereby removing its experiment from the jurisdiction of the MPRSA.[272]

During the dispute, the United States submitted an agenda item to the parties of the London Convention and the Protocol Secretariat regarding Planktos and the extension of the Convention to fertilization efforts.[273] In November 2007, the parties to the Convention concluded that it covers ocean fertilization.[274] The Contracting Parties also "urged states to use the

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267. *See* Kelly Hearn, *Plan to Dump Iron in Ocean as Climate Fix Attracts Debate*, NAT'L GEOGRAPHIC NEWS (July 25, 2007), news.nationalgeographic.com/news/pf/59308315.html (indicating that the EPA believes dumping iron into the ocean might require a permit under the MPRSA) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

268. *See* ELI KINTISCH, HACK THE PLANET 129 (2010) (describing Planktos's plan to sprinkle iron in the ocean); *see id* (stating that iron increases plankton growth and the plankton convert CO_2 into carbon stored in the plant tissue).

269. *See* Hearn, *supra* note 267 (stating that the EPA informed Planktos it may need a permit even though it was unsure if fertilization would be subject to the act).

270. *See* KINTISCH, *supra* note 268, at 129 (stating "minute" levels of iron will be added to the ocean under Planktos's plan); Steven Mufson, *Iron to Plankton to Carbon Credits*, WASH. POST (July 20, 2007), http://www.washingtonpost.com/wp-dyn/content/article/2007/07/19/AR2007071902553_pf.html (describing the process of fertilization and stating that the ratio of iron dust inserted into ocean water is comparable to a teaspoon of iron added to the water in an Olympic-size pool) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

271. 33 U.S.C. § 1411(a) (2012); *see also* 33 U.S.C. § 1410(f) (defining "dumping" somewhat vaguely as "a disposition of material," which should contemplate the fertilization of the sea with iron nutrients).

272. *See* KINTISCH, *supra* note 268, at 137 (explaining that Planktos chose not to use a United States vessel in order to avoid EPA regulations).

273. *See* Tatjana K. Rosen, Environmental Governance on the High Seas: A Case Study of Emerging Uses and Environmental Leadership 3 (undated) (unpublished manuscript presented at the Conference on Environmental Governance and Democracy, May 10–11, 2008, Yale Univ.), *available at* http://envirocenter.yale.edu/envdem/documents.htm#track22 (stating that the United States submitted an agenda item because of its apprehension with Planktos's use of a United States vessel) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

274. *See* Press Release: Large-Scale Fertilization Operations Not Currently Justified, Say Parties to International Treaties, International Maritime Organization (Nov. 16, 2007),

utmost caution when considering proposals for large-scale fertilization operations . . . ."[275] In 2008, the parties adopted a resolution to expand the London Convention and the London Protocol to allow ocean fertilization for research purposes.[276]

Because of its focus on ocean dumping, rather than subseabed burial, of "wastes," the MPRSA appears to have little applicability to carbon sequestration efforts.[277] First, the targeting of ocean dumping should render it inapplicable to efforts to sequester carbon since that involves injecting the fluid under the seabed.[278] Second, for the MPRSA to extend to subseabed injections, it would need to regulate the particular material, CO_2, being injected.[279] This is doubtful. As previously noted, the MPRSA regulates the dumping of waste.[280] While the MPRSA does not define "waste" generally, it defines "industrial waste" as any "solid, semisolid, or liquid waste generated by a manufacturing or processing plant."[281] Since CO_2 captured for sequestration is captured as a gas and not as a solid or a liquid,[282] it likely does not fall within this definition.

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available at http://www.imo.org/OurWork/Environment/SpecialProgrammesAndInitiatives/Pages/London-Convention-and-Protocol.aspx ("Parties . . . say that planned operations for large-scale fertilization of the oceans using micro-nutrients—for example, iron—to sequester carbon dioxide (CO_2), are currently not justified.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Davis, *supra* note 154, at 934 (stating that the London Convention covered and competently addressed ocean fertilization).

275. Davis, *supra* note 154, at 934.

276. *See infra* at Part III.B.1 (discussing the London Convention).

277. *See* Thomas Brugato, *The Property Problem: A Survey of Federal Options for Facilitating Acquisition of Carbon Sequestration Repositories*, 29 VA. ENVT'L L.J. 305, 352 (2011) ("[T]he MPRSA . . . does not appear to cover sub-seabed activities.").

278. *See id.* at 352 (stating the MPRSA does not cover subseabed activity); *see also* Ann Brewster Weeks, *Subseabed Carbon Dioxide Sequestration as a Climate Mitigation Option for the Eastern United States: A Preliminary Assessment of Technology and Law*, 12 OCEAN & COASTAL L.J. 245, 264 (2007) (noting that the MPRSA's only reference to the subseabed excludes it from the definition of "dumping," the act which triggers coverage by the act). *But see* Sumit Som, *Creating Safe and Effective Carbon Sequestration*, 17 N.Y.U. ENVT'L L.J. 961, 976–77 (2008) (arguing that the leaking of sequestered CO_2 could harm the marine environment, thus justifying application of the MPRSA to subseabed sequestration).

279. *See* Brugato, *supra* note 277, at 352 (noting that courts have not ruled on the question and that the London Convention leaves the question uncertain).

280. *See* 33 U.S.C. § 1411(a) (prohibiting vessels and ircraft from transporting material in order to dump it in the ocean water).

281. 33 U.S.C. § 1412a(b).

282. *See* PETER FOLGER, CONG. RESEARCH SERV., R42532, CARBON CAPTURE AND SEQUESTRATION (CCS): A PRIMER 2 (2013), *available at* http://www.fas.org/sgp/crs/misc/R42532.pdf (describing the process of carbon sequestration) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

6. Endangered Species Act

Congress passed the Endangered Species Act (ESA)[283] to protect endangered and threatened species of plants and animals, as well as the ecosystems upon which those species rely.[284] The ESA has two major provisions which may be pertinent to the regulation of geoengineering.[285] First, Section VII prohibits a federal agency from taking actions that might jeopardize a listed species.[286] To this end it requires an agency to consult with the Fish and Wildlife Service (FWS) or the National Marine Fisheries Service (NMFS)[287] to determine whether the contemplated agency action might jeopardize a protected species.[288] Section VII extends to all activities authorized, funded, or carried out by a federal agency.[289] Second, Section IX prohibits any person from "taking" any protected species.[290] The ESA defines "take" to mean, *inter alia*, harass, harm, wound, kill, or collect;[291] the regulations define "harm" to include significant habitat modification.[292]

The ESA is likely to have limited and uneven application to climate engineering efforts. Because "taking" a listed species is necessary to trigger

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283. Endangered Species Act, 16 U.S.C. §§ 1531–44 (2012).

284. *See id*. § 1531(b) ("The purposes of this chapter are to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species . . . .").

285. *See id*. §§ 1536(a), 1538(a)(1) (making it unlawful to endanger or take any listed species).

286. *See id*. § 1536(a)(2) (stating that all agencies must ensure that any action they take will not jeopardize an endangered species unless the agency receives an exemption); § 1533(a) (listing the factors used to determine whether a species is endangered or threatened).

287. *See* Interagency Cooperation—Endangered Species Act of 1973, as Amended, 50 C.F.R. § 402.01(b) (2013) (stating that these two agencies share responsibility for administering §§ 1536(a), 1538(a)).

288. *See* 16 U.S.C. § 1536(a)(2) ("Each Federal agency shall . . . insure that any action . . . is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species . . . .").

289. *See* 50 C.F.R. § 402.02 (identifying as examples of such activities the following: promulgation of regulations; granting of contracts, leases, or permits; or causing modifications to land, water, or air).

290. *See* 16 U.S.C. § 1538(a)(1) (stating it is unlawful to take any listed species).

291. *See id*. § 1532(19) ("The term 'take' means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct.").

292. *See* Endangered and Threatened Wildlife and Plants, 50 C.F.R. § 17.3 (2013) ("Harm . . . may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering."). *But see* 16 U.S.C. § 1539(a)(1)(A)–(B) (allowing the FWS to permit a taking for scientific purposes or when incidental to a lawful activity).

the statute's protections,[293] the ESA may restrict climate engineering only where such species are harassed, harmed, wounded, or killed.[294] For instance, one geoengineering proposal involves placing reflective materials over desert landscapes to reflect solar radiation.[295] This method may not be acceptable where a listed species lives, if it results in injury to listed species.[296] Of course, other technologies with generalized effects may be barred. For example, if sulfate aerosols, wherever emitted, were determined to threaten a particular listed species of bird, then this would support a complete ban on the method.[297]

If a certain method does, in fact, affect a listed species, an additional ground for ESA application may arise. Section 1536(a)(2) requires that a federal agency consult with the appropriate authority any time the agency is considering an action that may jeopardize a listed species.[298] Thus, if climate engineering involves agency action—whether it is participation in an experiment, provision of funding, or licensing and permitting—the agency must first consult with FWS or NMFS about the implications for listed species.[299] In the future, §1536(a)(2) may be implicated by most climate engineering efforts. Consequently, this suggests one means by which the federal government might play a larger role in the future.

7. National Environmental Policy Act

The National Environmental Policy Act (NEPA)[300] mandates the preparation of a detailed environmental impact statement (EIS) whenever a federal agency proposes "legislation and other major Federal actions significantly affecting the quality of the human environment."[301] Such "major Federal action" includes partial or complete financing of both

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293. *See generally* 16 U.S.C. §§ 1538, 1540 (describing prohibited actions "with respect to any endangered species of fish or wildlife listed pursuant to section 1533" that may result in a civil penalty).

294. *See id.* § 1532(19).

295. *See* Irvine et al., *supra* note 120, at 2 (describing desert albedo geoengineering).

296. *See* Endangered and Threatened Wildlife and Plants, 50 C.F.R. § 17.3 (2013).

297. *See* Hester, *supra* note 259, at 888 (discussing protection of birds and possible limitations on atmospheric methods under the Migratory Bird Treaty Act).

298. *See* 16 U.S.C. § 1536(a)(2) ("Each Federal agency shall . . . insure that any action . . . is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species . . . .").

299. *See* 50 C.F.R. § 402.01(b) (giving the Fish and Wildlife Service and National Marine Fisheries Service power to administer the act).

300. National Environmental Policy Act, 42 U.S.C. § 4321–4347 (2012).

301. *Id.* § 4332(C).

nonfederal and agency projects.[302] An EIS is a detailed written statement that addresses the environmental impact of the proposed action, alternatives to the action, and any irretrievable commitments of resources.[303] Moreover, NEPA mandates that the agency preparing the EIS shall seek comments from any federal agency with jurisdiction regarding the environmental impact of the action as well as comments from the public.[304]

NEPA, however, is merely a procedural statute.[305] It "does not mandate particular results."[306] Instead, it requires only "that the agency, in reaching its decision, will have available, and will carefully consider, detailed information concerning significant environmental impacts."[307] As a result, NEPA can be a powerful yet impotent force in regulating climate engineering efforts. NEPA can be powerful because it forces federal agencies to evaluate potential alternatives[308] and to provide public notice of all government-sponsored projects that affect the quality of the human environment.[309] On the other hand, NEPA provides no means to prevent implementation of these proposals.[310] Indeed, courts long have recognized that the remedy for a violation of NEPA is merely compliance with the procedural requirements of the statute.[311] A party cannot use a failure to comply with NEPA as a means to stop a proposed action permanently.[312]

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302. *See* 40 C.F.R. § 1508.18(a) ("Actions include new and continuing activities, including projects and programs entirely or partly financed, assisted, conducted, regulated, or approved by federal agencies . . . .").

303. *See* 42 U.S.C. § 4332(c) (listing environmental impact, adverse effects of implementation, alternatives, and irretrievable commitment of resources as required elements of a statement).

304. *See* 40 CFR § 1503.1(a) (requiring comment on the draft environmental impact statement from the public and the federal agency with jurisdiction before submitting a final environmental impact statement).

305. *See* Winter v. Natural Resources Defense Council, Inc., 555 U.S. 7, 23 (2008) ("NEPA imposes only procedural requirements . . . .").

306. Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 350 (1989).

307. *Id*. at 349.

308. *See* 42 U.S.C. § 4332(c) (requiring an agency to describe alternatives to the proposed action).

309. *See* 40 CFR § 1506.6(b) ("Agencies shall: . . . [p]rovide public notice of NEPA-required hearings, public meetings, and the availability of environmental documents so as to inform those persons and agencies who may be interested or affected.").

310. See *Winter*, 555 U.S. at 23 (discussing NEPA as a procedural statute that merely requires agencies to contemplate consequences of their action before the action is implemented).

311. *See* Vermont Yankee Nuclear Power Corp. v. Natural Res. Def. Council, Inc., 435 U.S. 519, 558 (1978) ("NEPA does set forth significant substantive goals for the Nation, but its mandate to the agencies is essentially procedural. . . . Administrative decisions should be set aside . . . only for substantial procedural or substantive reasons as mandated by statute.").

312. *See Winter*, 555 U.S. at 23 (concluding that NEPA ensures "that the agency, in reaching its decision, will have available, and will carefully consider, detailed information concerning significant environmental impacts" (internal quotations omitted)).

Moreover, NEPA requirements take effect only when the proposed action implicates a federal agency.[313] Absent such involvement, NEPA cannot compel any action.[314]

8. Clean Water Act

The Clean Water Act (CWA)[315] seeks to restore the integrity of the nation's waters[316] by eliminating the discharge of pollutants into them.[317] The CWA seeks to achieve this goal primarily by requiring a permit for the discharge of any pollutant by point sources.[318]

The CWA is unlikely to impede climate engineering for several reasons. Iron fertilization involves the growth of plankton in water,[319] and oceans, not lakes or rivers, provide the best waters for such efforts,[320] but CWA jurisdiction does not extend to these waters.[321] On the other hand, the CWA is consistent with geoengineering. Wetlands serve as efficient sources of carbon sequestration.[322] The CWA protects wetlands by requiring permits for activities that would harm wetlands.[323] Climate engineering efforts would favor the protection and increase of wetlands. Therefore, the

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313. *See* 40 C.F.R. § 1508.18 (requiring control by a federal agency as part of the definition of an action).

314. *See Winter*, 555 U.S. at 15–16 (stating that NEPA applies when federal agencies take a "major Federal actio[n] significantly affecting the quality of the human environment" (internal quotations omitted)).

315. Clean Water Act, 33 U.S.C. §§ 1251–1387 (2012).

316. *See id*. § 1251(a) ("The objective of this chapter is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters.").

317. *See id*. § 1251(a)(1) ("[I]t is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985 . . . .").

318. *See id*. § 1342(a)(1) (stating the procedure and conditions for obtaining a permit to discharge pollutants); *see also id.* § 1313 (amending the CWA to require states to implement water quality standards).

319. *See* Randall S. Abate & Andrew B. Greenlee, *Sowing Seeds Uncertain: Ocean Iron Fertilization, Climate Change, and the International Environmental Law Framework*, 27 PACE ENVTL. L. REV. 555, 560 (2010) ("[I]ron fertilization involves adding iron to the sea to artificially stimulate the rapid growth of phytoplankton.").

320. *See id.* at 559 ("[O]cean iron fertilization activities generally take place on the high seas.").

321. *See* 33 U.S.C. § 1362(7)–(8) (defining "navigable waters" of the United States to include the "territorial seas" that extend seaward a distance of only three miles).

322. *See* Blanca Bernal & William J. Mitsch, *Comparing Carbon Sequestration in Temperate Freshwater Wetland Communities*, 18 GLOBAL CHANGE BIOLOGY 1636, 1636 (2012) (describing wetlands' capacity as significant carbon sinks).

323. *See* 33 U.S.C. § 1344(a) (authorizing the Secretary to issue permits).

CWA is consistent with these objectives,[324] and such geoengineering efforts would not conflict with the CWA.

B. International Environmental Laws

Like domestic law, most international treaties are targeted to the control of pollution.[325] Even those international laws that regulate some aspect of climate engineering research and deployment will have limited impact on efforts conducted in the United States.[326] Although the United States has signed some of these agreements, it has not ratified most of them, and consequently, is not bound by their terms.[327]

1. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention)[328] became available for signature in 1972 and entered into force in 1975.[329] The United States is a signatory to the London Convention.[330]

As noted previously, the United States implements its obligations under the London Convention through the MPRSA.[331] The London Convention requires parties "to take all practicable steps to prevent the pollution of the sea by the dumping of waste and other matter."[332] In its definition of "dumping," however, the London Convention excludes the

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324. *See id*. § 1251(a) ("The objective of this chapter is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters.").

325. *See* Davis, *supra* note 154, at 930–31 (stating that it is a principle of international law to prevent pollution).

326. *See* Brugato, *supra* note 277, at 347–52 (discussing the lack of international treaties on domestic efforts at sequestration).

327. *See* Medellin v. Texas, 552 U.S. 491, 505 (2008) ("While treaties 'may comprise international commitments . . . they are not domestic law unless Congress has either enacted implementing statutes or the treaty itself conveys an intention that it be "self-executing" and is ratified on these terms.'" (quoting Iguartua-De La Rosa v. United States, 417 F.3d 145, 150 (1st Cir. 2005) (en banc) (Boudin, C.J.))).

328. Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, *opened for signature* Dec. 29, 1972, 26 U.S.T. 2403, [hereinafter London Convention], *available at* http://treaties.un.org/doc/Publication/UNTS/Volume%201046/volume-1046-I-15749-English.pdf.

329. *See* Brugato, *supra* note 277, at 349 ("The London Convention was opened for signature in 1972 and entered into force in 1975.").

330. *See id.* (stating the United States is one of eighty-five parties to the Convention).

331. *See* Hester, *supra* note 259 and accompanying text.

332. London Convention, *supra* note 328, art. I.

"placement of matter for a purpose other than the mere disposal thereof, provided that such placement is not contrary to the aims of this Convention."[333]

In 1996, the parties to the London Convention adopted the Protocol to the Convention on the Prevention of Marine Pollution (London Protocol) to update and supersede the London Convention.[334] The London Protocol permits subseabed sequestration of carbon.[335] As of May 2012, forty-two countries have joined as parties to the Protocol; the United States is not yet a party to the agreement.[336]

In 2008, the contracting parties to the London Convention and London Protocol adopted nonbinding Resolution LC-LP.1 (2008) on the Regulation of Ocean Fertilization (Resolution).[337] The Resolution expands the London Convention and the London Protocol to include ocean fertilization.[338] It further provides that "ocean fertilization activities other than legitimate scientific research should not be allowed."[339] The Resolution considers non-research activities to be contrary to the London Convention and Protocol and not exempt from the definition of dumping.[340] Research projects should be assessed case-by-case in conjunction with an

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333. *Id.* at art. III, ¶ 1(b)(ii).

334. *See* Carbon Capture and Storage Unit, Int'l Energy Agency, Carbon Capture and Storage and the London Protocol 10 (2011) (Int'l Energy Agency Working Paper), *available at* http://www.iea.org/publications/freepublications/publication/CCS_London_Protocol.pdf (explaining that the London Protocol was meant to replace the London Convention) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

335. *See* Brugato, *supra* note 277, at 351 (describing how the parties of the London Protocol effectively allowed for subseabed sequestration by adopting an amendment to Annex I in 2006).

336. *See* INTERNATIONAL MARITIME ORGANIZATION, 1996 PROTOCOL TO THE LONDON CONVENTION 1972: OVERVIEW OF CONTRACTING STATES (2012), *available at* http://www.imo.org/OurWork/Environment/SpecialProgrammesAndInitiatives/Pages/London-Convention-and-Protocol.aspx (providing a list of the parties to the London Protocol, and noting that the United States is a signatory, but not a party) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

337. *See* Resolution LC-LP.1 (2008) on the Regulation of Ocean Fertilization, *adopted* Oct. 31, 2008, IMO Doc. LC30/16, Annex 6 [hereinafter LC-LP.1], *available at* http://www.imo.org/blast/blastData.asp?doc_id=14101&filename=1.doc%E2%80%8E.

338. *See id.* ¶ 1 (stating that "the scope of the London Convention and Protocol includes ocean fertilization activities"); *see also* Till Markus & Harald Ginzky, *Regulating Climate Engineering: Paradigmatic Aspects of the Regulation of Ocean Fertilization*, 5 CARBON & CLIMATE L. REV. 477, 480 (2011) (describing why the contracting parties came to adopt the nonbinding LC-LP.1 resolution).

339. LC-LP.1, *supra* note 337, ¶ 1.

340. *See id.* ¶ 8 (stating that activities other than scientific research "should be considered as contrary to the aims of the Convention and Protocol").

Assessment Framework.[341] This Framework requires a "scientific quality check and environmental impact assessment."[342]

Therefore, these agreements bind the United States to restrict ocean fertilization activities to scientific research but allow carbon sequestration under the sea.

2. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques

The Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD)[343] is a binding treaty targeted to weather manipulation.[344] ENMOD arose in part as a response to efforts by the United States during the Vietnam War to use cloud seeding to gain military advantage.[345] Although only seventy-four nations are parties to the convention, these parties include most of the world's major economies.[346] The United States ratified the treaty in 1979.[347]

Under ENMOD, each party "undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other State Party."[348] Several relevant points become apparent from this statement. First, the drafters targeted ENMOD to address militaristic or hostile efforts.[349] Second, ENMOD pertains to environmental modification that serves as the "means of destruction,

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341. *See* Markus & Ginzky, *supra* note 341, at 480 (listing a summary of the requirements of LC-LP.1).

342. *Id.* at 481.

343. Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, *opened for signature* May 18, 1977, 31 U.S.T. 333 [hereinafter ENMOD].

344. *See id.* at 335 ("Desiring to prohibit effectively military or any other hostile use of environmental modification techniques.").

345. *See* Davis, *supra* note 154, at 935–36 (describing how the United States "injected silver iodide flares into clouds" over the Ho Chi Minh Trail to increase rainfall and reduce the ability of the North Vietnamese to transport troops and material, and stating that ENMOD was enacted "in response to these 'weather warfare' efforts").

346. *See* Catherine Redgwell, *Geoengineering the Climate: Technological Solutions to Mitigation—Failure or Continuing Carbon Addiction?*, 2 CARBON & CLIMATE L. REV. 178, 183 (2011) ("The treaty enjoys only limited participation, with 74 State Parties, though it should be observed that this includes most major economies . . . .").

347. *See* ENMOD, 343 note 342, at 333 ("The President of the United States of America ratified the Convention on December 13, 1979, in pursuance of the advice and consent of the Senate.").

348. *Id.* at 336.

349. *See id.* (stating that parties to the treaty cannot use military or hostile "environmental modification techniques").

damage or injury."[350] While some climate engineering technologies may create disparate effects across the globe,[351] the motivation for their use is benevolent rather than hostile.[352] Moreover, ENMOD recognizes that "environmental modification techniques for peaceful purposes could . . . contribute to the preservation and improvement of the environment for the benefit of present and future generations."[353] Thus, ENMOD appears inapplicable to geoengineering for the purpose of improving the environment.[354] Finally, even if it were applicable, at least one major gap exists in its coverage: ENMOD addresses state action.[355] However, as discussed previously, some climate engineering methods are sufficiently inexpensive that one or more private individuals could fully finance them.[356]

3. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies

In 1967 the United Nations' Committee on the Peaceful Uses of Outer Space developed the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and

350. *Id.*
351. *See* Michael C. MacCracken, *Geoengineering: Worthy of Cautious Evaluation?*, 77 CLIMATIC CHANGE 235, 238–39 (2006) (noting that "climate" is actually a "mathematical construct created by averaging weather," and ENMOD might prohibit geoengineering for climate change because a plan implemented by a few countries may affect several others, creating hostility). *But see* Rob Gurto, *What's the Difference Between Weather and Climate?*, NASA (Feb. 1, 2005), http://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html (recognizing that climate and weather pertain to different periods of time, which may weaken MacCracken's argument that relies on the similarities between weather and climate) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).
352. *See* ROYAL SOCIETY, *supra* note 5, at 1 (explaining that geoengineering projects are focused on mitigating the effects of, and adaptation to, climate change).
353. ENMOD, *supra* note 343, at 336.
354. *See id.* at 335 ("[E]nvironmental modification techniques for peaceful purposes could . . . contribute to the preservation and improvement of the environment for the benefit of present and future generations.").
355. *See id.* (including only "State Parties" in the provisions and requirements of the convention).
356. *See* Burns, *supra* note 142 (claiming that even a single state or private individual could finance climate engineering projects).

Other Celestial Bodies (Outer Space Treaty).[357] The United States Senate ratified the Outer Space Treaty shortly after it was opened for signature.[358]

The Outer Space Treaty arose in response to the Cold War and the resulting "Space Race."[359] Because of the concerns of the day, the Outer Space Treaty sought mainly to prevent the use of outer space as a base for military operations and to avoid military conflict regarding space.[360] For these reasons, the Outer Space Treaty is especially focused on the peaceful and beneficial use of space.[361] Thus, the Outer Space Treaty's preamble notes that the parties desire outer space to be used for peaceful purposes,[362] and Article I notes that space exploration should be carried out for the benefit of all countries.[363]

While the Outer Space Treaty primarily seeks to ensure the peaceful exploration and use of space,[364] which would be consistent with space-based climate engineering proposals,[365] it also addresses liability for

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357. Treaty on the Principles Governing the Activities of the States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, *opened for signature* Jan. 27, 1967, 18 U.S.T. 2410 [hereinafter Outer Space Treaty].

358. *See id.* at 2410 (listing the dates when the treaty was formed (Jan. 27, 1967) and ratified by the United States (Oct. 10, 1967)).

359. *See* Matthew Johnshoy, Note, *The Final Frontier and a Guano Islands Act for the Twenty-First Century: Reaching for the Stars Without Reaching for the Stars*, 37 J. CORP. L. 717, 723 (2012) ("This treaty was adopted during the height of the Cold War under the intense pressures of the race to the moon."); *see also* Vladimír Kopal, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies: Introduction*, UNITED NATIONS AUDIOVISUAL LIBRARY OF INT'L LAW (2008), http://untreaty.un.org/cod/avl/ha/tos/tos.html (explaining the history of the development of the Outer Space Treaty under the Committee on the Peaceful Uses of Outer Space) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

360. *See* Blake Gilson, Note, *Defending Your Client's Property Rights in Space: A Practical Guide for the Lunar Litigator*, 80 FORDHAM L. REV. 1367, 1369 (2011) (describing the main concerns behind the Outer Space Treaty relating to potential military development and conflict).

361. *See* Lyndon B. Johnson, Remarks at the Signing of the Treaty on Outer Space (Jan. 27, 1967), *available at* http://www.lbjlib.utexas.edu/johnson/archives.hom/speeches.hom/670127.asp ("This treaty means that the moon and our sister planets will serve only the purposes of peace and not war.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

362. *See* Outer Space Treaty, *supra* note 357, at 2411 ("Recognizing the common interest of mankind in the exploration and use of outer space for peaceful purposes . . . .").

363. *See id.* at 2412 ("The exploration of outer space . . . shall be carried out for the interests of all countries . . . .").

364. *See id.* at 2411, 2413, 2418 (noting that the treaty encourages peaceful use and exploration of outer space).

365. *See* ROYAL SOCIETY, *supra* note 5, at 40 (explaining that the Outer Space Treaty would require use of climate engineering technologies that would not interfere with "peaceful exploration and use of outer space").

space-based activities.[366] Specifically, Article VII provides for liability for damage by an object launched into space.[367] The Outer Space Treaty extends liability to damage occurring in the atmosphere or outer space.[368] While not necessarily a limit on geoengineering, it may be argued that this provision imposes liability for damage that such technologies cause.[369] The terms of this provision, however, suggest that the intent of the drafters was to address direct physical damage, such as a collision in space or the atmosphere, caused by launched objects.[370] Although the Outer Space Treaty extends liability to damage caused in Earth's atmosphere, it appears not to cover the emission of sulfur or other particles.[371] The Outer Space Treaty is targeted to objects that are launched with the intent of entering outer space.[372] SRM methods, however, propose to emit particles into the stratosphere, rather than outer space.[373]

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366. *See* Outer Space Treaty, *supra* note 357, at 2415 (including the obligations of State Parties in article VI and liabilities of these parties in article VII).

367. *See id.* ("Each State Party to the Treaty that launches or procures the launching of an object into outer space . . . is internationally liable for damage to another State Party to the Treaty . . . .").

368. *See id.* (describing liability for damage as extending to damage "in air space or in outer space").

369. *See* Ralph Bodle et al., *The Regulatory Framework for Climate-Related Geoengineering Relevant to the Convention on Biological Diversity* 99, 132 (Convention on Biological Diversity, Technical Series No. 66, 2012), *available at* http://www.cbd.int/doc/publications/cbd-ts-66-en.pdf (stating that article VII may create liability if one can prove an "adequate level of causation" between the geoengineering technique and the damage) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

370. *See* Eilene Galloway, *The United States and the 1967 Treaty on Outer Space*, *in* PROCEEDINGS OF THE FORTIETH COLLOQUIUM ON THE LAW OF OUTER SPACE 18, 26 (1998) (stating that United States Ambassador Arthur Goldberg testified before the Senate about the treaty and how article VII only covers "damage caused by an impact of a space vehicle or object").

371. *See* Outer Space Treaty, *supra* note 357, at 2415 (providing that states will be liable for damages to other states if they launch an object which causes damage to property of other states, whether in the air or in space).

372. *See Science: Ozone Basics*, STRATOSPHERIC OZONE: MONITORING AND RESEARCH IN NOAA, http://www.ozonelayer.noaa.gov/science/basics.htm (last updated Mar. 20, 2008) (defining the stratosphere as the section of Earth's atmosphere that is between ten and thirty miles above the Earth's surface) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); Joseph S. Imburgia, *Space Debris and Its Threat to National Security: A Proposal for a Binding International Agreement to Clean Up the Junk*, 44 VAND. J. TRANSNAT'L L. 589, 612 (2011) (describing the popular, unofficial standard that Earth's atmosphere ends, and outer space begins, 100 kilometers above Earth's surface).

373. *See, e.g.*, Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?*, 77 CLIMATIC CHANGE 211, 212 (2006) (describing a proposal to inject sulfur into the stratosphere); ROYAL SOCIETY, *supra* note 5, at 26 (explaining cloud-albedo enhancement).

4. Long-Range Transboundary Air Pollution Treaty for Europe and North America

The Long-Range Transboundary Air Pollution Treaty for Europe and North America (LRTAP)[374] was developed in 1979 in response to acid rain.[375] The LRTAP addresses the international implications of acid rain.[376] Three Protocols to the Treaty regulate sulfur emissions.[377]

As its title indicates, the LRTAP is targeted to the reduction and prevention of air pollution.[378] Nevertheless, its definition of "air pollution" may be broad enough to extend to some aerosol particle methods: "the introduction . . . of substances . . . into the air resulting in deleterious effects of such a nature as to endanger human health, [and] harm living resources and ecosystems . . . ."[379] Although climate engineers would argue that their actions are not intended to endanger humans or ecosystems,[380] without further research into potential damage, the LRTAP appears to restrict sulfate aerosols.[381]

5. Vienna Convention for the Protection of the Ozone Layer

The Vienna Convention for the Protection of the Ozone Layer (Vienna Convention)[382] arose in response to concerns that humans produced

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374. Convention on Long-Range Transboundary Air Pollution, *opened for signature* Nov. 13, 1979, 34 U.S.T. 3044 [hereinafter LRTAP].

375. *See* Amy A. Fraenkel, Comment, *The Convention on Long-Range Transboundary Air Pollution: Meeting the Challenge of International Cooperation*, 30 HARV. INT'L L.J. 447, 449 (1989) (explaining that acid rain was the impetus for LRTAP).

376. *See id.* at 95 ("The problem required an international response and led eventually to the Convention on Long-Range Transboundary Air Pollution.").

377. *See* Redgwell, *supra* note 346, at 185 (explaining that LRTAP has several protocols, two of which regulate sulfur emissions).

378. *See* LRTAP, *supra* note 374, at 3046 ("The Contracting Parties . . . are determined to . . . gradually reduce and prevent air pollution including long-range transboundary air pollution.").

379. *Id.* at 3046.

380. *See* ROYAL SOCIETY, *supra* note 5, at 1 (discussing the goals of geoengineering proposals to reduce the effects of climate change).

381. *See Status of the Convention on Long-Range Transboundary Air Pollution and its Related Protocols*, UNITED NATIONS ECONOMIC COMM'N FOR EUROPE (Sept. 11, 2013), http://www.unece.org/fileadmin/DAM/env/documents/2013/air/1convention_status_2pager_7May2013_rev.pdf (listing subsequent protocols to the LRTAP, including the 1985 and 1994 protocols, which limit sulfur emissions, and noting that the United States did not sign or ratify these protocols) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

382. Vienna Convention for the Protection of the Ozone Layer, *opened for signature* Mar. 22, 1985, T.I.A.S. No. 11097, 1 [hereinafter Vienna Convention].

chemicals that would reduce the planet's ozone layer.[383] The Vienna Convention opened for signature in 1985.[384] Two years later the Montreal Protocol on Substances that Deplete Ozone Layer (Montreal Protocol) opened for signature.[385] Parties to the Vienna Convention agree to reduce activities that would adversely impact the ozone layer.[386] The Montreal Protocol requires reductions in the production and consumption of certain controlled substances.[387]

The Vienna Convention and Montreal Protocol target their regulations to materials that harm the ozone layer.[388] Thus, they likely would apply to aerosol injection methods that would adversely impact the ozone layer.[389] Sulfur, the most prominent ingredient for atmospheric injections, reacts with chlorine in cold temperatures to form molecules that destroy ozone.[390] Scientists have calculated that injecting sulfur into the atmosphere to the extent required to engineer the climate would seriously impact the ozone levels at the poles.[391] Thus, the use of sulfur particles likely would violate the Vienna Convention and Montreal Protocol. Sulfur

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383. *See* Edith Brown Weiss, *Introductory Note: The Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances That Deplete the Ozone Layer*, UNITED NATIONS AUDIOVISUAL LIBRARY OF INT'L LAW, http://untreaty.un.org/cod/avl/ha/vcpol/vcpol.html (last visited Sept. 8, 2013) (stating that in the 1970s, scientists realized that manmade chemicals could harm the ozone layer) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

384. *See id.* ("The Convention . . . was opened for signature at Vienna on 22 March 1985.").

385. *See* Montreal Protocol on Substances that Deplete the Ozone Layer, *opened for signature* Sept. 16 1987, 1522 U.N.T.S. 28, 28 [hereinafter Montreal Protocol].

386. *See* Vienna Convention *supra* note 382, at art. 2 ¶ 2(b) (stating that parties will work to "control, limit, reduce, or prevent" activities that harm the ozone layer).

387. *See* Montreal Protocol, *supra* note 385, at 31–33 (listing requirements related to certain controlled substances, and the limits for use and production).

388. *See* Vienna Convention, *supra* note 382, at pmbl. (stating that parties to the convention are "[d]etermined to protect human health and the environment against adverse effects resulting from modifications of the ozone layer"); Montreal Protocol, *supra* note 385, pmbl. (stating that parties to the convention are "[d]etermined to protect the ozone layer by taking precautionary measures to control . . . global emissions of substances that deplete it").

389. *See generally* Simone Tilmes et al., *The Sensitivity of Polar Ozone Depletion to Proposed Geoengineering Schemes*, SCIENCE MAG., May 30, 2008, at 1201, *available at* http://www.sciencemag.org/content/320/5880/1201.full.pdf?sid=f502b927-7b6a-4d39-817f-caf88a076324 (discussing the impact of atmospheric injection on the ozone layer) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

390. *See id.* at 1201 ("The combination of very low temperatures and increasing sunlight after the polar night results in a strong transformation of chlorine from reservoir forms to reactive radicals, leading to the rapid destruction of polar ozone.").

391. *See* Tilmes et al., *supra* note 161, at 20 ("The injection of a constant amount of sulfur in the stratosphere, as considered here, results in a constant offset of temperatures in the tropics at different altitudes after an adjustment time in the troposphere of approximately 5 years.").

substitutes that do not deplete the ozone layer should not fall within the restrictions of these treaties.

6. Convention on Biological Diversity

The Convention on Biological Diversity (CBD)[392] seeks to conserve biodiversity and promote sustainable uses of its components.[393] The overarching principle that guides the agreement is that nations have "the sovereign right to exploit their own resources" but the "responsibility to ensure" that activities within their own borders "do not cause damage beyond the limits of [their] national jurisdiction."[394]

In 2008, the parties to the CBD considered adopting a moratorium on all ocean fertilization efforts.[395] Instead, they adopted an approach similar to the approach taken by the London Convention, requiring an adequate scientific basis and a global regulatory mechanism.[396] In 2010, the parties adopted COP 10 Decision X/33, which expands the CBD to address all climate engineering activities.[397] Decision X/33 provides that parties ensure that "no climate-related geo-engineering activities that may affect biodiversity take place, until there is an adequate scientific basis on which to justify such activities, . . . with the exception of small scale scientific research studies . . . ."[398] Thus, even though the CBD restricts the implementation of climate engineering, the parties nevertheless recognize

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392. Convention on Biological Diversity, *opened for signature* June 5, 1992, 1760 U.N.T.S. 142 [hereinafter CBD].

393. *See id.* at 146 (stating that objectives include the "conservation of biological diversity, [and] the sustainable use of its components").

394. *Id.* at 147.

395. *See* Subsidiary Body on Scientific, Technical and Technological Advice [SBSTTA], *Biodiversity and Climate Change: Options for Mutually Supportive Actions Addressing Climate Change Within the Three Rio Conventions*, § A, ¶ 21, SBSTTA 13 Recommend. XIII/6 (Feb. 18–22, 2008), *available at* http://www.cbd.int/recommendation/sbstta/default.shtml?id=11619 (urging parties to adopt a moratorium on all ocean fertilization activities because of questions about its effectiveness and its potential adverse impacts on marine biodiversity) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

396. *See* Redgwell, *supra* note 346, at 187 (explaining the approach to ocean fertilization activities that the CBD adopted).

397. *See* Conference of the Parties to the Convention on Biological Diversity, *Biodiversity and Climate Change*, ¶ 8(w), Decision X/33 (Oct. 29, 2010), [hereinafter COP Decision X/33.8(w)], *available at* http://www.cbd.int/doc/decisions/cop-10/cop-10-dec-33-en.pdf (addressing "climate-related geo-engineering activities," and not just ocean fertilization activities) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

398. *See id.* ¶ 8(w) n.3 (explaining that geoengineering activities are defined as "any technologies that deliberately reduce solar insulation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity").

the need to allow small-scale research.[399] Regardless, these provisions do not apply to the United States, since it is not a party to the CBD.[400]

7. United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC)[401] commits parties to gather information regarding greenhouse gas (GHG) emissions, and to prepare for the effects of climate change.[402] The United States became a party to the UNFCCC in 1992.[403] The subsequent Kyoto Protocol requires nations to commit to legally binding reductions in GHGs.[404] The United States has signed the Kyoto Protocol, but the Senate has not ratified it.[405]

Because of their focus on mitigation and adaptation, neither the UNFCCC nor any of the related agreements, such as the Kyoto Protocol, address climate engineering directly.[406] Parties to the UNFCCC commit to conserve and enhance carbon sinks, however, including forests and oceans.[407] Given these sinks' ability to remove carbon from the atmosphere, this commitment is consistent with the aims of geoengineering, particularly

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399. *See id.* ¶ 8(w) (stating that climate engineering technologies that influence biodiversity cannot take place unless they are small-scale research projects).

400. *See* CBD, *supra* note 392, at n.1 (listing the parties to the convention and their date of ratification, and the United States is not included).

401. United Nations Framework Convention on Climate Change, *opened for signature* May 9, 1992, 1771 U.N.T.S. 164 [hereinafter UNFCCC Treaty], *available at* http://treaties.un.org/doc/source/RecentTexts/unfccc_eng.pdf.

402. *See id.* (introducing the requirements of the convention).

403. *See id.* at 166 n.1 (indicating that the United States ratified the UNFCCC on Oct. 15, 1992).

404. *See Background on the UNFCCC: The International Response to Climate Change*, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, http://unfccc.int/essential_background/items/6031.php (last visited October 24, 2013) (explaining how the Kyoto Protocol adds on to UNFCCC) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

405. *See Status of Ratification of the Kyoto Protocol*, UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE, http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php (last visited October 24, 2013) (noting that the United States signed the Kyoto Protocol on Nov. 12, 1998, but has not ratified it) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

406. *See generally* UNFCCC Treaty, *supra* note 401 (focusing entirely on mitigation of climate change, and not addressing geoengineering).

407. *See id.* at art. 4, ¶ 1(d) (stating that one of the UNFCCC Treaty's purposes is to "promote sustainable management, and promote and cooperate in the conservation and enhancement . . . of sinks and . . . forests").

CDR.[408] As this paper will discuss later, the UNFCCC also requires nations to cooperate in the "full, open, and prompt exchange" of scientific and technological information concerning the climate system.[409]

8. Regulation of Transboundary Pollution

Transboundary pollution consists of "pollution whose physical origin is situated wholly or in part within the area under the jurisdiction of one [state] and which has adverse effects, other than effects of a global nature, in the area under the jurisdiction of [another state]."[410] Customary international law requires states to ensure that activities under their jurisdiction do not cause such harm.[411] The Trail Smelter Arbitration between the United States and Canada applied this principle.[412]

Subsequently, the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention)[413] was formed to regulate transboundary harms.[414] The Espoo Convention requires parties to assess the environmental impact of activities at an early stage and to notify and consult each other on all major projects likely to have a

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408. *See* ROYAL SOCIETY, *supra* note 5, at 1 (stating that geoengineering aims to offset the effects of climate change, and the commitments under the UNFCCC also have this goal).

409. UNFCCC Treaty, *supra* note 401, at art. 4, ¶ 1(h); *see also* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, Agreed Reference Material for the IPCC Fifth Assessment Report (2013) (unpublished outline), *available at* http://www.ipcc.ch/pdf/ar5/ar5-outline-compilation.pdf (including several geoengineering topics in the chapter outlines, even though UNFCCC has not yet addressed climate engineering) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

410. Agreement on Air Quality art. I, ¶ 2, U.S.-Can., Mar. 13, 1991 30 I.L.M. 676, 679 (1991).

411. *See* RESTATEMENT (THIRD) OF FOREIGN RELATIONS LAW OF THE U. S. § 601 (2013) (describing state responsibility for environmental injury to other jurisdictions as a result of the state's actions).

412. *See* Jon M. Van Dyke, *Liability and Compensation for Harm Caused by Nuclear Activities*, 35 DENVER J. INT'L L. & POL'Y 13, 13 (2006) (stating that the Trail Smelter Arbitration applied the "no-harm rule"); *see also* Noah D. Hall, *Transboundary Pollution: Harmonizing International and Domestic Law*, 40 U. MICH. J. L. REFORM 681, 696 (2007) (describing the facts of the case and how the Trail Smelter Arbitration is unique because it remains the only international decision that specifically involves transfrontier pollution); *id.* at 696–98 (describing how the tribunal held that no state may permit its territory to be used in a manner to cause injury by fumes in the territory of another state).

413. Convention on Environmental Impact Assessment in a Transboundary Context, *opened for signature* Feb. 25, 1991, 1989 U.N.T.S. 309 [hereinafter Espoo Convention].

414. *See id.* at pmbl. (stating that one of the purposes of the Espoo Convention is to "enhance international co-operation in assessing environmental impact in particular in a transboundary context").

significant, adverse environmental impact across boundaries.[415] Although a signatory to the Espoo Convention, the United States has not ratified it.[416] Separately, though, the United States and Canada entered into an agreement to address acid rain caused by transboundary pollution.[417] This agreement would implicate sulfur aerosols.[418] Other aerosol methods, however, are unlikely to fall under this agreement or related precedent.[419]

C. A Summary—Regulatory Coverage of Climate Engineering by the United States.

Because both domestic and international environmental laws developed to address pollution, there are only a series of patchwork amendments provide sporadic coverage of climate engineering research and testing.[420] A comprehensive regulatory regime has been developed for only one method, a subcategory of carbon sequestration.[421] Other methods, including ocean fertilization and stratospheric aerosol injections, may be

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415. *See id.* at art. III (describing requirements for notifying nearby states of activities likely to have a transboundary impact).

416. *See Status: Convention on Environmental Impact Assessment in a Transboundary Context*, UNITED NATIONS TREATY COLLECTION, https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-4&chapter=27&lang=en (last visited Jan. 6, 2014) (indicating that the United States signed the convention on Feb. 26, 1991) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

417. *See* Agreement on Air Quality, U.S.-Can., Mar. 13, 1991, 1852 U.N.T.S. 80 (noting that a broader North American Agreement on Transboundary Environmental Impact Assessment between Canada, Mexico, and the United States has been drafted, but final negotiations have stalled over the application of the agreement to state and local governments); *see also* Charles M. Kersten, *Rethinking Transboundary Environmental Impact Assessment*, 34 YALE J. INT'L LAW 173, 178 (2009) (describing the value of international environmental impact statements).

418. *See* Agreement on Air Quality, *supra* note 417, at annex (enumerating objectives concerning the reduction of sulfur dioxide); *id.* at art. I (defining "air pollution" as "the introduction by man, directly or indirectly, of substances into the air resulting in deleterious effects of such a nature as to endanger human health, harm living resources and ecosystems").

419. *See* Davidson et al., *supra* note 117, at 4266 (describing the properties of alternatives to sulfur aerosols).

420. *See* BRACMORT & LATTANZIO, *supra* note 165, at 24 ("While no federal law has been enacted with the express purpose of covering geoengineering activities, some legal instruments may currently apply to domestic geoengineering practices and their impacts, depending on the type, location, and sponsor of the activity.").

421. *See id.* ("In July 2008, the [EPA] relied on its authority under the Safe Water Drinking Act to issue a draft rule that would regulate CO_2 injection for the purposes of geological sequestration.").

affected by existing federal law.[422] Meanwhile, other methods of climate engineering remain almost wholly unregulated.[423]

The following table identifies the primary climate engineering methods currently identified by scientists and the United States laws and binding international treaties that regulate their research and testing:

Table 1

Method	**Regulating Laws**
Ocean fertilization	MPRSA, London Convention
Ground-based reflectors	ESA (indirect)
Sequestration—underground	Safe Drinking Water Act
Sequestration - subseabed	(None)
Aerosols - sulfur	CAA, Montreal Protocol, LRTAP, Canada-U.S. Agreement
Aerosols - non-sulfur	(None)
Space-based mirrors	(None)
Enhanced up/downwelling	(None)
Cloud whitening	(None)

Table 1 highlights several aspects of the patchwork nature of the United States' regulation of climate engineering activities. First, only three methods are regulated directly: carbon dioxide sequestration, ocean fertilization, and sulfur aerosol injection.[424] The parties to the London

422. *See id.* at 24–25 (discussing geoengineering methods and the federal laws that may regulate them).

423. *See id.* at 26 (noting the lack of unified federal regulatory authority over geoengineering techniques); *id.* at 25 ("Moreover, in the absence of federal lawmaking, some states have begun developing their own policies to address particular geoengineering activities.").

424. *See id.* at 23–25 (noting the EPA's jurisdiction pursuant to the Clean Air Act and Clean Water Act to regulate carbon dioxide sequestration, ocean fertilization, and stratospheric aerosol injection).

Convention and the London Protocol, after the disputes arising from the Planktos incident, amended those agreements to incorporate ocean fertilization.[425] The EPA recently approved regulations pursuant to the Safe Drinking Water Act to control carbon sequestration.[426] Finally, sulfur aerosols fall within both domestic (Clean Air Act) and international (the LRTAP, Montreal Protocol, and the Canada-U.S. Agreement) regulations.[427]

To the extent that United States law or binding international law regulates other methods, it does so indirectly, occasionally, or loosely. For example, the ESA does not directly regulate the placement of reflectors,[428] but it may be implicated if their placement harmed a threatened or endangered species.[429] NEPA also does not apply to any particular method,[430] but its requirements may be implicated by any geoengineering efforts that require major federal action.[431] The Outer Space Treaty extends to injuries caused by space objects,[432] but it addresses militaristic uses of space.[433] Similarly, ENMOD, which prohibits weather manipulation, is directed to military efforts.[434]

Table 1 also demonstrates that no uniform body of regulations governs the development and deployment of climate engineering. Sections of different statutes or treaties address different aspects of geoengineering, but they were approved at different times in response to different circumstances.[435] Moreover, these laws were approved at different times in response to different circumstances.[436] No comprehensive regulatory

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425. *See supra* Part III.B.1 (discussing the development of the London Convention).

426. *See generally* Class VI Rule, *supra* note 210 (implementing requirements for carbon sequestration).

427. *See generally supra* Part III.A and B (discussing domestic and international laws that may govern aerosol injection).

428. *See* 16 U.S.C. § 1531–44 (lacking explicit mention of solar reflectors).

429. *See id.* § 1538(a)(1)(B) ("[I]t is unlawful for any person subject to the jurisdiction of the United States to . . . take any [endangered] species within the United States . . . .").

430. *See* 42 U.S.C. § 4332 (2012).

431. *See id.* § 4332(c) (requiring detailed environmental impact statement for major federal action affecting the quality of the human environment).

432. *See* Outer Space Treaty, *supra* note 357 (noting the application of the treaty to injuries from outer space activities).

433. *See id.* (discussing that the context of the treaty relates to military action).

434. *See* ENMOD, *supra* note 343 (observing that the application of this agreement affects military action).

435. *See* BRACMORT & LATTANZIO, *supra* note 165, at 24–28 (describing the piecemeal nature of government oversight of geoengineering activities).

436. *See id.* at 24 (describing how the Clean Air Act Amendments of 1990 might apply to aerosol injection).

scheme has been developed for climate engineering, nor does any single body regulate these efforts.[437]

Finally, no federal law expressly prohibits any type of climate engineering.[438]

IV. The United States Should Enact a Comprehensive Legal Scheme to Regulate and Encourage Climate Engineering Research and Testing

Nothing short of drastic measures can avert significant climate change.[439] Thus, society must explore alternatives to mitigation and adaptation to minimize the consequences of this change.[440] The United States should take a leadership role in this effort. To do so, it must develop a comprehensive scheme of regulation, establish a regulatory body to oversee these efforts, and facilitate this research. Furthermore, by instituting a domestic program addressing climate engineering research, this program may become a model for a future international agreement.

A. The United States Should Promptly Commence a Geoengineering Research Program

For several reasons, the United States should not wait for an international agreement to be reached; it should commence its own research on geoengineering.[441] Several reasons support this conclusion. First, the realities of climate change and the time to develop responsive technologies necessitate that research commence forthwith.[442] As discussed previously, the planet is already warming, and numerous feedbacks in the climate

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437. *See id.* (discussing how in the absence of a federal program, "some legal instruments may currently apply to domestic geoengineering efforts and their impacts").

438. *See id.* ("[N]o federal law has been enacted with the express purpose of covering geoengineering activities . . . .").

439. *See* ROYAL SOCIETY, *supra* note 5, at ix ("It is likely that global warming will exceed 2° C this century unless global greenhouse gas emissions are cut by at least 50% of 1990 levels by 2050, and by more thereafter.").

440. *See id.* ("Unless future efforts to reduce greenhouse gas emissions are much more successful than they have been so far, additional action may be required should it become necessary to cool the Earth this century.").

441. *See* Davis, *supra* note 154, at 907–08 (suggesting the United States should not wait to complete such arrangements before commencing its program).

442. *See* BRACMORT & LATTANZIO, *supra* note 165, at 3 ("Little research has been done on most geoengineering methods, and no major directed research programs are in place . . . [but] more research would be required to test the feasibility, effectiveness, cost, social and environmental impacts, and the possible unintended consequences of geoengineering before deployment.").

system may accelerate this warming,[443] which will continue regardless of the success of mitigation efforts.[444] Structural characteristics of our energy system will perpetuate significant carbon emissions for decades.[445] Moreover, research, modeling, and testing climate engineering proposals will require many years.[446]

Second, a meaningful international agreement is not likely to be adopted soon.[447] Particularly when novel issues are involved, the process of reaching international agreement can be time-intensive.[448] Further complicating the process will be the conflicting interests of nations.[449] Some countries, for instance, may seemingly benefit from climate change (especially northern countries such as Russia and Canada);[450] fossil fuel producers and developing countries stand to benefit from business as usual, while smaller nations may be concerned that larger or richer countries will determine their fates.[451] Because of the nature of climate engineering, the only international consensus on the issue might be to impose a moratorium on research and deployment.[452] Unfortunately, the parties most likely to abide by a moratorium are precisely those most likely to study, test, and

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443. *See supra* Part II.B (noting, for example, that increasing global temperatures will melt permafrost and release methane, further exacerbating global warming).

444. *See supra* Part II.C (summarizing arguments that mitigation alone is inadequate to prevent global warming).

445. *See supra* Part II.C (discussing structural aspects of the energy market that impede adoption of clean technologies).

446. *See* ROYAL SOCIETY, *supra* note 5, at 52 ("A R&D programme on geoengineering methods . . . could reduce many of the uncertainties within 10 years.").

447. *See* Carlin, *supra* note 145, at 725 (arguing that an international agreement "appears very unlikely given the history of voluntary international cooperation between nations"); David G. Victor, *On the Regulation of Geoengineering*, 24 OXFORD REV. ECON. POL'Y 322, 324 (2008) ("From today's vantage point, a treaty negotiation would yield inconclusive outcomes . . . .").

448. *See* ROYAL SOCIETY, *supra* note 5, at xi (discussing current and potential international governance problems).

449. *See id.* ("The acceptability of geoengineering will be determined as much by social, legal and political issues as by scientific and technical factors.");

450. *See* Nives Dolsak, *Mitigating Global Climate Change: Why Are Some Countries More Committed Than Others?*, 29 POL'Y STUD. J. 414, 422 (2001) (discussing how geographic and economic factors influence countries' climate change goals).

451. *See* Victor., *supra* note 447, at 324 (" Economic growth tends to trump vague and elusive global aspirations.").

452. *See* BRACMORT & LATTANZIO, *supra* note 165, at 22–23 (noting that at the 2012 climate talks in Doha, the U.N. Climate Change Secretariat dismissed suggestions that the time had arrived to explore geoengineering); *see also* Alister Doyle, *Geo-Engineering Wins Scant Enthusiasm at U.N. Climate Talks*, REUTERS (Dec. 2, 2012), http://www.reuters.com/article/2012/12/02/us-climate-talks-geoengineering-idUSBRE8B103Y20121202 (discussing the uncertainty surrounding geoengineering and potential responses) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

assess these technologies responsibly.[453] A moratorium would thus "leave less responsible governments and individuals—those most prone to ignore or avoid inconvenient international norms—to control the technology's fate."[454]

Another aspect of international treaties, their inherent conservatism, will further reduce the value of an agreement.[455] Nations typically water down the terms of treaties to levels that ensure that compliance is readily achievable.[456] When compliance is not easily achievable, nations simply do not join.[457] In the context of climate engineering, this tendency might limit the methods that are open for consideration or minimize the amount of research and testing that is conducted.[458] Nations lacking the technical ability might seek to limit research and testing.[459] If a treaty's conditions were too restrictive, nations with the ability to pursue climate engineering might simply decline to join the treaty.[460] We already see examples of this process in the recent amendments to the London Protocol and in the Convention on Biological Diversity.[461]

Finally, the United States should commence its own program now to ensure that domestic geoengineering activities are appropriately overseen.[462] Theoretical understanding of climate engineering is increasing, so that scientists and entrepreneurs are beginning to commence their own

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453. *See* Victor, *supra* note 447, at 326 ("A taboo is likely to be most constraining on the countries (and their subjects) who are likely to do the most responsible testing, assessment, and (if needed) deployment of geoengineering systems.").

454. *Id.* at 327.

455. *See id.* at 331 (describing how opposing interests water down the treaty-making process).

456. *See id.* ("[C]ountries adjust their commitments to the point where they are sure that compliance is feasible and because they do not join when commitments are too demanding.").

457. *See id.* at 333 (pointing to the Kyoto Protocol as an example of these tendencies of international agreements).

458. *See id.* (noting that the participation of more nations would lead to more research).

459. *See id.* ("Most nations would probably favor a ban on geoengineering because only a few countries actually have the capability to geoengineer on their own.").

460. *See id.* ("[T]he few nations with unilateral geoengineering capabilities would seek favorable (i.e. vague) language [in the treaty]; if unsuccessful, those countries could simply refuse to join.").

461. *See supra* Part III.B.7 (describing how European nations inserted restrictive language on genetically-engineered crops and the United States, the leader in this field, then refused to join the treaty; *see also* Victor, *supra* note 447, at 331 (stating that the development of the CBD followed this pattern).

462. *See* BRACMORT & LATTANZIO, *supra* note 165, at 21 (discussing concerns in an oversight regime for geoengineering); Andy Ridgwell, Chris Freeman & Richard Lampitt, *Geoengineering: Taking Control of Our Planet's Climate?*, 370 PHIL. TRANSACTIONS ROYAL SOC'Y A 4163, 4163–65 (2012) (examining the level of technological innovation as compared to governance development).

field experiments.[463] In light of the paucity of applicable domestic and international laws, few limitations restrict these activities.[464]

B. The United States Needs to Establish a Single Oversight Body for Climate Engineering Research

The federal government should oversee climate engineering research through a multi-disciplinary body. Federal oversight is important to ensure that uniform regulations and guidelines control these efforts.[465] Indeed, states have already begun to step into the vacuum created by federal inaction.[466] The oversight body should be multidisciplinary to confront managerial, legal, and scientific issues that could arise.[467] The oversight body should also be able to address the historical, ethical and social implications of geoengineering.[468]

Not only should the oversight body incorporate multiple perspectives, it should also be a single, self-contained agency.[469] Creating a

463. *See* Henry Fountain, *A Rogue Climate Experiment Outrages Scientists*, N.Y. TIMES Oct. 18, 2012, at A1 (examining the ability of individuals to conduct their own climate engineering tests).

464. *See* BRACMORT & LATTANZIO, *supra* note 165, at 24 ("The federal government could expand these existing laws to specifically address geoengineering activities or develop new laws. In addition, administrative agencies could interpret their statutory authority to authorize new rules explicitly addressing particular geoengineering activities.").

465. *See* GAO, *supra* note 7, at 23 ("However, without the guidance of an operational definition for what constitutes geoengineering or a strategy to capitalize on existing research efforts, federal agencies may not recognize or be able to report the full extent of potentially relevant research activities.").

466. *See, e.g.*, CAL. PUB. UTIL. CODE § 8341(d)(5) (West 2013); *see also* TEX. NAT. RES. CODE ANN. § 91.802(c) (West 2013) (ensuring that both California and Texas incorporate consideration of carbon sequestration into their codes.); *see also* CAL. PUB. RES. CODE § 35650(b)(2)(J)(i) (West 2013) (providing state funding for research into carbon sequestration in the ocean).

467. *See* Alan Carlin, *Implementation & Utilization of Geoengineering for Global Climate Change Control*, 7 SUSTAINABLE DEV. L. & POL. 56, 56–57 (2007) (explaining that any organization charged with implementing climate change should strive to establish a high level of scientific review, limited legal liability, and cost-efficiency).

468. *See* American Meteorological Society, Policy Statement on Geoengineering the Climate System 1 (Mar. 7, 2009) (draft statement), *available at* http://www.ametsoc.org/policy/draftstatements/geoengineering_draftstatement.pdf ("As with inadvertent human-induced climate change, the consequences of such actions would almost certainly not be the same for all nations and individuals, thus raising legal, ethical, diplomatic, and even national security concerns.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

469. *See* Cesar Cordova-Novion & Stephane Jacobzone, *Strengthening the Institutional Setting for Regulatory Reform: The Experience from OECD Countries* 17, 17 (OECD Working Papers on Public Governance, No. 19, 2011) (noting that multiple governance

single entity will yield the obvious benefits of efficiency, avoidance of regulatory gaps or overlap, consistent oversight, and coordination of efforts.[470] Indeed, while federal agencies have funded some modest climate engineering research efforts, these efforts have been disjointed.[471] At least five agencies have funded geoengineering research.[472] Despite this breadth of effort, the federal government has yet to form a position or strategy concerning climate engineering.[473] While the diversity of geoengineering technologies lends itself to specialization within different federal agencies,[474] those familiar with current federally-funded research efforts urge the creation of a single, interagency, coordinating body.[475]

One benefit of a single oversight body is that it can clearly identify those projects which the federal government would consider to fall within the umbrella of climate engineering.[476] The current lack of such guidance stems from the absence of an operational definition of what geoengineering incorporates.[477] This lack of a clear definition creates several problems. First, climate engineering research is difficult to identify, since projects are

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organizations can "foster duplicative and even contradictory initiatives and efforts") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

470. *See id.* at 18 ("[Reliance on multiple governance bodies] presents costs: budgetary and institutional costs, as various bodies have to compete for scarce talent among officials; administrative costs to co-ordinate these institutions; and most importantly the lack of a more robust single voice advocating regulatory quality.").

471. *See Geoengineering III: Domestic and International Research Governance*, *Hearing Before the H. Comm. on Science, Space and Technology*, 111th Cong. 8–10 (2010) (statement of Frank Rusco, Director of Natural Resources and Environment, Gov't Accountability Office), *available at* http://archives.democrats.science.house.gov/publications/Testimony.aspx?TID=15379 ("Our observations to date indicate that federal agencies . . . have funded some research and small-scale technology testing relevant to proposed geoengineering approaches on an ad-hoc basis.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

472. *See id.* (explaining how efforts are spread among the Department of Energy, the National Science Foundation, the Department of Agriculture, NASA, and the EPA).

473. *See id.* at 9 ("Staff from federal offices coordinating the U.S. response to climate change . . . stated that they do not currently have a geoengineering strategy or position.").

474. *See id.* ("Federal officials noted that a large fraction of the existing federal research and observations on basic climate change and earth science could be relevant to improving understanding about proposed geoengineering approaches and their potential impacts.").

475. *See* GAO, *supra* note 7, at 38 (noting that absent a definition, some actions may not be identified as geoengineering).

476. *See id.* (examining the regulatory options for a federal geoengineering program).

477. *See* Ralph Bodle, *Climate Law and Geoengineering*, *in* CLIMATE CHANGE AND THE LAW 447, 466–67 (Erkki J. Hollo, Kati Kulovesi & Michael Mehling, eds., 2013) (discussing the technical problems with identifying what activities fall under the label of "geoengineering") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

not consistently recognized as falling within it.[478] Second, this lack of clarity hampers efforts to coordinate geoengineering research.[479] Third, it risks some activities being brought under the umbrella of climate engineering that most scientists would not label as such.[480] Not only is a functional definition of climate engineering necessary, the oversight body also needs to be flexible in its application to take into account technological advancements that may suggest new methods to engineer the climate.[481]

C. The United States' Program Should be Fully Transparent

The United States' program should follow certain guidelines. First, it should be transparent, research plans and results should be readily available.[482] Transparency will serve several purposes. First, it will assure that others conducting similar research will remain informed of the most recent developments.[483] Second, transparency will assure other nations and the general public of the integrity and objectives of the program.[484] Absent such assurances, the development of a research and testing program may

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478. *See* GAO, *supra* note 7, at 38 (discussing the lack of consensus about what activities constitute geoengineering).

479. *See id.* ("Variations in agencies' interpretation of our data request, as well as the comments noted above, support our recommendation that additional clarity and guidance regarding the federal approach to geoengineering is needed, and that further discussion of what types of activities should be included in a federal operational definition of geoengineering may be warranted."); *see also* Gordon, *supra* note 5, at 38–39 (noting that government actions need to be clear before going forward with geoengineering).

480. *See* GORDON, *supra* note 5, at 38 (stating that many low-risk activities undertaken for centuries, such as reforestation, could technically fall within this category).

481. *See* Memorandum from the The Royal Society ¶ 18 (Dec. 2009), *available at* http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/10011319.htm (explaining that commentators have called for flexibility in the definition of nanotechnology to allow regulations to adapt as the science develops and new information comes to light) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); *see also* Diana Bowman, Joel D'Silva & Geert van Calster, *Defining Nanomaterials for the Purpose of Regulation within the European Union*, 1 EUROPEAN J. RISK REG. 115, 121 (2010) (noting the difficulty policymakers have had in defining nanomaterials given advances in technology).

482. *See* GAO, *supra* note 7, at 37 ("[A]ny framework governing research should include several elements, such as transparency . . . .").

483. *See id.* at 38 ("[L]ack of information may hinder policy decisions and governance at the domestic and international level.").

484. *See* The Principles, *supra* note 192 (urging transparency to minimize the tendency for individual action to be perceived as potentially infringing on the sovereignty of other nations by crossing national boundaries); *see also* Memorandum from the Dep't of Energy and Climate Change (Jan. 2010), *available at* http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/10011306.htm (examining the need for international regulation of geoengineering) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

inspire an "arms race" in which other nations ramp up their own programs, possibly reducing interest in cooperation on other climate issues.[485] Furthermore, some segment of society is likely to remain skeptical of climate engineering.[486] Full disclosure of its strengths and weaknesses will help to keep this response to a minimum.[487]

Transparency can also help to discourage unilateral testing and implementation of climate engineering.[488] Already, private interests have attempted or begun field testing.[489] Keeping all nations equally informed of geoengineering findings can help to deter rogue entities from unilaterally implementing methods determined to have exceptional risks.[490] Transparency also will better enable nations to monitor for unsanctioned geoengineering implementation.[491] Dissemination of results will keep nations informed of methods, technologies, and their consequences, thereby better enabling nations to monitor for "covert" geoengineering.[492] Finally, it will foster an expectation of transparency around climate engineering, which will be critical should circumstances necessitate that implementation be given serious consideration.[493]

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485. *See* SCI. AND TECH. COMM., THE REGULATION OF GEOENGINEERING—FIFTH REPORT, 2010, H.C. 221, at 32, *available at* http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/221.pdf ("[N]on-public SRM research would exacerbate international mistrust about unilateral control, provoking such disputes and potentially sparking a proliferation of similarly closed programs.").

486. *See* Jay Michaelson, *Geoengineering and Climate Management: From Marginality to Inevitability*, 46 TULSA L. REV. 221, 239 (2010) (discussing the changing values and approaches to climate change management).

487. *See id.* at 227–29 (describing the probability of eventual acceptance of climate management actions).

488. *See* ROBERT L. OLSON, GEOENGINEERING FOR DECISION MAKERS 53 (2011), *available at* http://www.wilsoncenter.org/sites/default/files/Geoengineering_for_Decision_Makers_0.pdf (explaining how an international governance system needs to be able to deter experimentation) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

489. *See, e.g.*, Fountain, *supra* note 463 (describing the actions of a "California businessman" who experimented with ocean fertilization and "outraged scientists and government officials").

490. *See* Olson, *supra* note 488, at 32 ("But if research indicates that deploying that technology could be expected to have dreadful side effects, it is less likely to be used by a rogue actor. We need to know what approaches to avoid even if we are desperate.").

491. *See id.* at 58 (discussing one of the major risks of geoengineering implementation without appropriate governance).

492. *See* Lawrence, *supra* note 177, at 246 (discussing problems with poorly-informed policymakers).

493. *See* Olson, *supra* note 488, at 39–40 (explaining how establishing legitimacy is crucial to any consensus on geoengineering).

D. The Program Should Prohibit Actual Implementation

The research program must be exactly that—a program for research and testing, and not the beginning of implementation.[494] Thus, when it commences this program, the United States must place a moratorium on the use of climate engineering.[495] This will serve two purposes. First, it will ameliorate concerns, especially from other nations, that the United States is preparing to commence geoengineering unilaterally.[496] Second, it will encourage a clear demarcation between research and implementation.[497] A clear division is important so that concerns regarding implementation will not affect decisions regarding research.[498]

E. The United States Should Use NEPA and Financial Incentives to Conduct Geoengineering Research and Testing

The United States should combine a set of regulations and incentives as part of a climate engineering program.[499] Computer modeling, which would be nearly impossible to police and engenders few risks,[500] would not need to be regulated. All field testing would require federal approval, however.[501] Prior to approval, which would be considered a major federal action, the agency would be required to complete the NEPA process.[502] This would make advance consideration of testing's impacts more likely.[503] More importantly, it will ensure that the public is fully informed about the experiment.[504]

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494. *See id.* at 44 (arguing that unapproved implementation could hamper geoengineering governance).

495. *See* Davis, *supra* note 154, at 946 ("First, in order to head off a backlash by the international community against geoengineering, environmental research and testing should be implemented in conjunction with a unilateral moratorium against deployment.").

496. *See id.* at 945–46 (arguing that the United States should both self-impose a moratorium and should "attempt to persuade other countries conducting active environmental research programs to adopt such a moratorium").

497. *See id.* at 944–45 ("A self-imposed prohibition on deployment would clarify the distinction between research and deployment.").

498. *See id.* at 946 (explaining the difference between a research and experimental program).

499. *See* BRACMORT & LATTANZIO, *supra* note 165, at 25–26 (discussing the current and potential uses of government entities to encourage and regulate geoengineering).

500. *See* ROYAL SOCIETY, *supra* note 5, at 17 (noting that computer modeling is already occurring).

501. *See* Davis, *supra* note 154, at 944 (noting how procedural requirements should accompany any action).

502. *See* GAO, *supra* note 7, at 30 ("[G]eoengineering activities undertaken, funded, or authorized by federal agencies would be subject to [NEPA].").

503. *See id.* at 36 ("[T]he legal experts who spoke about domestic regulation generally agreed that the federal government should play a role in governing geoengineering

This proposal thus parallels the approach taken by the CBD.[505] Although the parties amended the CBD to place a moratorium on geoengineering implementation in 2010, it nevertheless allows small-scale scientific research studies.[506] The CBD allows such efforts only where justified by the need to gather specific data and the studies have been subject to a thorough prior assessment of the potential impacts on the environment.[507] Similarly, this proposal prohibits climate engineering implementation and allows limited field testing, but requires extensive pre-testing disclosure and consideration.[508]

Second, to encourage private participation and to facilitate testing, the federal government should clarify the liability of parties conducting field tests.[509] It should impose strict liability because of the potentially ultra-hazardous nature of these activities.[510] On the other hand, the federal government should minimize the costs of liability to encourage participation in the program. For instance, the federal government could require the maintenance of sufficient liability insurance as a precondition to approval, but the government could subsidize the premiums or indemnify the party for any liability found in excess of the required coverage. Currently, the federal government requires nuclear power plant operators to maintain insurance, but it covers claims exceeding the mandated amount.[511] Of course, to receive protection from liability, private parties would need to satisfy all NEPA and related disclosure requirements and any other mandates.[512] Furthermore, the federal government should issue appropriate

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research—either by developing research norms and guidelines or applying existing regulations and guidelines.").

504. *See id.* ("[O]ne expert cautioned that discussing deployment could raise the level of controversy surrounding the subject.").

505. *Supra* notes 392–94 and accompanying text.

506. *Supra* note 399 and accompanying text.

507. *See* International Institute for Sustainable Development, EARTH NEGOTIATIONS BULL. 20, Nov. 2010 (discussing the development of geoengineering policy in the CBD) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

508. *See* Davis, *supra* note 154, at 945 (discussing the need for a balance between real life testing and avoiding negative side effects).

509. *See* GAO, *supra* note 7, at 37–38 (stressing the importance of defining liability and restitution for damage caused by geoengineering activities).

510. *See* RESTATEMENT (FIRST) OF TORTS § 519 (stating that until climate engineering technologies are tested, they should be categorized as ultrahazardous activities because they "necessarily involve a risk of serious harm . . . , and [are] not [matters] of common usage").

511. *See* 42 U.S.C. § 2210 (2012) (defining the amount of required financial protection for power plant licensees).

512. *See* GAO, *supra* note 7, at 30 (discussing the role of NEPA).

regulations governing the procedures for testing to ensure, among other aspects, safety, data collection, and publication of results.[513]

F. A United States Program Can Serve as a Model for an International Agreement

An additional benefit of the United States taking the lead in supporting and regulating climate engineering research is that its efforts can provide a model for, if not a prod to, a future international regime.[514] As noted previously, only France, Germany, Norway, and the United Kingdom have commenced any efforts concerning geoengineering.[515] Nevertheless, the likelihood of significant warming is increasing, and mitigation is not likely by itself to keep the planet from warming at least 2° C.[516] Given the decades required to study, test, and assess the results from climate engineering,[517] such efforts must commence shortly.

Establishment of a domestic program can facilitate development of an international agreement.[518] National laws often serve as models for international agreements.[519] For instance, the Americans with Disabilities Act and other domestic disability laws served as models for the United Nations Convention on the Rights of Persons with Disabilities.[520] In the

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513. *See* Davis, *supra* note 154, at 905 (arguing that an appropriate level of regulation is beneficial).

514. *See id.* at 940 ("[Defense Advanced Research Projects Agency]'s organizing elements . . . ; cooperation between governments, corporations, and academic institutions; and use of networked, collaborative teams organized around specific technological challenges have contributed to its success in fostering technological advances. . . . [T]his collaborative and performance-oriented approach should be applied internationally.").

515. *See supra* Part II.B.1 (discussing the existing state of international environmental regulation on geoengineering).

516. *See supra* note 100 and accompanying text.

517. *See* Swart & Marinova, *supra* note 197, at 541 (noting that techniques such as solar radiation management may take two decades to study and implement).

518. *See* Victor, *supra* note 447, at 331 (arguing that research efforts by individual nations or academic institutions "would help nations craft the norms that should govern the testing and possible deployment of newly developed technologies").

519. *See id.* ("[C]onnected national efforts would link together in a transnational partnership of expert regulators, as has happened in many other areas where regulation rests on experts and benefits from international coordination.").

520. *See* LUISA BLANCHFIELD, CYNTHIA BROUGHER & JAMES V. DEBERGH, CONG. RESEARCH SERV., R42749, THE UNITED NATIONS CONVENTION ON THE RIGHTS OF PERSONS WITH DISABILITIES: ISSUES IN THE U.S. RATIFICATION DEBATE 9–10 (2012), *available at* http://www.fas.org/sgp/crs/misc/R42749.pdf (reporting that the Senate fell five votes short of ratifying the U.N. treaty) (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT); *see also US Senate Rejects UN Treaty on Disability Rights Amid GOP Opposition*, THE GUARDIAN (Dec. 4, 2012), http://www.theguardian.com/world/2012/dec/04/senate-rejects-un-treaty-disability/print.

environmental arena, the United States sulfur emissions trading system has served as a model for the European Union Emissions Trading System,[521] which serves as a "fundamental component of the international framework"[522] for greenhouse gas emissions trading.

A domestic program can also provide information critical to the development of a future international agreement.[523] Specifically, it can provide a base of experience from which to develop regulatory norms for a subsequent international agreement.[524]

Many of these proposals find support from those scientists likely to be integral in researching and developing climate engineering.[525] In 2010, the Asilomar International Conference on Climate Intervention Technologies convened over 165 experts to consider the conditions and precautions appropriate to undertake climate engineering research.[526] Their recommendations included the creation of new governance and oversight

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("The [Americans with Disabilities Act] . . . became the blueprint for the UN treaty.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

521. *See* Joseph Kruger, *From SO_2 to Greenhouse Gases*, *in* ACID IN THE ENVIRONMENT 261, 273 (Gerald R. Visgilio & Diana M. Whitelaw eds., 2007) (discussing the regulation of sulfur dioxide).

522. *See* Joseph Kruger, *From SO_2 to Greenhouse Gases* 1 (Resources for the Future, Discussion Paper No. 05-20, 2005), *available at* http://www.rff.org/rff/Documents/RFF-DP-05-20.pdf ("Internationally, emissions trading is no longer considered a 'crazy American idea.' It is now a fundamental component of the international framework to address climate change. Even developing countries from Chile to China are beginning to consider emissions trading programs to control conventional pollutants.") (on file with the WASHINGTON AND LEE JOURNAL OF ENERGY, CLIMATE, AND THE ENVIRONMENT).

523. *See* Victor, *supra* note 447, at 332–33 (describing the incremental approach in developing most international norms).

524. *See id.* at 332 (discussing how "lead countries" help set norms that can be integrated into an international agreement).

525. *See* ASILOMAR SCIENTIFIC ORGANIZING COMMITTEE, THE ASILOMAR CONFERENCE RECOMMENDATIONS ON PRINCIPLES FOR RESEARCH INTO CLIMATE ENGINEERING TECHNIQUES 8–9 (2010), *available at* http://www.climate.org/PDF/AsilomarConferenceReport.pdf (outlining principles for responsible scientific involvement in geoengineering).

526. *See id.* at 20 ("Data needed to assess the performance of technologies and approaches should be disclosed to allow for open review and evaluation.").

mechanisms,[527] coordination of research efforts,[528] transparency,[529] and no-fault liability.[530]

IV. Conclusion

Society needs to increase its mitigation and adaptation efforts. Nevertheless, we have reason to expect that these actions alone will not prevent significant climate change and its consequences. Accordingly, we need to consider additional approaches, such as climate engineering. Because of the long lead time necessary to study, test, and prepare geoengineering methods should it become necessary, such efforts should commence immediately. Since an international agreement may be both inadequate and long in coming, the United States should take the lead and initiate its own program.

527. *See id.* at 9 ("Governments must clarify responsibilities, and, when necessary, create new mechanisms, for the governance and oversight of large-scale climate engineering research activities that have the potential or intent to significantly modify the environment or affect society.").

528. *See id.* at 20 ("Climate engineering research should be conducted openly and cooperatively, preferably within a framework that has broad international support.").

529. *See id.* ("[G]overnance mechanisms will need to include provisions for . . . promoting transparency and disclosure.").

530. *See id.* at 24 ("Liability and compensation processes based on 'no-fault' principles over some range of potential impacts defined in advance of particular experiments may be needed as part of the approval process.").