

The Regulation of Climate Engineering

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INTRODUCTION

Among the greatest challenges faced by society today is the threat of anthropogenic climate change. Its economic costs alone could be 5 to 20 per cent of global production.¹ These costs will be disproportionately borne by the world's vulnerable populations. In addition, there will be non-economic costs, such as human suffering and loss of biodiversity.² Estimates of the likely impact of climate change have become increasingly dire.³

Unfortunately, there is little reason for optimism. Atmospheric concentrations of greenhouse gases, the cause of anthropogenic climate change, continue to rise.⁴ Models which extrapolate current activities estimate that average global warming will double the oft-cited 2°C target limit by the end of the century.⁵ International agreements to reduce

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- 1 Nicholas Stern, *The Economics of Climate Change: The Stern Review* (HM Treasury, 2006) is generally considered the most comprehensive economic analysis of climate change.
 - 2 See eg Chris D Thomas *et al*, 'Extinction Risk from Climate Change' (2004) 427 *Nature* 145.
 - 3 Compare conclusions of the four Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), issued in 1990, 1995, 2001 and 2007.
 - 4 For recent concentrations see TJ Blasing, 'Recent Greenhouse Gas Concentrations' (Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, updated February 2011), http://cdiac.ornl.gov/pns/current_ghg.html (accessed 7 June 2011). Annual greenhouse gas emissions are generally rising. Jos GJ Olivier and JAHW Peters, *No Growth in Total Global CO₂ Emissions in 2009* (Netherlands Environmental Assessment Agency (PBL), 2010); International Energy Agency, 'Prospect of Limiting the Global Increase in Temperature to 2°C is Getting Bleaker' (30 May 2011), www.iea.org/index_info.asp?id=1959 (accessed 9 June 2011).
 - 5 According to the most recent IPCC Assessment Report, the projected global average surface warming at the end of the 21st century in the A1FI scenario (an integrated world with rapid economic growth and a continued reliance upon fossil fuels) is 4°C. Working Group I of the Intergovernmental Panel on Climate Change, 'Summary for Policymakers' in Susan Solomon *et al* (eds), *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007); Working Group III of the Intergovernmental Panel on Climate Change, 'Summary for Policymakers' in Nebojsa Nakicenovic and Rob Swart (eds), *Emissions Scenarios* (Cambridge University Press, 2000). The 2°C limit was adopted in the non-binding Copenhagen Accord at the 2009 Conference of Parties to the UN Framework Convention on Climate Change (1992). It

greenhouse gas emissions have had limited results.⁶ These efforts face difficult problems not only of coordination, collective action and free-riding, but also of global and inter-generational equity and justice.⁷

In response to the risks of climate change, academics and policymakers have considered increasingly drastic measures. For example, advocates of reducing greenhouse gas emissions were originally concerned that their efforts would be undermined by public discussion of adapting society to a different climate. Now, however, both emissions reductions and adaptation are generally considered to be the two pillars of effective climate change policy.⁸

A third potential set of responses to the threat of climate change is increasingly entering public debate. Climate engineering, or geoengineering,⁹ is a group of proposals to intentionally intervene in global physical, chemical and biological systems on a massive scale in order to reduce the threat of anthropogenic climate change. These proposals carry their own risks and have been controversial and, until recently, open discussion of climate engineering has been limited.

Although there is near unanimous agreement that deployment of climate engineering should be regulated, there is wide variation as to whether regulation is feasible and, if so, how it should be done. Various authors have ranged from concluding that climate engineering will inevitably be prohibited¹⁰ to arguing that it cannot be controlled.¹¹

had been the consensus of industrialised countries, but was recently challenged by leaders of various developing nations who called for a lower limit. For a history of the limit see Michael Oppenheimer and Annie Petsonk, 'Article 2 of the UNFCCC: Historical Origins, Recent Interpretations' (2005) 73 *Climatic Change* 195; Chris Shaw, 'The Dangerous Limits of Dangerous Limits: Climate Change and the Precautionary Principle' (2009) 57 *Sociological Review* 103.

- 6 The Kyoto Protocol (1997) to the UN Framework Convention on Climate Change (UNFCCC) is the primary international agreement relating to reductions in greenhouse gas emissions. The countries not bound by the Protocol include three of the top four emitters (China, the USA and India) and account for approximately 70% of emissions (2008 data in International Energy Agency, *CO₂ Emissions from Fuel Combustion 2010: Highlights* (IEA, 2010)). Although the countries that are bound by it are on track to collectively meet the 2012 target, much of this emissions reduction is due to decreased economic activity, in Russia and Eastern Europe in the 1990s and throughout the globe in more recent years. See Olivier and Peters (n 4). The Protocol expires at the end of 2012 and no successor is apparent.
- 7 See eg Stephen M Gardiner, 'Ethics and Climate Change: An Introduction' (2010) 1 *Wiley Interdisciplinary Reviews: Climatic Change* 54.
- 8 See eg Roger Pielke *et al*, 'Climate Change 2007: Lifting the Taboo on Adaptation' (2007) 445 *Nature* 597.
- 9 Although 'geoengineering' is more common, the term 'climate engineering' is increasingly used because of its greater accuracy and to avoid confusion with geoengineering in the context of civil engineering.
- 10 William Daniel Davis, 'What Does "Green" Mean?: Anthropogenic Climate Change, Geoengineering, and International Environmental Law' (2009) 43 *Georgia Law Review* 901.
- 11 '[I]t may be impossible for countries to keep a commitment to abstain from experimenting with geoengineering. The incentives for countries to reduce emissions on a substantial scale are too weak, and the incentives for them to develop geoengineering are too strong, for commitment to be a realistic prospect. Indeed, these two incentives combined are so powerful that many countries may be prepared to develop and deploy geoengineering unilaterally.' Scott Barrett, 'The Incredible Economics of Geoengineering' (2008) 39 *Environmental and Resource Economics* 45, 46.

Elected lawmakers appear reluctant to address it, and an earlier attempt at self-regulation stumbled.¹² A new effort, the Solar Radiation Management Governance Initiative, seeks to tackle this problem by focusing on only one of the two main categories of climate engineering, and on only matters of research, not of deployment. Will this approach help or hinder the initiative in the attempt to surmount some of the regulatory challenges presented by climate engineering?

This essay seeks to answer this question by exploring climate engineering and its regulatory challenges. Part I introduces the history and proposed forms of climate engineering, in particular distinguishing its two primary categories. Part II provides an overview of various international legal instruments that may be relevant to climate engineering, and concludes that one of the two primary forms is largely addressed by existing legal instruments. Part III describes how climate engineering's technical, environmental and political characteristics engender regulatory challenges, which are mostly distinct between its two primary forms. Part IV explores the logic and legal basis of regulation of scientific research, in general, and the implications for the regulation of climate engineering research. Part V highlights specific strengths of and challenges to the Solar Radiation Management Governance Initiative, focusing on legitimacy and the definition of research. Part VI offers a brief concluding summary.

I. AN INTRODUCTION TO CLIMATE ENGINEERING

The consideration of climate engineering is historically intertwined with the awareness of anthropogenic climate change. Soon after Svante Arrhenius proposed that industrial emissions of carbon dioxide may warm the climate, his 'good friend' Nils Ekholm proposed that such emissions would be beneficial, and could be increased.¹³ The first government report on the threat of anthropogenic climate change, submitted to US President Lyndon Johnson in 1965, recommended increasing the earth's reflectivity by using buoyant ocean particles, yet it did not consider reducing fossil fuel consumption.¹⁴ In 1977, leading Soviet climatologist Mikhail Budyko proposed what remains the most widely discussed climate engineering method: injecting aerosols into the stratosphere.¹⁵

¹² The Asilomar International Conference on Climate Intervention Technologies is described below, at text to nn 102–6.

¹³ Svante Arrhenius, 'On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground' (1896) 41 *Philosophical Magazine and Journal of Science* 237; Nils Ekholm, 'On the Variations of the Climate of the Geological and Historical Past and their Causes' (1901) 27 *Quarterly Journal of the Royal Meteorological Society* 1; Svante Arrhenius, *Worlds in the Making: The Evolution of the Universe* (Harper, 1908).

¹⁴ President's Science Advisory Committee, *Restoring the Quality of Our Environment* (1965).

¹⁵ Mikhail Budyko proposed sulfate aerosols. Mikhail I Budyko, *Climatic Changes* (American Geophysical Union, 1977). Recent research indicates that sulfate may not be ideal, and some scientists propose engineered nanoparticles. David W Keith, 'Photophoretic Levitation of Engineered Aerosols for Geoengineering' (2010) 107 *Proceedings of the National Academy of Sciences* 16428.

The term ‘geoengineering’ was coined soon thereafter, in the context of deep ocean storage of carbon dioxide.¹⁶ A 1992 major climate change report from the US National Academies included a chapter on climate engineering.¹⁷ By the next decade, an internal US government white paper had suggested a \$64 million climate engineering research initiative, but the White House rejected this on political grounds.¹⁸

The academic and public debates about climate engineering have grown dramatically in the last five years.¹⁹ The breakthrough was a pair of editorials in 2006 by atmospheric chemists, one a Nobel Laureate and the other the president of the US National Academy of Science.²⁰ In the last two years, the UK Royal Society, the US National Research Council, the UK Institution of Mechanical Engineers, and committees of the UK Parliament and the US Congress issued reports, and the American Meteorological Society and the American Geophysical Union released statements, all of which called for climate engineering research.²¹ Recently, modest research projects began to receive funds, both publicly, from the European Union and the United Kingdom, and privately, from billionaires Bill Gates and Richard Branson.²² The leading body responsible for assessing climate change

16 Cesare Marchetti, ‘On Geoengineering and the CO₂ Problem’ (1977) 1 *Climatic Change* 59.

17 Committee on Science, Engineering and Public Policy, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (National Academies Press, 1992).

18 Ehsan Khan et al, *Response Options to Limit Rapid or Severe Climate Change: Assessment of Research Needs* (2001); Michael MacCracken, ‘Geoengineering: Worthy of Cautious Evaluation?’ (2006) 77 *Climatic Change* 235; Eli Kintisch, *Hack the Planet: Science’s Best Hope—or Worst Nightmare—for Averting Climate Catastrophe* (John Wiley & Sons, 2010) 197–9.

19 For example, in 2009 and 2010 the per annum references in academic literature were approximately 10 times greater than those during the period 1992–2005. See the graph in ‘Lift-Off’ *The Economist*, 4 November 2010.

20 Paul Crutzen, ‘Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?’ (2006) 77 *Climatic Change* 211; Ralph Cicerone, ‘Geoengineering: Encouraging Research and Overseeing Implementation’ (2006) 77 *Climatic Change* 221.

21 Royal Society, *Geoengineering the Climate: Science, Governance and Uncertainty* (2009); America’s Climate Choices: Panel on Advancing the Science of Climate Change, *Advancing the Science of Climate Change* (National Academies Press, 2010); Institution of Mechanical Engineers, *Geo-Engineering: Giving Us the Time to Act?* (2009); Science and Technology Committee, *The Regulation of Geoengineering* (HC 2009–10); Rep Bart Gordon, *Engineering the Climate: Research Needs and Strategies for International Collaboration* (2010); American Meteorological Society Council, *AMS Policy Statement on Geoengineering the Climate System* (2009); American Geophysical Union Council, *Position Statement: Geoengineering the Climate System* (2009).

22 ‘Implications and Risks of Engineering Solar Radiation to Limit Climate Change’, <http://implicc.zmaw.de> (accessed 7 June 2011). The National Environment Research Council and the Engineering and Physical Sciences Research Councils supported a public dialogue on geoengineering and are now funding two multi-university research teams. NERC Public Dialogue on Geoengineering Steering Group, *Experiment Earth? Report on a Public Dialogue on Geoengineering* (2010); ‘Integrated Assessment of Geoengineering Proposals’, <http://iagp.ac.uk> (accessed 7 June 2011); Engineering and Physical Sciences Research Council, ‘Details of Grant Ep/I01473x/1’ (19 November 2010), <http://gow.epsrc.ac.uk/ViewGrant.aspx?GrantRef=EP/I01473X/1> (accessed 7 June 2011); ‘Fund for Innovative Climate and Energy Research’, <http://people.ucalgary.ca/~keith/FICER.html> (accessed 7 June 2011); Eli Kintisch, ‘Bill Gates Funding Geoengineering Research’ *ScienceInsider*, 26 January 2010, <http://news.sciencemag.org/scienceinsider/2010/01/bill-gates-fund.html> (accessed 7 June 2011). Branson offered a reward, not traditional research funding. James Kanter, ‘Cash Prize for Environmental Help Goes Unawarded’ *New York Times*, 21 November 2010.

information, the Intergovernmental Panel on Climate Change, will consider climate engineering to a significant degree in its next Assessment Report.²³

Forms of Climate Engineering

Climate engineering schemes vary significantly in their goals, means, feasibility, costs, time scales of response, and potential environmental consequences, and are divided into two primary categories.²⁴ The first, *carbon dioxide removal* (CDR), would collect and sequester this leading greenhouse gas from the atmosphere. Proposals include capturing carbon dioxide from ambient air, fertilising oceans to increase biological uptake, and enhanced mineral weathering.²⁵ CDR would address the threat of climate change relatively close to its cause, but would be expensive and slow. Therefore, CDR could be a longer-term component in a portfolio of responses to anthropogenic climate change. Most proposed CDR methods would have environmental risks which can be assessed and managed fairly well; a significant exception is ocean fertilisation.

The second form of climate engineering is *solar radiation management* (SRM), which would essentially increase the planet's reflectiveness and thus counteract warming. Proposed methods include injecting aerosols into the upper atmosphere, spraying seawater to increase the brightness of clouds, and injecting microbubbles into the ocean.²⁶

23 Alister Doyle, 'Futuristic Climate Schemes to Get UN Hearing' *Reuters*, 27 October 2010; Co-Chairs of Working Groups I, II and III, *Proposal for an IPCC Expert Meeting on Geoengineering* (Intergovernmental Panel on Climate Change, 2010). Three previous Assessment Reports briefly touched upon climate engineering: Rik Leemans *et al.*, 'Mitigation: Cross-Sectoral and Other Issues' in Robert T Watson, MC Zinyowera and Richard H Moss (eds), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses: Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 1995) 811–13; Pekka Kauppi *et al.*, 'Technological and Economic Potential of Options to Enhance, Maintain, and Manage Biological Carbon Reservoirs and Geo-Engineering' in Bert Metz *et al.* (eds), *Climate Change 2001: Mitigation: Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2001) 332–4; Terry Barker *et al.*, 'Mitigation from a Cross-Sectoral Perspective' in Bert Metz *et al.* (eds), *Climate Change 2007: Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2007) 624–5.

24 The Royal Society's *Geoengineering the Climate* (n 21) is the most comprehensive and accessible overview of climate engineering methods. A more recent and technical review is Naomi E Vaughan and Timothy M Lenton, 'A Review of Climate Geoengineering Proposals' (2011) *Climatic Change* (forthcoming); published online 22 March 2011 at <http://dx.doi.org/10.1007/s10584-011-0027-7>.

25 See eg David W Keith, 'Why Capture CO₂ from the Atmosphere?' (2009) 325 *Science* 1654; Ken O Buesseler *et al.*, 'Ocean Iron Fertilization—Moving Forward in a Sea of Uncertainty' (2008) 319 *Science* 162; Peter Köhler, Jens Hartmann and Dieter A Wolf-Gladrow, 'Geoengineering Potential of Artificially Enhanced Silicate Weathering of Olivine' (2010) 107 *Proceedings of the National Academy of Sciences* 20228.

26 See eg Crutzen (n 20); John Latham *et al.*, 'Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds' (2008) 366 *Philosophical Transactions of the Royal Society A* 3969; Russell Seitz, 'Bright Water: Hydrosols, Water Conservation and Climate Change' (2011) 105 *Climatic Change* 365.

In contrast to CDR, these schemes are estimated to be inexpensive and rapid.²⁷ For example, the economic costs of stratospheric aerosol injection may be as little as 1 per cent of those of emissions reductions—a characteristic which has been called ‘incredible’.²⁸ However, SRM would address only the warming aspect of climate change and altered atmospheric composition. Other manifestations, such as ocean acidification, would continue.²⁹ Furthermore, SRM would have significant and unpredictable negative environmental effects. Precipitation patterns would likely change, potentially including a reduction in tropical precipitation, upon which billions rely for agriculture.³⁰ Incoming light would be more diffuse, increasing primary plant productivity and altering ecosystems.³¹ The El Niño/La Niña-Southern Oscillation, a major global climate pattern, may be altered.³² Sulfate particles, the most widely discussed candidate for injection into the stratosphere, may damage the ozone layer.³³ Because of these characteristics, SRM is more often suggested as a potential (1) medium-term method to minimise the effects of climate change as society transitions to low carbon systems and as greenhouse gas concentrations are reduced, and/or (2) response to abrupt climate change.³⁴

II. CURRENT RELEVANT INTERNATIONAL LEGAL INSTRUMENTS

Building on the foregoing introduction to climate engineering, this part reviews some relevant international legal instruments.³⁵ Although no such international agreements directly address climate engineering, some have applicable provisions whose relevance

²⁷ Estimates of the economic cost of stratospheric sulfate injection are generally between a few billion (eg William D Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming* (MIT Press, 2003)) and 50 billion (eg Crutzen (n 20)) US dollars per year. In their modelling, Nordhaus and Boyer consider this to be so low as to be essentially costless.

²⁸ ‘The economics of geoengineering are—there is no better word for it—incredible.’ Barrett (n 11) 49.

²⁹ ‘[B]iological communities under acidified seawater conditions are less diverse and calcifying species absent ... Ocean acidification is irreversible on timescales of at least tens of thousands of years.’ Secretariat of the Convention on Biological Diversity, *Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity*, Technical Series No 46 (Secretariat of the Convention on Biological Diversity, 2009) 9.

³⁰ Alan Robock, Luke Oman and Georgiy L Stenchikov, ‘Regional Climate Responses to Geoengineering with Tropical and Arctic SO₂ Injections’ (2008) 113 *Journal of Geophysical Research* D16101; Gabriele C Hegerl and Susan Solomon, ‘Risks of Climate Engineering’ (2009) 325 *Science* 955.

³¹ Lianhong Gu *et al*, ‘Response of a Deciduous Forest to the Mount Pinatubo Eruption: Enhanced Photosynthesis’ (2003) 299 *Science* 2035.

³² Peter Braesicke, Olaf Morgenstern and John Pyle, ‘Might Dimming the Sun Change Atmospheric ENSO Teleconnections as We Know Them?’ (2011) 12 *Atmospheric Sciences Letters* 184.

³³ P Heckendorn *et al*, ‘The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone’ (2009) 4 *Environmental Research Letters* 045108.

³⁴ Jason J Blackstock *et al*, *Climate Engineering Responses to Climate Emergencies* (Novim, 2009).

³⁵ Other relevant international agreements include the Antarctic Treaty System (1959), the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967), and the United Nations Convention on the Law of the Sea (1982).

varies among the proposed climate engineering methods. In general, international legal instruments are more applicable to CDR than to SRM.

The leading climate change treaty is the United Nations Framework Convention on Climate Change (UNFCCC), whose objective is the ‘stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’.³⁶ It makes repeated references to the removal of greenhouse gases by sinks, and to the enhancement thereof.³⁷ Whereas its definition of sink as ‘any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere’ seems to include CDR, the UNFCCC’s Kyoto Protocol—currently the primary platform of national commitments—limits credit for emission reduction via sinks to ‘human-induced land-use change and forestry activities’.³⁸

Climate engineering proposals to fertilise oceans in order to increase biological carbon dioxide uptake, which have already been the focus of around a dozen field trials,³⁹ are subject to existing international agreements. Most importantly, fertilisation could be considered ocean dumping. Whether a particular form of ocean dumping is prohibited under the London Convention and its London Protocol, which regulate the practice, depends upon, *inter alia*, the action’s purpose, quantity, and potential for harm.⁴⁰ Following controversy surrounding ocean fertilisation field trials,⁴¹ the International Maritime Organization (IMO), which administers the Convention and Protocol, resolved that ocean fertilisation does fall within the treaties’ scope, and that fertilisation, other than ‘legitimate scientific research’, should currently not be permitted.⁴² It later developed a framework tool for assessing whether a proposed activity is ‘legitimate scientific research’.⁴³

Due to its broad mandate and the risks to biodiversity from climate change, the Convention on Biological Diversity (CBD) may be relevant to climate engineering. In particular, its parties must work to ‘[p]revent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species’.⁴⁴ This could include

³⁶ United Nations Framework Convention on Climate Change (1992), Art 3.

³⁷ *Ibid*, Arts 3.1, 4 (throughout), 7.2(d), 12.1(a), and 12.1(b).

³⁸ *Ibid*, Art 1.8; Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997), Art 3.3.

³⁹ These field trials are reviewed in Aaron Strong, John J Cullen and Sallie W Chisholm, ‘Ocean Fertilization: Science, Policy, and Commerce’ (2009) 22 *Oceanography* 236.

⁴⁰ Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972), Art 3.1(b) and Annex 2; its 1996 Protocol, Art 1.4.2 and Annex 1.

⁴¹ See eg Aaron Strong *et al*, ‘Ocean Fertilization: Time to Move On’ (2009) 461 *Nature* 347.

⁴² Contracting parties to the London Convention and contracting parties to the London Protocol, Resolution LC-LP.1 on the Regulation of Ocean Fertilization (2008).

⁴³ Contracting parties to the London Convention and contracting parties to the London Protocol, Resolution LC-LP.2 on the Assessment Framework for Scientific Research Involving Ocean Fertilization (2010).

⁴⁴ Convention on Biological Diversity (1992), Art 8(h).

ocean fertilisation, which typically operates by creating algal blooms. Responding to the ocean fertilisation field trials, in 2008 the parties to the CBD took a firmer position than that of the IMO, requesting that

ocean fertilization activities do not take place until there is an adequate scientific basis on which to justify such activities, including assessing associated risks, and a global, transparent and effective control and regulatory mechanism is in place for these activities; with the exception of small scale scientific research studies within coastal waters.⁴⁵

This apparent divergence between the IMO and the CBD continued in 2010. Just after the former released its framework assessment for legitimate ocean fertilisation research, the parties to the CBD broadened their call, inviting

[p]arties and other Governments ... to consider [e]nsur[ing] ... in the absence of science based, global, transparent and effective control and regulatory mechanisms for geo-engineering, and in accordance with the precautionary approach and Article 14 of the Convention, 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 and appropriate consideration of the associated risks for the environment and biodiversity and associated social, economic and cultural impacts, with the exception of small scale scientific research studies that would be conducted in a controlled setting in accordance with Article 3 of the Convention, and only if they are justified by the need to gather specific scientific data and are subject to a thorough prior assessment of the potential impacts on the environment.⁴⁶

In a footnote, the statement defined that

any technologies that deliberately reduce solar insolation or increase carbon sequestration from the atmosphere on a large scale that may affect biodiversity (excluding carbon capture and storage from fossil fuels when it captures carbon dioxide before it is released into the atmosphere) should be considered as forms of geo-engineering which are relevant to the Convention on Biological Diversity.⁴⁷

Compared to CDR, SRM is poorly addressed by international legal instruments. For example, the Environmental Modification Convention prohibits the military use of ‘the deliberate manipulation of natural processes—the dynamics, composition or structure of

⁴⁵ Decisions Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Ninth Meeting (2008), IX/16(C)4.

⁴⁶ Report of the Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity (2010), X/33(w).

⁴⁷ *Ibid*, fn 3. At the time of writing, the CBD Secretariat is forming a liaison group to work on ‘defining climate-related geo-engineering, and assessing the potential impacts of geo-engineering on biodiversity’. Secretariat of the Convention on Biological Diversity, ‘Call for Experts on Climate-Related Geo-Engineering as it Relates to the Convention on Biological Diversity’ (2011), Ref SCBD/STTM/JW/ac/74873.

the Earth, including its biota, lithosphere, hydrosphere and atmosphere, or of outer space'. However, it explicitly permits peaceful activities.⁴⁸

The most widely discussed SRM proposal, stratospheric aerosol injection, could potentially be interpreted as air pollution, albeit intentional. The Convention on Long-Range Transboundary Air Pollution is of limited applicability, as it is weak, focuses on only Europe's air quality, and addresses pollution 'which has adverse effects ... at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources'.⁴⁹ Sulfate is presently the most likely candidate for aerosol injection, and the Convention's sulfur Protocols, while requiring parties to reduce sulfur emissions, do not prohibit intentional releases.⁵⁰ Furthermore, the amount of sulfate to be injected under stratospheric aerosol injection would be small relative to that from 'unintentional' pollution.⁵¹ Customary international law, under which states generally have duties to minimise transboundary harm and to cooperate in mitigating risks, would likely be more relevant.⁵²

Finally, stratospheric sulfate aerosol injection could damage the ozone layer, which is already thinned.⁵³ A thinner ozone layer would allow more ultraviolet radiation to reach the earth's surface, creating risks to the environment and human health. The Montreal Protocol is currently phasing out certain substances which contribute to this depletion.⁵⁴ Although the Protocol uses a 'black list' of prohibitions which does not include sulfates, deployment of or research into stratospheric sulfate aerosol injection could instigate action.

III. REGULATORY CHALLENGES

Although some existing international legal instruments may be applicable to climate engineering, as outlined in the previous section, significant regulatory gaps clearly remain. This section describes how the technical, environmental and political characteristics of

⁴⁸ Convention on the Prohibition of Military or any other Hostile Use of Environmental Modification Techniques (1977), Arts II and III.

⁴⁹ Convention on Long-Range Transboundary Air Pollution (1979), Art 1(b).

⁵⁰ Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or their Transboundary Fluxes by at least 30 per cent (1985); Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions (1994).

⁵¹ The amount necessary is in the order of 5 million metric tons (teragrams) per year. See eg Crutzen (n 20). Current global anthropogenic sulfur emissions are approximately 58 metric tons per year. SJ Smith *et al*, 'Anthropogenic Sulfur Dioxide Emissions: 1850–2005' (2011) 11 *Atmospheric Chemistry and Physics* 1101.

⁵² See 'Trail Smelter Case. United States of America, Canada. April 16, 1938, and March 11, 1941' 3 *RIAA* 1905; Rio Declaration on Environment and Development (1992), principles 2, 8, 19; International Court of Justice, *Case Concerning the Gabčíkovo-Nagymaros Project* [1997] ICJ Rep 7; International Law Commission, 'Prevention of Transboundary Harm from Hazardous Activities' (2001) *A/56 Official Records of the General Assembly*.

⁵³ Heckendorn *et al* (n 33).

⁵⁴ Montreal Protocol on Substances that Deplete the Ozone Layer (1987).

climate engineering contribute to regulatory challenges and thus make filling these gaps difficult.

The UK Royal Society's report concluded that '[t]he greatest challenges to the successful deployment of geoengineering may be the social, ethical, legal and political issues associated with governance, rather than scientific and technical issues'.⁵⁵ Fortunately, however, presently there are opportunities to identify the challenges, to examine existing law, and to propose and implement new regulatory instruments before risks are borne and any technologies may become locked-in. In short, this is the technology control dilemma: Early on, the risks and negative consequences of a new, powerful technology are poorly known while appropriate regulation is relatively easy to implement. As the risks become clearer, regulation becomes more difficult to enact.⁵⁶

The regulatory challenges vary among the proposed climate engineering methods, and are greater for—and often exclusive to—SRM compared to CDR.⁵⁷ In fact, the Royal Society asserted that 'CDR technologies could mostly be adequately controlled by existing national and international institutions and legislation'.⁵⁸ Steve Rayner described this as the 'geoengineering paradox':

The technology that seems to be nearest to maturity and could technically be used to shave a few degrees off a future peak in anthropogenic temperature rise [ie SRM by stratospheric aerosol injection] is likely to be the most difficult to implement from a social and political standpoint, while the technology that might be easiest to implement from a social perspective and has the potential to deliver a durable solution to the problem of atmospheric carbon concentrations [ie ambient air capture CDR] is the most distant from being technically realized.⁵⁹

Some CDR methods which are labelled 'climate engineering' differ little from the enhancement of natural sinks, except in their proposed scale.⁶⁰ As with sink enhancement,

⁵⁵ Royal Society (n 21) xi.

⁵⁶ 'By the time undesirable consequences are discovered, however, the technology is often so much part of the whole economics and social fabric that its control is extremely difficult. This is the dilemma of control. When change is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult and time consuming.' David Collingridge, *The Social Control of Technology* (St Martin, 1980) 11.

⁵⁷ In its report, the House of Commons Science and Technology Committee concluded (n 21, 17): 'In our view, geoengineering as currently defined covers such a range of Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM) technologies and techniques that any regulatory framework for geoengineering cannot be uniform.'

⁵⁸ Memorandum Submitted by the Royal Society to the UK House of Commons Science and Technology Committee (2009), para 13.

⁵⁹ Steve Rayner, 'The Geoengineering Paradox' (2010) 1 *The Geoengineering Quarterly* 7, www.oxfordgeoengineering.org/pdfs/geoengineering_quarterly_first_edition.pdf (accessed 7 June 2011).

⁶⁰ Consider, for example, harvesting biomass and sequestering it as soil organic material, or large scale afforestation or reforestation. Johannes Lehmann, John Gaunt and Marco Rondon, 'Bio-Char Sequestration in Terrestrial Ecosystems: A Review' (2006) 11 *Mitigation and Adaptation Strategies for Global Change* 395; Committee on Science, Engineering and Public Policy (n 17).

these methods will require determinations as to whether they qualify as carbon credits, a process which can be managed using existing legal instruments and institutions. In some cases of CDR, local law can adequately deal with environmental concerns, such as how to store captured carbon dioxide. An exception is enhanced maritime storage, particularly through ocean fertilisation, which is associated with greater environmental risks which are transboundary in character. However, even ocean fertilisation is being addressed through the London Convention and Protocol,⁶¹ even though it may not be an effective CDR method.⁶²

Furthermore, those difficulties that *are* held in common by both SRM and CDR may not be of the sort to be addressed through regulation. For example, one common concern is that climate engineering is not merely a distraction from addressing the causes of climate change, but presents a ‘moral hazard’ which will weaken incentives for emissions cuts and adaptation.⁶³ Although almost all climate engineering researchers and advocates repeatedly emphasise the primacy of emissions cuts,⁶⁴ a handful assert that climate engineering could be a substitute.⁶⁵ There is also the related possibility that climate engineering research is a slippery slope to deployment,⁶⁶ especially considering the

⁶¹ Contracting parties to the London Convention and contracting parties to the London Protocol (n 42 and n 43).

⁶² A report of the Intergovernmental Oceanographic Commission concluded that ‘even using the highest estimates for both carbon export ratios and atmospheric uptake efficiencies, the overall potential for ocean fertilization to remove CO₂ from the atmosphere is relatively small’. Doug WR Wallace *et al*, *Ocean Fertilization: A Scientific Summary for Policy Makers* (IOC/BRO/2010/2, 2010). See also Strong *et al* (n 41); Mary W Silver *et al*, ‘Toxic Diatoms and Domoic Acid in Natural and Iron Enriched Waters of the Oceanic Pacific’ (2010) 107 *Proceedings of the National Academy of Sciences* 20762.

⁶³ See eg Stephen H Schneider, ‘Earth Systems Engineering and Management’ (2001) 409 *Nature* 417; Mark Lawrence, ‘The Geoengineering Dilemma: To Speak or Not to Speak’ (2006) 77 *Climatic Change* 245. Ironically, some supporters of climate engineering research are concerned about the moral hazard (David W Keith, ‘Geoengineering the Climate: History and Prospect’ (2000) 25 *Annual Review of Energy and the Environment* 245), while some skeptics are less so (Martin Bunzl, ‘Researching Geoengineering: Should Not or Could Not?’ (2009) 4 *Environmental Research Letters* 045104).

⁶⁴ See eg the first ‘headline message’ and ‘key recommendation’ of the Royal Society (n 21, ix): ‘The safest and most predictable method of moderating climate change is to take early and effective action to reduce emissions of greenhouse gases. No geoengineering method can provide an easy or readily acceptable alternative solution to the problem of climate change ... Parties to the UNFCCC should make increased efforts towards mitigating and adapting to climate change, and in particular to agreeing to global emissions reductions.’ For specifics see TML Wigley, ‘A Combined Mitigation/Geoengineering Approach to Climate Stabilization’ (2008) 314 *Science* 452.

⁶⁵ Edward Teller, Roderick Hyde and Lowell Wood, ‘Active Climate Stabilization: Practical Physics-Based Approaches to Prevention of Climate Change’, paper delivered at the National Academy of Engineering Symposium, Washington, DC, 23–24 April 2002; Alan Carlin, ‘Global Climate Change Control: Is there a Better Strategy than Reducing Greenhouse Gas Emissions?’ (2007) 155 *University of Pennsylvania Law Review* 1401; Barrett (n 11).

⁶⁶ Climate engineering researcher Ken Caldeira concedes that ‘[t]here’s a slippery slope from laboratory research to large-scale deployment’. Ken Caldeira, ‘Has the Time Come for Geoengineering?’ (2008) *Bulletin of the Atomic Scientists*, www.thebulletin.org/web-edition/roundtables/has-the-time-come-geoengineering (accessed 7 June 2011).

potential entrenchment of powerful interests under a large research program.⁶⁷ Finally, some observers have questioned the ethics of intentionally modifying the earth on a massive scale.⁶⁸

Because, in general, CDR appears to be able to be adequately controlled through existing instruments, this essay will henceforth focus on SRM.

The scientific characteristics of climate change and the technical characteristics of SRM exacerbate the technology control dilemma. Climate science is ‘post-normal’ science, in which ‘facts are uncertain, values in dispute, stakes high and decisions urgent’.⁶⁹ Furthermore, SRM presents an extreme case of a risk-risk tradeoff,⁷⁰ which makes attempts to apply the precautionary principle ambiguous.⁷¹ It operates in a state of not mere uncertainty, but of ignorance, the condition in which knowledge about both outcomes and their probabilities is low.⁷² Finally, climate engineering techniques may be developed and modified rapidly, making a ‘connection’ between the regulation and technology difficult to maintain.⁷³

The development of regulation is a political process, yet the mere discussion of climate engineering gives rise to a complicated political landscape. Among environmental advocates, climate engineering (to the extent that it is even discussed) has divided pragmatists, who focus on minimising the impacts of climate change, and ‘deeper’ Greens, who seek a more modest relationship with the planet.⁷⁴ Public statements from environ-

67 David G Victor *et al*, ‘The Geoengineering Option: A Last Resort against Global Warming?’ (2009) 88 *Foreign Affairs* 64, 72.

68 See eg Dale Jamieson, ‘Ethics and Intentional Climate Change’ (1996) 33 *Climatic Change* 323.

69 Silvio O Funtowicz and Jerome R Ravetz, ‘Science for the Post-Normal Age’ (1993) 25 *Futures* 739. See also Mike Hulme, *Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity* (Cambridge University Press, 2009) 78–81.

70 John D Graham and Jonathan Baert Wiener (eds), *Risk vs Risk: Tradeoffs in Protecting Health and the Environment* (Harvard University Press, 1995).

71 In the UNFCCC, the Precautionary Principle is given as: ‘Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures.’ UNFCCC (n 36) Art 3.3. However, both climate change and climate engineering pose ‘threats of serious or irreversible damage’ and lack ‘full scientific certainty’. Consequently, the relationship between climate engineering and precaution is unclear.

72 Andy Stirling distinguishes risk, uncertainty, ambiguity and ignorance. Andy Stirling, ‘Risk, Uncertainty and Precaution: Some Instrumental Implications from the Social Sciences’ in Frans Berkhout, Melissa Leach and Ian Scoones (eds), *Negotiating Environmental Change: New Perspectives from Social Science* (Edward Elgar, 2003).

73 Roger Brownsword, *Rights, Regulation, and the Technological Revolution* (Oxford University Press, 2008).

74 Amongst the groups sympathetic to climate engineering research, the Environmental Defense Fund is a convening partner of the Solar Radiation Management Governance Initiative, and Greenpeace and WWF UK are stakeholder partners thereof. ‘Solar Radiation Management Governance Initiative’, www.srmgi.org (accessed 7 June 2011). Friends of the Earth (UK) has supported ambient air CDR but opposed other CDR methods with wider environmental side-effects and SRM by aerosol injection. Friends of the Earth (UK), *Briefing Note: Geoengineering* (2009). Nature Conservancy’s lead scientist called for an aggressive climate engineering research program, albeit with some caveats. M Sanjayan, ‘Forum: Geoengineering Research’ (2011) 27 *Issues in Science and Technology*, www.issues.org/27.2/forum.html (accessed 7 June 2011). The

mental groups have often criticised climate engineering but have fallen short of outright condemnation of it or calls for its prohibition.⁷⁵ At the other end of the traditional political spectrum, industrial interests that would benefit from continued greenhouse gas emissions have been notably quiet on climate engineering.⁷⁶ Some of these have previously denied the threat of anthropogenic climate change;⁷⁷ backing climate engineering could be interpreted as a tacit admission. Moreover, public support of climate engineering from such industries may make it even more controversial. Among the public, the prospect of scientists tinkering with the entire planet's climate systems is likely to be greeted with concern and skepticism.⁷⁸ Given this complex political landscape, establishing legitimacy will be both crucial and difficult for any regulatory scheme.

The regulatory challenges raised by the political characteristics of SRM are most apparent in the deployment context. Various countries and powerful interests would disagree about what climate is ideal, and the possibility of unilateral deployment would make any agreements difficult to maintain. Furthermore, the low estimated financial cost of SRM would enable small nations and non-state actors to implement it. How would the international community manage SRM deployment, some of which could be unauthorised and performed by rogue actors? Furthermore, some parties may feel that they have been harmed by the negative effects of SRM. In these cases, climate counter-engineering and militarisation appear possible. Finally, SRM would need to be maintained

Natural Resources Defense Council sent its Director of Climate Programs to the 2010 Asilomar meeting (see text to nn 102–6), and it later issued a report backing research into biochar for CDR. Michael MacCracken *et al*, *The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques* (Climate Institute, 2010) 32; Stephen Brick, *Biochar: Assessing the Promise and Risks to Guide US Policy* (Natural Resources Defense Council, 2010). For groups opposed to climate engineering, see two efforts led by the ETC Group: *Open Letter to the Climate Response Fund and the Scientific Organizing Committee* (ETC Group, 2010); Hands Off Mother Earth, 'Organisations', www.handsoffmotherearth.org/organisations (accessed 7 June 2011).

⁷⁵ See eg David Adam, 'Extreme and Risky Action the Only Way to Tackle Global Warming, Say Scientists' *The Guardian*, 1 September 2008; Doug Parr, 'Geo-Engineering is No Solution to Climate Change' *The Guardian*, 1 September 2009.

⁷⁶ Industrial and corporate support for climate engineering research has been limited. The American Enterprise Institute, a business-friendly conservative think tank, has a geoengineering policy program. American Enterprise Institute for Public Policy Research, 'Research Areas: Geoengineering', www.aei.org/yra/100009 (accessed 7 June 2011). The CDR project Cquestrate was funded by the oil company Shell. Cquestrate, 'About Us', www.cquestrate.com/about-us (accessed 7 June 2011).

⁷⁷ 'For more than a decade the Global Climate Coalition, a group representing industries with profits tied to fossil fuels, led an aggressive lobbying and public relations campaign against the idea that emissions of heat-trapping gases could lead to global warming ... But ... even as the coalition worked to sway opinion, its own scientific and technical experts were advising that the science backing the role of greenhouse gases in global warming could not be refuted.' Andrew C Revkin, 'Industry Ignored its Scientists on Climate' *New York Times*, 23 April 2009. See also David Adam, 'Royal Society Tells Exxon: Stop Funding Climate Change Denial' *The Guardian*, 20 September 2006.

⁷⁸ The only significant investigation into public opinion on climate engineering is the NERC Public Dialogue on Geoengineering Steering Group (n 22).

for a long time—perhaps centuries—because its cessation would result in a dangerously rapid temperature increase.⁷⁹ Establishing institutions for such a time scale is obviously challenging, and any parties responsible for SRM maintenance would wield enormous power.

Some challenges to effectively limit the environmental and human health effects of SRM extend from deployment scenarios to field research. This is particularly the case because weather is naturally variable, and thus field trials may need to increase quickly in size in order to produce significant results discernable from background noise. Furthermore, in the case of stratospheric aerosol injection, merely observing whether the particles stay aloft or sink would require large aerosol clouds. Some scientists have gone so far as to assert that ‘geoengineering cannot be tested without full-scale implementation’.⁸⁰ Because current SRM models predict spatially uneven results and negative side-effects, both deployment and field trials could place the environment and people at significant risk. This will challenge existing international norms of transboundary risk, and raise questions of liability. Furthermore, SRM deployment and large field trials may have entirely unpredicted effects.⁸¹ Populations near test areas will be in a situation similar to that of human biomedical research subjects, yet it is unclear how to apply traditional bioethical principles such as respect for autonomy, beneficence and justice.⁸² These risks, both known and unknown, are most apparent in the case of stratospheric aerosol injection, which by its nature will impact a large area. However, smaller scale and more remote methods, such as spraying seawater to increase the brightness of clouds and injecting microbubbles into the ocean, also pose environmental risks.⁸³

Nevertheless, effective regulation of SRM field research is needed soon. SRM research is crucial in order to improve understanding of possible responses to climate change and to prevent uninformed action in the face of abrupt climate change. Furthermore, scientists are moving rapidly toward SRM field experiments. Calls for coordinated funding of

79 SRM ‘may have to last for the length of perhaps a millennium. And ... the efforts will be of little use unless we continue the aerosol emission without interruptions.’ Lennart Bengtsson, ‘Geo-Engineering to Confine Climate Change: Is it at all Feasible?’ (2006) 77 *Climatic Change* 229, 232. See also H Damon Matthews and Ken Caldeira, ‘Transient Climate-Carbon Simulations of Planetary Geoengineering’ (2007) 104 *Proceedings of the National Academy of Sciences* 9949.

80 Alan Robock *et al*, ‘A Test for Geoengineering?’ (2010) 327 *Science* 530, 530.

81 Alan Robock, ‘20 Reasons why Geoengineering may be a Bad Idea’ (2008) 64 *Bulletin of the Atomic Scientists* 14.

82 ‘[T]he potential severity of its effects merits the application of ethical norms similar to those governing biomedical studies. We suggest that [SRM] research is, in this respect, similar to nuclear weapons testing, in which an experiment’s indirect effects are dangerous enough to be ethically significant.’ David R Morrow, Robert E Kopp and Michael Oppenheimer, ‘Toward Ethical Norms and Institutions for Climate Engineering Research’ (2009) 4 *Environmental Research Letters* 045106, 3. See also Pablo Suarez, Jason J Blackstock and Maarten van Aalst, ‘Towards a People-Centered Framework for Geoengineering Governance: A Humanitarian Perspective’ (2010) 1 *The Geoengineering Quarterly* 2.

83 See eg Alan Robock, ‘Bubble, Bubble, Toil and Trouble’ (2011) 105 *Climatic Change* 383.

climate engineering research are almost ubiquitous in reports and articles.⁸⁴ Some scientists are outlining how a research program could scale up to large outdoor trials.⁸⁵ A new project in the UK plans to test aerosol spraying outdoors.⁸⁶ A private American company intends to undertake a 10,000km² trial of maritime cloud brightening.⁸⁷ One Russian team, led by a prominent scientist, has already conducted a small scale field experiment, spraying aerosols into the lower atmosphere.⁸⁸

Climate engineering scientists and advocates themselves acknowledge the need for regulation of SRM research. For example, the Royal Society report concluded:

A research governance framework is required to guide the sustainable and responsible development of research activity so as to ensure that the technology can be applied if it becomes necessary. Codes of practice for the scientific community should be developed, and a process for designing and implementing a formal governance framework initiated.⁸⁹

Because discussions of SRM deployment quickly raise problematic matters, such as geopolitics, jointly considering the regulation of field research and that of deployment will unnecessarily impede the progress of the former. Efforts toward SRM regulation will thus be more likely to be successful if they are initially limited to matters of field research.

IV. THE REGULATION OF SCIENTIFIC RESEARCH

The previous section demonstrated that effective regulation of climate engineering will be difficult; that the regulatory challenges vary between CDR and SRM, and between deployment and research; and that regulation of SRM field research should be developed

⁸⁴ The Royal Society (n 21) called for £10 million (US \$16 million) per year. David W Keith *et al* wrote: 'An international research budget growing from about \$10 million to \$1 billion annually over this decade would probably be sufficient to build the capability to deploy SRM and greatly improve the understanding of its risks.' David W Keith, Edward Parson and M Granger Morgan, 'Research on Global Sun Block Needed Now' (2010) 463 *Nature* 426, 427. The lead scientist of the Nature Conservancy called for US \$50 million per year. Sanjayan (n 74).

⁸⁵ See eg Ken Caldeira and David W Keith, 'The Need for Climate Engineering Research' (2010) 27 *Issues in Science and Technology*, www.issues.org/27.1/caldeira.html (accessed 7 June 2011).

⁸⁶ The Stratospheric Particle Injection for Climate Engineering project 'will investigate the effectiveness of stratospheric particle injection. It will address the three grand challenges in solar radiation management: 1. How much, of what, needs to be injected where into the atmosphere to effectively and safely manage the climate system? 2. How do we deliver it there? 3. What are the likely impacts?' 'Details of Grant Ep/I01473x/1' (n 22).

⁸⁷ Ben Webster, 'Bill Gates Pays for "Artificial" Clouds to Beat Greenhouse Gases' *The Times*, 8 May 2010.

⁸⁸ Y Izrael *et al*, 'Field Studies of a Geo-Engineering Method of Maintaining a Modern Climate with Aerosol Particles' (2009) 34 *Russian Meteorology and Hydrology* 635. The lead author was chairman of the Soviet Committee for Hydrometeorology, was vice-chair of the IPCC, and is director of the Institute of Global Climate and Ecology of the Russian Academy of Sciences.

⁸⁹ Royal Society (n 21) xii.

first and separately. Before going into further detail, an exploration of the logic and legal basis of regulation of scientific research is warranted.

Any current or proposed regulation of scientific research must address a potential challenge that such research or the communication of its results is protected by fundamental rights, particularly the right to free speech. In general, the case for such protection is weak. For example, while the UN Universal Declaration on Human Rights recognises a right ‘to share in scientific advancement and its benefits’, it does not refer to the actual conducting of scientific research.⁹⁰ Although the Charter of Fundamental Rights of the European Union clearly states that ‘The arts and scientific research shall be free of constraint’, this right must be balanced against others. However, the right is yet to be interpreted by the courts due to the newness of the document.⁹¹ In contrast, several international agreements do acknowledge or even regulate certain dangerous or unethical scientific practices.⁹² Nationally, claims to US First Amendment protection of research are generally limited to the content of science, not its practice. For example, a seminal paper which asserts a general constitutional right to research concedes that:

the right to experiment—the right to select appropriate means of conducting research—is a weaker right than the right to select the end of research. The right to experiment is less absolute: it includes the qualification that although the scientist is free to choose any means of conducting research he thinks scientifically sound, he may not cause direct, substantial harm to the cognizable interests of others.⁹³

However, even these claims may not withstand scrutiny.⁹⁴

There are three sets of reasons to regulate or prohibit certain forms of scientific research. Each has relationships with regulation, rights, and climate engineering.

First, some concerns about scientific research are based upon the possible implications or misuse of results. Perhaps the best-known instance is the so-called ‘dual-use’ technologies, which have both peaceful and military or terroristic uses. Scrutiny of fields

⁹⁰ United Nations Universal Declaration on Human Rights (1948), Art 27.

⁹¹ Charter of Fundamental Rights of the European Union (2000), Art 13. The Charter became effective in 2009. Among the Charter’s other passages which could be relevant in the context of scientific research are human dignity (Art 1), respect for privacy (Art 7), and protection of personal data (Art 8).

⁹² See eg Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction (1972); Declaration of Helsinki (1975, revised through 2000); UNESCO Universal Declaration on the Human Genome and Human Rights (1997).

⁹³ John A Robertson, ‘The Scientist’s Rights to Research: A Constitutional Analysis’ (1977) 51 *Southern California Law Review* 1203, 1206. See also R Alta Charo, ‘Prepared Statement of R Alta Charo’ in *Cloning: A Risk to Women? Hearing before the Subcommittee on Science, Technology and Space of the Committee on Commerce, Science and Transportation, United States Senate* (US Government Printing Office, 2002) 29, which similarly asserts a right to research and concedes that ‘even protected activities are subject to reasonable regulation to avoid interfering with the rights of others’.

⁹⁴ J Weinstein, ‘Democracy, Individual Rights and the Regulation of Science’ (2009) 15 *Science and Engineering Ethics* 407.

such as biological and nuclear sciences has increased, in some cases resulting in new laws.⁹⁵ Similarly, certain topics, such as the relationships among race, genes and intelligence, may have troubling social implications and are often taboo for researchers.⁹⁶ A third example is potential breaches of privacy when communicating research results. In this set of reasons for concern, if experiments were to occur but the results never released, there would be no cause for unease. Thus, concern is not with the experiment *per se* but with the communication of its results. Therefore, relative to the other two categories presented here, the regulation of the publication of results from research which is otherwise permitted would face the strongest criticism that it would violate free speech rights. For climate engineering, the dual-use concerns could possibly be relevant, given the low economic cost of SRM and its potential for militarisation. Perhaps more likely, however, opponents of climate engineering could raise the spectre of the slippery slope, described above, and argue that dissemination of the results of climate engineering research would make its deployment unacceptably more probable.

Second, certain actions in the research process, such as the destruction of human embryos or animal testing, may be seen as inherently immoral. To its strongest critics, whether the action occurs within or outside of the research context matters little, if at all: If destroying a human embryo is wrong in the lab, then it is also wrong elsewhere. However, the law does, in fact, often distinguish based upon the scientific context. For example, research practices which may be permitted in the lab would be animal cruelty outside, due to the potential benefits of research. The challenge to developing regulation of these research actions will be primarily political, in that opponents of an action viewed as inherently immoral may be unlikely to compromise. To them, a law designed to minimise but not prohibit the practice may be seen as a tacit endorsement. It is unlikely that climate engineering research would be the subject of regulation or prohibition based upon the inherent immorality of the action. Even those who argue that climate engineering deployment may be fundamentally wrong concede that its research may need to go forward.⁹⁷

⁹⁵ See eg *Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism Act 2001 (USA)*, s 81; *Public Health Security and Bioterrorism Preparedness and Response Act 2002 (USA)*; Committee on Advances in Technology and the Prevention of their Application to Next Generation Biowarfare Threats, *Globalization, Biosecurity, and the Future of the Life Sciences* (National Academies Press, 2006).

⁹⁶ See eg Steven Rose, 'Darwin 200: Should Scientists Study Race and IQ? No: Science and Society Do Not Benefit' (2009) 457 *Nature* 786; Stephen Ceci and Wendy M Williams, 'Darwin 200: Should Scientists Study Race and IQ? Yes: The Scientific Truth Must be Pursued' (2009) 457 *Nature* 788.

⁹⁷ Both Dale Jamieson and Stephen M Gardiner place the ethical bar for climate engineering quite high, but concede that research should go forward. Jamieson (n 68); Stephen M Gardiner, 'Is "Arming the Future" with Geoengineering Really the Lesser Evil? Some Doubts About the Ethics of Intentionally Manipulating the Climate System' in Stephen M Gardiner *et al* (eds), *Climate Ethics: Essential Readings* (Oxford University Press, 2010). See also Claire L Parkinson, *Coming Climate Crisis? Consider the Past, Beware the Big Fix* (Rowman & Littlefield, 2010).

Finally, scientific research may negatively affect human health or the environment. Of course, some people give their informed consent to be affected, sometimes negatively, by an experiment. The oversight of human subjects research is perhaps the most established form of regulation of scientific conduct. More relevant to climate engineering research are externalities which pose risks to non-consenting third parties and the environment. As with the previous category, there is a strong legal case to be made that the scientific context is relevant, and that the positive external benefit of greater knowledge may outweigh the negative external risks to non-consenting people and the environment. This is not *carte blanche* for unregulated scientific conduct. The balance of these benefits and risks is the fundamental question of the regulation of climate engineering research.

Perhaps the best historical analogy to SRM is above-ground nuclear weapons testing. It carried significant risks to the health of humans, who essentially were non-consenting research subjects, and to the environment, including major irreversible harm. The tests operated under similar conditions of ignorance and post-normal science. Furthermore, as in the case of climate engineering, these risks needed to be balanced with others, such as that of a nuclear attack by one's opponents, and the benefits of reducing the risks.⁹⁸ However, above-ground nuclear weapons testing largely ended before the implementation of modern norms of human research subjects and environmental protection.⁹⁹ Thus, it is unclear how and whether such testing could be compatible with current bioethical standards.

V. TOWARD THE REGULATION OF SRM FIELD RESEARCH

In this section, I will highlight the background, specific strengths and challenges of a current effort to regulate SRM field research, namely the SRM Governance Initiative, emphasising claims to legitimacy and the definition of research.

Any regulatory regime for SRM field research must address the challenges described above in section III: It must minimise the risks to human health and the environment posed by experiments, and ensure that trials are as encapsulated and reversible as possible. To maintain ethical norms, it must obtain some form of consent from those who are placed at risk, while providing recourse for those who are demonstrably and significantly impacted. It must prevent commercial interests from unduly influencing the research in a manner contrary to the public interest. It must be flexible enough to adapt to a variety

⁹⁸ Of course, given the dynamics of escalation and mutually assured destruction during the Cold War, the risk of attack may have been exaggerated, and the need for testing a self-fulfilling prophecy.

⁹⁹ The Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water took effect in 1963. France and China continued limited atmospheric nuclear testing through 1974 and 1980, respectively. Major milestones in human research subject protection include the Nuremberg Code (1947), the Declaration of Helsinki (1964), and the Belmont Report (1979).

of SRM proposals, a wide range of scales, and an evolving knowledge base. And it must perform these functions under conditions of ignorance, political volatility, and post-normal science.

Unsurprisingly, the present actors in the policymaking arena differ over how to proceed toward regulation of SRM research. How wide a consensus is needed? Climate engineering research is occurring in only a few countries. Is agreement needed throughout the international community, or only among the capable countries? How should top-down and bottom-up approaches to developing regulation be balanced? Is a 'stamp of approval' from national governments or international bodies needed, or can the scientific community act on its own? How binding must regulation be? Are mere 'guidelines' acceptable?

Some observers believe that binding regulations are not only unnecessary, but could do more harm than good. They emphasise the present lack of knowledge and the absence of incentives for countries with the capacity for climate engineering to endorse a binding agreement. Furthermore, detailed constraints on behaviour now may prevent valuable research from occurring. Instead, such writers thus recommend the development of norms from the bottom up.¹⁰⁰

The Convention on Biological Diversity, as described above, may offer a vehicle for the regulation of climate engineering research.¹⁰¹ Almost all countries are parties to it, and decisions of its Conference of Parties thus carry significant weight. However, the United States—the world's largest economy and leading site of research—is not a party. Furthermore, the CBD more closely resembles a framework treaty, and detailed obligations have thus far required further protocols.

Climate engineering scientists and advocates have already taken steps toward regulation of climate engineering research. In March 2010, they organised a week-long meeting at the Asilomar Conference Grounds in California in order to develop self-regulation, explicitly invoking early self-regulation by the first genetic engineering researchers,¹⁰² which has been touted as a paragon of scientific responsibility.¹⁰³ However,

¹⁰⁰ David G Victor, 'On the Regulation of Geoengineering' (2008) 24 *Oxford Review of Economic Policy* 322; Keith *et al* (n 84). A scenario study by the RAND Corporation concludes that the US leadership should prefer norms to regulate SRM research if it believes that SRM could be effective. Robert J Lempert and Don Prosnitz, *Governing Geoengineering Research: A Political and Technical Vulnerability Analysis of Potential Near-Term Options* (RAND Corporation, 2011).

¹⁰¹ See text to nn 44–47.

¹⁰² The Asilomar International Conference on Climate Intervention Technologies chose the same venue as the 1975 Asilomar Conference on Recombinant DNA, and was even informally dubbed 'Asilomar 2'. The 'honorary chair' of its Scientific Organizing Committee was Paul Berg, who was the chair and a principle architect of the 1975 conference. 'The conference recalled the important role that early agreement on guidelines by the recombinant DNA research community played in limiting the research risk and clearing a path for that research.' MacCracken *et al* (n 74) 4.

¹⁰³ Retrospective analyses of the 1975 meeting are more mixed. See eg Marcia Barinaga, 'Asilomar Revisited: Lessons for Today?' (2000) 287 *Science* 1584.

the meeting met with strong criticism, from both inside and outside the climate engineering community, arising from a lack of transparency, concerns over personal commercial interests, and the limitations of self-regulation.¹⁰⁴ Consequently, the conference's legitimacy suffered, and it produced only a modest statement.¹⁰⁵ The conference leadership later produced five principles for climate change research:

1. Collective benefit ...
2. Establishing responsibility and liability ...
3. Open and cooperative research ...
4. Iterative evaluation and assessment ...
5. Public involvement and consent ...¹⁰⁶

More recently, the UK's Royal Society, in partnership with a major US environmental organisation and the developing world's network of academies of science, launched the SRM Governance Initiative, which 'seeks to develop guidelines to ensure that geoengineering research is conducted in a manner that is transparent, responsible and environmentally sound'.¹⁰⁷ In contrast to the Asilomar meeting, it focuses on the regulation of SRM research, excluding CDR.

As the Asilomar process highlighted, the development of legitimacy presents a particularly difficult task in order for any regulation of SRM field research to be effective. Climate engineering carries such enormous risk and is so controversial that any regulatory regime must pass a high bar of legitimacy. State lawmakers, often a source of regulation with great legitimacy, have generally been quiet on the topic, potentially due to its political volatility.¹⁰⁸ However, legislation is not the sole claim to legitimacy. Robert Baldwin cites other means: accountability, due process, expertise, and efficiency.¹⁰⁹

¹⁰⁴ See eg Joe Romm, 'Exclusive: Chief Sponsor of Landmark Climate Manipulation Conference Maintains Close Financial Ties to Controversial Geo-Engineering Company', *Climate Progress*, 18 March 2010, <http://climateprogress.org> (accessed 7 June 2011); ETC Group (n 74).

¹⁰⁵ The statement implicitly acknowledges the limitations of complete self-regulation: 'The group recognized that given our limited understanding of these methods and the potential for significant impacts on people and ecosystems, further discussions must involve government and civil society.' Michael MacCracken *et al*, *Asilomar Conference Statement* (2010), reprinted as Appendix B in MacCracken *et al* (n 74).

¹⁰⁶ Margaret Leinen, 'The Asilomar International Conference on Climate Intervention Technologies: Background and Overview' (2011) 4 *Stanford Journal of Law, Science & Policy* 1.

¹⁰⁷ 'Solar Radiation Management Governance Initiative' (n 74).

¹⁰⁸ Consider the case of John Holdren, who as US President Obama's newly appointed top science advisor came under strong criticism after saying that climate engineering must 'be looked at. We don't have the luxury of taking any approach off the table', and that 'we might get desperate enough to want to use it'. Seth Borenstein, 'Obama Looks at Climate Engineering' *Associated Press*, 8 April 2009. Holdren later clarified his position. An exception to the trend of politicians avoiding discussion of climate engineering is UK House of Commons Science and Technology Committee (n 21).

¹⁰⁹ Robert Baldwin, *Rules and Government* (Clarendon, 1995).

The SRM Governance Initiative may establish its legitimacy claim by emphasising expertise. Whereas the Asilomar meeting was a one-off event involving many individuals, almost entirely from industrialised countries, gathered under the banner of a largely unknown organisation,¹¹⁰ the new project's convening partners are the world's oldest scientific academy (the Royal Society), the union of scientific academies of the developing world (TWAS), and a major environmental organisation (Environmental Defense Fund). Its working group further reinforces this expertise and diversity with, for example, representatives of other environmental organisations, and one-third of its members are from the developing world. On top of that, the working group contains prominent skeptics of climate engineering.¹¹¹

Another critical yet difficult requirement will be a definition of 'field research'. At the lower boundary, as laboratory and small field experiments increase in scale, at what point should they be regulated? The UK Science and Technology Committee proposed that small SRM field tests need comply only with a set of international principles (yet to be agreed upon), as long as the project has a 'negligible or predictable environmental impact' and 'no trans-boundary effects'. However, if assessment of potential impacts on the environment and human health is among the purposes of a novel experiment, how can negative effects be ruled out *ex ante*? A more precautionary approach may be justified, given the potential negative consequences and the condition of risk ignorance. The initial placement of the lower regulatory threshold at the transition from the laboratory to the field would be advantageous: It would be unambiguous, and it would identify any negative environmental or health effects better and sooner. If early experiments indicate *de minimis* risk, then the lower boundary could be raised.

How to define the upper end of research, distinguishing it from deployment, is less clear. If there is no sharp line between them, and if some scientists argue that relevant field research amounts to small scale deployment, how can regulation be limited to the former?¹¹² Could any definition prevent deployment from masquerading as research?¹¹³ Analogous cases may be able to shed light on a path forward.

First, the development of drugs and medical devices proceeds through stages of clinical trials before approval.¹¹⁴ Like SRM field tests, these trials operate in the environ-

¹¹⁰ The Asilomar meeting was convened by the Climate Response Fund, which has seen little activity other than the meeting.

¹¹¹ Robock (n 81); Clive Hamilton, 'An Evil Atmosphere is Forming around Geoengineering' *New Scientist*, 21 July 2010.

¹¹² Robock *et al* (n 80).

¹¹³ Consider that Japanese and Icelandic whalers harvest hundreds of whales per year claiming 'scientific research' despite an international moratorium. International Convention for the Regulation of Whaling (1946), Art VIII; Schedule to the International Convention for the Regulation of Whaling, para 10(e) (adopted 1982); International Whaling Commission, 'Scientific Permit Whaling', <http://iwcoffice.org/conservation/permits.htm> (accessed 14 June 2011).

¹¹⁴ See generally Richard E Ashcroft and Adrian M Viens, 'Clinical Trials' in Peter A Singer and Adrian M Viens (eds), *Cambridge Textbook of Bioethics* (Cambridge University Press, 2008).

ment (ie, the human body) where they may eventually be utilised, and they carry significant risk. Furthermore, there is some lack of clarity at the upper boundary of research. In later stage clinical trials, research may provide medical benefits. Consequently, the actors have dual roles: Clinical researchers can be cast into the second role of physician, and research subjects seek to participate in experiments expecting therapeutic benefits, and can thus simultaneously be patients.¹¹⁵ The clinical trials are generally reviewed by an institutionally-affiliated ethics board, while approval of the drug or device is done by national or EU regulators.¹¹⁶ However, even after approval, post-marketing surveillance can further clarify the safety and effectiveness of the drug or device.¹¹⁷

Second, genetically modified organisms are similarly tested in increasingly large trials, moving from the laboratory to the field. In the EU, for example, an extensive regime regulates and distinguishes among field trials, agricultural production, and consumption as food and feed.¹¹⁸ There is a relatively clear upper boundary for research, in this case 'placing on the market' a GMO product.¹¹⁹ Regulations address the need for public consultation;¹²⁰ labelling, traceability and valid methods of detection;¹²¹ the coexistence of GMO and non-GMO agriculture;¹²² and the avoidance of accidental transboundary movement.¹²³

Finally, research into ocean fertilisation, as described above, is newly regulated under international law. The IMO has developed a framework to determine whether a project is 'legitimate scientific research', which is based upon four criteria:

¹¹⁵ Nancy MP King and Larry R Churchill, 'Clinical Research and the Physician-Patient Relationship: The Dual Roles of Physician and Researcher' in Singer and Viens, *ibid*; Madison Powers, 'Theories of Justice in the Context of Research' in Jeffrey P Kahn, Anna C Mastroianni and Jeremy Sugarman (eds), *Beyond Consent: Seeking Justice in Research* (Oxford University Press, 1998).

¹¹⁶ Clinical trials are regulated in the EU under the European Clinical Trial Directive (2001/20/EC), and in the US under the so-called 'Common Rule' (45 CFR 46).

¹¹⁷ Post-marketing surveillance is sometimes called 'phase IV clinical trials'.

¹¹⁸ Directive on the Deliberate Release into the Environment of Genetically Modified Organisms (2001/18/EC); Regulation on Genetically Modified Food and Feed (EC, No 1829/2003).

¹¹⁹ "[P]lacing on the market" means making available to third parties, whether in return for payment or free of charge.' Directive 2001/18/EC (n 118) Art 2(B).

¹²⁰ Directive 2001/18/EC (n 118) Art 24; Decision Laying Down Detailed Arrangements for the Operation of the Registers for Recording Information on Genetic Modifications in GMOs (2004/204/EC); Regulation (EC) No 1829/2003 (n 118) Art 28.

¹²¹ Regulation (EC) No 1829/2003 (n 118); Regulation Concerning the Traceability and Labelling of Genetically Modified Organisms and the Traceability of Food and Feed Products Produced from Genetically Modified Organisms (EC, No 1830/2003); Regulation on Detailed Rules for the Implementation of Regulation (EC) No 1829/2003 (EC, No 641/2004).

¹²² Commission Recommendation on Guidelines for the Development of National Co-Existence Measures to Avoid the Unintended Presence of GMOs in Conventional and Organic Crops (2010/C200/01).

¹²³ Cartagena Protocol on Biosafety to the Convention on Biological Diversity (2000); Regulation on Transboundary Movements of Genetically Modified Organisms (EC, No 1946/2003).

The proposed activity should be designed to answer questions that will add to the body of scientific knowledge ...

Economic interests should not influence the design, conduct and/or outcomes of the proposed activity ...

The proposed activity should be subject to scientific peer review at appropriate stages in the assessment process ...

The proponents of the proposed activity should make a commitment to publish the results in peer reviewed scientific publications.¹²⁴

If the proposal is deemed to be legitimate, passes a six-point environmental assessment, and is not otherwise contrary to the London Convention and Protocol, it may conditionally proceed while being monitored. Although ocean fertilisation is a proposed form of CDR, it resembles SRM schemes in its risks of large transboundary environmental effects. Thus, the framework may be able to provide a precedent and model for making the distinction between research and deployment.¹²⁵

However, these cases are of rather limited utility. SRM field research has three characteristics, described above, which make its regulation challenging, yet these characteristics are not shared by these examples. First, effective outdoor research into SRM may require large scale testing, bordering on deployment, whereas the effects and risks of a drug, a GMO crop and ocean fertilisation can generally be assessed from experiments of a limited scale. Second, the potential consequences of experimenting with the earth's atmosphere and climate are greater than those posed by the examples. While the significance of injured research participants, genetic contamination and reduced marine biodiversity should not be belittled, I assert that SRM—even its field research—poses risks of a greater magnitude. Third, in all three cases, 'deployment' (ie, use beyond the test scale) is legally prohibited until research indicates that a particular application poses an acceptable level of risk to human health and the environment. Of course, an international moratorium on SRM deployment could address this gap, and will be needed in any effective regulatory regime for SRM research.¹²⁶ However, such a moratorium would need to define the boundary of scale between research and deployment, and thus presents something more like tautology instead of a step toward the regulation of research.

¹²⁴ Contracting parties to the London Convention and contracting parties to the London Protocol (n 43).

¹²⁵ David Santillo and Paul Johnston, 'Governance of Geoengineering Research Cannot be Left to Voluntary Codes of Conduct' (2010) 1 *The Geoengineering Quarterly* 4; Till Markus, 'Regulating Scientific Ocean Fertilization Experiments under the Law of the Sea', paper delivered at the Bremen Environmental Law Conference, 'The Law on Climate Engineering', Bremen, 17 February 2011.

¹²⁶ Depending on interpretations of the role and language of the CBD, such a moratorium may already exist. See text to nn 44–47.

CONCLUSION: IMPLICATIONS FOR THE
SRM GOVERNANCE INITIATIVE

Climate engineering is coming under increasing consideration, and may prove to be an important component of a portfolio of responses to the threat of climate change. However, it presents several regulatory challenges. Key to overcoming them is the separation of solar radiation management (SRM) climate engineering from carbon dioxide removal (CDR), and of deployment from research. CDR can generally be controlled through existing legal instruments and institutions. SRM presents a more difficult case, and discussions often become mired in the geopolitics of deployment. Thus, initial steps toward regulation should focus on research. Because this is the approach of the SRM Governance Initiative, it holds potential for significant progress toward regulation of SRM research. Furthermore, the initiative may be able to stake a particular claim to legitimacy via expertise. However, crafting an effective definition of field research will still present a significant challenge. More binding, top-down regulation or less binding, bottom-up norms remain possible alternatives. The outcome will largely be politically contingent.