Iron Fertilization: A Scientific Review with International Policy Recommendations

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TABLE OF CONTENTS

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INTRODUCTION

Climate change is a problem that faces the entire world. As evidence of its impacts increases and its effects are more deeply felt, people scramble to find mitigation strategies. Within the last 15 years, iron fertilization has emerged as one such strategy. This paper examines the effectiveness and appropriateness of iron fertilization in reducing atmospheric carbon dioxide concentrations. The costs and benefits of iron fertilization will be discussed from a scientific standpoint, as well as its coverage under international law. Recommendations will be made for how this fairly new technology can be addressed in existing international agreements in order to prevent damage to the ocean, as well as the generation of erroneous carbon credits.

I. CLIMATE CHANGE AND THE OCEAN

A. Describing the problem

Since the dawn of the industrial age, humans have been producing carbon dioxide (CO_2) and other greenhouse gases in increasing quantities. Seventy-five percent of these emissions come from the use of fossil fuels.[1] While naturally occurring in the earth's atmosphere, the increased concentration of these gases is cause for concern because they can alter the climate dynamics of the planet. Greenhouse gases act to warm the planet by trapping or absorbing the sun's infrared rays as they try to leave the atmosphere. Without the retention of this heat, the earth would be a very cold and inhospitable place; with it, life is possible.[2] However, as with all aspects of nature, there is a fine balance. Humans have been disturbing this balance and the earth is starting to see the resulting negative effects.

These negative effects include increasing intensity of storms, shifting ecological ranges of species, reduced crop production, sea level rise, coral bleaching, and many others.[3] But not all of the effects are negative. In some parts of the world, the weather will become milder, the storms less harsh, or the crop production will increase.[4] However, as a whole, the effects of global warming are considered negative and of great concern given their pervasive and cascading nature.

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1 ENERGY INFORMATION ADMINISTRATION, GREENHOUSE GASES, CLIMATE CHANGE, AND ENERGY 1 (2008), http://www.eia.doe.gov/bookshelf/brochures/greenhouse/greenhouse.pdf.

2 U.S. Environmental Protection Agency, Climate Change - Science, http://www.epa.gov/climatechange/science/index.html (last visited Mar. 24, 2009).

3 Intergovernmental Panel on Climate Change [IPCC], *Summary for Policymakers*, *in* CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY. CONTRIBUTION OF WORKING GROUP II TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 7-22 (M. L. Parry et al. eds., 2007).

4 D. HUNTER, J. SALZMAN & D. ZAELKE, INTERNATIONAL ENVIRONMENTAL LAW AND POLICY 641-43 (2007).

The consensus of the scientific world is that humans are the driving force of the recent climate warming. While it is true that the earth has undergone warming in other periods of time and is constantly in a periodic cycle of glacial and interglacial periods, the current rate of warming acceleration indicates that we are not in a period of purely natural progression. The Intergovernmental Panel on Climate Change shares this sentiment as its reports have expressed increasing certainty of the link between human activity and global warming. In 1995, its Second Assessment concluded that the warming trend was "unlikely to be entirely natural in origin" and possessed a "discernible human influence." In 2001, the Third Assessment strengthened the link between warming and human activities by describing the connection as "likely." Finally, the most recent Fourth Assessment in 2007 solidified the warming trend connection to "very likely" attributable to human actions.[5]

As of December 2008, atmospheric carbon dioxide levels were 389.7 ppm. The concentration has grown at a rate of 1.60-2.53 ppm per year over the last 5 years.[6] Scientists are still debating what a safe concentration level is but typically cite a desire to be below 350 ppm.[7] The biggest fear is overstepping some tipping point past which the negative effects of climate change rapidly accelerate and are perhaps inescapable.[8] It is important to note that even if reductions are made immediately, the lasting effects might not be seen for many years, as CO_2 has a residence time of up to 200 years in the atmosphere.[9]

B. *Identifying a potential solution*

Recognition of the climate problem is not new. Climate change has been the focus of international environmental agreements since 1979.[10] However the greatest and most widely recognized action that has been taken to address the problem is the Kyoto Protocol. Signed in 1997 and having entered into force in 2005, the Kyoto Protocol addresses the climate change problem by setting reduction targets for greenhouse gases and proposing methods for achieving them. In very simple terms, the Kyoto Protocol stipulates that the developed nation Parties must reduce their emissions below 1990 levels by a certain, country-specific percentage, typically 7-8%.[11] The Protocol provides four

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5 J. B. RUHL, J. C. NAGLE & J. SALZMAN, THE PRACTICE AND POLICY OF ENVIRONMENTAL LAW 1325 (2008).

6 PIETER TANS, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, TRENDS IN ATMOSPHERIC CARBON DIOXIDE - MAUNA LOA (2009), www.esrl.noaa.gov/gmd/ccgg/trends.

7 James Hansen et al., *Target Atmospheric CO2: Where Should Humanity Aim?* 2 OPEN ATMOSPHERIC SCI. J. 217, 226. *See also* Gang He, *Finding a Safe Level of Carbon Dioxide for the Global Atmosphere: Results of the Tallberg Forum*, EARTHTRENDS ENVIRONMENTAL INFORMATION, July 9, 2008, http://earthtrends.wri.org/updates/node/320.

8 Hansen et al., *supra* note 7.

9 HUNTER ET AL., *supra* note 4, at 636.

10 *Id.* at 667.

11 Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 10,

primary methods for achieving these emission reduction targets: reductions, trading, joint-implementation, and the Clean Development Mechanism.[12]

In general, the types of approaches needed to achieve the goals of these four methods can be grouped into two categories: reduction and storage.[13] The former category addresses the problem at its source by making operations produce less emissions and restricting the use of fossil fuels for power. The latter category is an "end-of-the-pipe" approach, which attempts to sequester or store produced emissions, largely through natural processes. These natural processes are generally referred to as sinks because they produce a net storage of greenhouse gases. The two major sinks on the planet are vegetation and the ocean.

The expanded use of both of these sinks has been a relatively recent development, first emerging in the early 1990s.[14] However, of the two, the use of the ocean sink is less well understood. Currently, the oceans sequester one third of all of the planet's emissions[15] and approximately 80% of all atmospheric carbon will end up in the ocean in some period of its lifecycle.[16] Accordingly, scientists and policy makers alike are interested in determining if the oceans could be a remedy for the global warming problem.

The ocean is able to serve as a large sink for two primary reasons. First, the oceans naturally absorb carbon dioxide from the atmosphere through what is known as the solubility pump. Driven by the principles of chemistry, the ocean is able to absorb atmospheric carbon because the partial pressure of carbon in it is lower than that in the atmosphere. The rate of absorption is not fixed but instead is linked to many factors, including the salinity and temperatures of the water, and thus varies by region.[17]

The second mechanism through which the oceans absorb carbon dioxide is through the incorporation of atmospheric carbon by phytoplankton through photosynthesis. As a whole, phytoplankton are responsible for approximately half of all carbon fixation on the planet.[18] This fixation occurs as atmospheric

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1997, 37 I.L.M. 22, *available at* http://unfccc.int/resource/docs/convkp/kpeng.html.

12 For a more in-depth discussion of these mechanisms see HUNTER ET AL., *supra* note 4, at 690-700.

13 Katrin Rehdanz, Richard S. J. Tol & Patrick Wetzel, *Ocean Carbon Sinks and International Climate Policy*, 34 ENERGY POLICY 3516, 3516 (2006).

14 *Id.* at 3517.

15 Irina Marinov & Jorge L. Sarmiento, *The Role of Oceans in the Global Carbon Cycle: an Overview*, *in* THE OCEAN CARBON CYCLE AND CLIMATE 251, 270 (Mick Follows & Temel Oguz, eds., 2004).

16 Howard Herzog, Ken Caldera & John Reilly, *An Issue of Permanence: Assessing the Effectiveness of Temporary Carbon Storage*, 59 CLIMATIC CHANGE 293, 302 (2003).

17 Tom R. Anderson & Ian J. Totterdell, *Modelling the Response of the Biological Pump to Climate Change*, *in* THE OCEAN CARBON CYCLE AND CLIMATE 65, 66 (Mick Follows & Temel Oguz, eds., 2004).

18 Sallie W. Chisholm, Paul G. Falkowski & John J. Cullen, *Dis-Crediting Ocean Fertilization*, 294 SCIENCE 309, 309 (2001).

carbon dioxide is drawn in and stored in the body material of these microscopic plants in the process of photosynthesis. Eventually, this stored carbon then makes its way to the deep ocean through one of two pathways. The phytoplankton can die and then sink to the bottom, carrying their carbon with them, or they can be eaten by zooplankton and then excreted in fecal pellets, which also sink to the bottom. These processes are collectively known as the biological or soft-tissue pump.[19]

Dr. John Martin catapulted the concept of using the biological pump to address climate change to the forefront of climate discussions by suggesting that a lack of iron was limiting phytoplankton growth in the ocean, and thus the addition of iron to the ocean could increase carbon drawdown from the atmosphere. To this end he famously claimed, "Give me half a tanker of iron and I'll give you the next Ice Age."[20] What Martin referred to is the un-maximized use of the ocean sink. Certain areas of the ocean, namely the subarctic Pacific, the equatorial Pacific, and the Antarctic,[21] are high in nutrients but low in chlorophyll concentration[22] ("HNLC" regions). This elemental composition is anomalous because the lack of nutrients tends to be the factor limiting growth in most regions of the ocean.[23] However, in the HNLC regions, phytoplankton growth is much lower than would normally be predicted. Several alternative hypotheses for this have been proposed including the effects of vertical mixing, grazing pressure, and exposure to sunlight. However, the iron deficiency hypothesis has gained the most traction and the widest support.[24] According to this hypothesis, as Martin suggested, if the amount of iron present in these HNLC areas could be increased, then the amount of phytoplankton growth would also increase, resulting in a greater drawdown of atmospheric carbon dioxide. Thus, if achievable on a large scale, iron fertilization of the oceans could be a silver bullet for climate change.[25]

Since iron does not occur naturally in quantities great enough to maximize the utilization of the nutrients of the HNLC regions, it has been suggested that

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[19] James E. Peterson, *Can Algae Save Civilization? A Look at Technology, Law, and Policy Regarding Iron Fertilization of the Ocean to Counteract the Greenhouse Effect*, 6 COLO. J. INT'L ENVTL. L. & POL'Y 69, 69 (1995).

[20] Chisolm et al., *supra* note 18, at 309.

[21] Peterson, *supra* note 19, at 69; H. J. W. de Baar & P. W. Boyd, *The Role of Iron in Plankton Ecology and Carbon Dioxide Transfer of the Global Oceans*, *in* THE CHANGING OCEAN CARBON CYCLE: A MIDTERM SYNTHESIS OF THE JOINT GLOBAL OCEAN FLUX STUDY 89 (R. B. Hanson et al. eds., 2000).

[22] Chlorophyll is used as a proxy for phytoplankton growth.

[23] MICHELLE ALLSOPP, DAVID SANTILLO & PAUL JOHNSTON, GREENPEACE RESEARCH LABORATORIES, A SCIENTIFIC CRITIQUE OF OCEAN IRON FERTILISATION AS A CLIMATE CHANGE MITIGATION STRATEGY 2 (2007), http://www.greenpeace.to/publications/iron_fertilisation_critique.pdf.

[24] Peterson, *supra* note 19, at 69; de Baar & Boyd, *supra* note 21, at 68, 124.

[25] Paul Mooney, *Global Warming: the Quick Fix is In*, FOREIGN POLICY IN FOCUS, Feb. 20, 2007, http://www.fpif.org/fpiftxt/4006.

artificial fertilization of these regions is the solution. This process is commonly known as iron fertilization and falls under the broader category of ecosystem or planetary engineering.[26] Typically the fertilization is executed through the gradual deposition of tons of particulate iron by an ocean tanker traveling in uniform transect lines. It is worth noting, however, that there are two other methods of ocean sequestration: deep-sea injection and geological storage. In the former, carbon dioxide is pumped several hundred meters below the surface. In the latter, carbon dioxide is injected into natural, hollow formations in the ocean floor.[27] However, a strong majority sees iron fertilization seen as the most promising venture for carbon sequestration in the oceans because it is the method that appears to be the most cost-effective and efficient.[28] It is also the method that has seen the greatest volume of scientific research, and as such it will be the focus of the rest of this discussion.

Since 1993, twelve scientific projects involving ten different nations have been carried out to test the effects of iron fertilization in the oceans.[29] The findings of these experiments are described collectively in the next section and will form the basis of the discussion of the validity of iron fertilization as a method for mitigating global warming..

II. IRON FERTILIZATION EXAMINED

A. *Potential benefits*

Iron fertilization has been touted as the silver bullet, or more aptly the Geritol,[30] for global warming. As previously discussed, this has occurred because the oceans have a great capacity for CO_2 storage, largely due to their massive volume. Covering over 70% of the earth's surface with a total volume of 1.37 billion cubic kilometers,[31] the oceans are a vast greenhouse gas sink that some suggest is far from being fully utilized. Phytoplankton, the microscopic plants of the sea, are responsible for roughly half of all the carbon that is fixed

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[26] Richard A. Kerr, *Iron Fertilization: a Tonic, but No Cure for the Greenhouse*, 263 SCIENCE 1089, 1089 (1994).

[27] Karen N. Scott, *The Day After Tomorrow: Ocean CO2 Sequestration and the Future of Climate Change*, 18 GEO. INT'L ENVTL. L. REV. 57, 60 (2005).

[28] Hugh Powell, *Will Ocean Fertilization Work? Getting Carbon Into the Ocean is One Thing. Keeping It There is Another*, 46 OCEANUS 10, *available at* http://www.whoi.edu/cms/files/OceanusIron_Will_It_Work_30703.pdf.

[29] The ten nations involved in the experiments are: Australia, New Zealand, the United States, the United Kingdom, Germany, Mexico, Canada, the Netherlands, Japan, and the European Union. An excellent review of these experiments can be found in: P. W. Boyd et al., *Mesoscale Iron Enrichment Experiments 1993-2005: Synthesis and Future Directions*, 315 SCIENCE 612, 612-617 (2007); *See generally* ALLSOPP ET AL., *supra* note 23.

[30] A. Monastersky, *Pumping Iron: Too Weak to Slow Warming*, 145 SCIENCE NEWS 148, 148 (1994).

[31] ALYN C. DUXBURY, AN INTRODUCTION TO THE WORLD'S OCEANS (6th ed. 2000).

on Earth's surface and are the primary component of the biological pump that draws carbon dioxide out of the atmosphere into the deep ocean.[32] Once in the deep ocean, water circulates very slowly, on the order of centuries, such that the carbon that sinks within the bodies of the plankton in the Southern Ocean today will not return to the surface again for a few hundred years.[33] However, if the carbon remains in the surface waters, it will be re-released in less than a year.[34] Consequently, assuring transport of carbon to the deep ocean is essential to the viability of fertilization as a climate change mitigation strategy.

Proponents of iron fertilization believe that iron is the primary factor that is holding back nutrient utilization in the HNLC regions and point to geologic records to support their position. These records show that in past glacial periods, the amount of iron deposited in the ocean was far greater, increasing the growth potential of phytoplankton and thus the amount of carbon sequestered in the oceans. As a consequence, the atmospheric concentration of carbon dioxide was 80-100 ppm lower in glacial times than today.[35] Moreover fertilization proponents see the ocean's increased capacity within recent record to absorb growing amounts of carbon dioxide as an indication that the ocean's sink potential is under-utilized in this interglacial period.[36] However, most significantly (at least in the eyes of proponents), all twelve iron fertilization experiments have shown phytoplankton blooms immediately following iron addition.[37] Supporters have consequently assumed that the iron hypothesis is accurate and thus iron fertilization is a global warming solution.

The boom in phytoplankton populations seen with iron fertilization is hypothesized to have secondary benefits beyond reducing atmospheric CO_2. The two most cited benefits are the increase in biomass up through the food chain and the consequent production of dimethyl sulfide ("DMS"). The former benefit results from the increased phytoplankton population, which would trigger an increase in predatory zooplankton populations, which would then increase fish populations, and so on up the food chain. Scientists suggest therefore that iron fertilization will benefit the ecosystem as a whole and increase fisheries, which have been in global decline since the 1950s.[38]

The latter benefit only occurs, however, if certain phytoplankton are the source of the bloom. If this class of phytoplankton dominates the bloom (as was recorded in some but not all of the twelve experiments), then DMS is produced

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32 Chisolm et al., *supra* note 18, at 309; Christopher. L. Sabine, et al., *The Ocean Sink for Anthropogenic CO2*, 305 SCIENCE 367, 367 (2004).

33 Herzog et al., *supra* note 16, at 302; ALLSOPP ET AL., *supra* note 23, at 5.

34 *See* Kenneth S. Johnson et al., *Is Ocean Fertilization Credible and Creditable?*, 296 SCIENCE 467 (2002).

35 Anderson & Totterdell, *supra* note 17, at 74.

36 *See e.g.* Marinov & Sarmiento, *supra* note 15, at 269.

37 Boyd et al., *supra* note 29, at 612.

38 Jeremy B. C. Jackson et al., *Historical Overfishing and the Recent Collapse of Coastal Ecosystems*, 27 SCIENCE 629, 629 (2001).

through respiration.[39] The DMS is released into the atmosphere, where it oxidizes to form a sulfate aerosol. This aerosol then serves as a point of condensation for cloud formation. Because clouds cause backscattering of the sun's rays, they act to cool the planet. Thus, proponents of iron fertilization stress that fertilization is a positive feedback system, one that causes more greenhouse gas mitigation than directly expected.[40]

B. *Potential problems*

It is not surprising that proponents of iron fertilization push for its incorporation in the carbon credit systems established by the Kyoto Protocol. They defuse concerns about monitoring and verification by citing the ability to track phytoplankton blooms from space with satellites. However, a closer examination reveals that there are problems with this optimism and that the negative consequences of iron fertilization far outweigh the potential benefits.

Addressing the monitoring and verification aspects first, the satellites that proponents refer to merely assess or interpret the amount of chlorophyll present in the very top layer of the ocean. While chlorophyll concentration is related to phytoplankton biomass, a direct mathematical relationship cannot be derived because chlorophyll to carbon ratios vary by species and by the ambient environmental conditions.[41] Satellites are unable to identify which types of plankton are present in each bloom or if the composition changes with depth.[42] Furthermore, the satellites are unable to detect the amount of carbon that is re-released back into the atmosphere through phytoplankton respiration.[43]

The re-release of carbon back into the atmosphere is a problem not only in the short-term through respiration but over longer time scales as well. There is concern over the destination of the phytoplankton once they have sequestered the carbon; if they sink, then the carbon will be sequestered, but if they are

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[39] Peterson, *supra* note 19, at 77; ALLSOPP ET AL., *supra* note 23, at 13.

[40] Peterson, *supra* note 19, at 77; BOYCE THORNE-MILLER, THE LIVING OCEAN: UNDERSTANDING AND PROTECTING MARINE BIODIVERSITY 10 (2d ed. 1999); Hugh Powell, at 10, *Fertilizing the Ocean with Iron: Should We Add Iron to the Sea to Help Reduce Greenhouse Gases in the Air?*, 10 OCEANUS 4 (2007), *available at* http://www.whoi.edu/cms/files/OceanusIron_Fertilizing_30751.pdf.

[41] CHARLES. B. MILLER, BIOLOGICAL OCEANOGRAPHY 41-44 (5th ed. 2004); X. J. WANG ET AL., *Regulation of Phytoplankton Carbon to Chlorophyll Ratio by Light, Nutrients, and Temperature in the Equatorial Pacific Ocean: a Basin Scale Model*, 5 BIOGEOSCIENCE DISCUSSIONS 3869, 3871 (2008).

[42] T. Platt, S. Sathyendranath & A. Longhurst, *Remote Sensing of Primary Production in the Ocean: Promise and Fulfillment*, *in* THE CHANGING OCEAN CARBON CYCLE, *supra* note 21, at 447, 462; *See generally* Milton Kampel & Salvador A. Gaeta, *Calculation of Primary Production from Remotely-Sensed Ocean Color Data: SE Brazil, SW Atlantic*, *in* XI SBSR: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO [Brazilian Remote Sensing Symposium] 1575 (2003), *available at* http://marte.dpi.inpe.br/col/ltid.inpe.br/sbsr/2002/11.18.00.12/doc/13_361.pdf.

[43] J. E. Bardach, J. Lewis, *The Oceans, Algae, and the Greenhouse Effect*, OCEANS '91: OCEAN TECH. & OPPORTUNITIES PAC. FOR 90'S. PROC. 1731 (1991).

merely eaten by zooplankton, then a lot of the carbon will be re-released through the metabolic processes of the zooplankton, and only a small amount will make it to the deep ocean through fecal pellets.[44]

There is also concern over environmental factors that will limit the drawdown of the carbon to the deep ocean. Drawdown to the deep ocean is highly dependent on vertical mixing and the currents found in the HNLC regions. The vertical overturn of the water determines not only how quickly the carbon absorbed by the ocean makes it to the deep ocean, but also how frequently the nutrients are returned to the HNLC regions. As such, it is a key factor in the effectiveness of iron fertilization in decreasing atmospheric CO_2 concentrations.[45] If the carbon drawn down from the atmosphere does not make it to the deep ocean, then it has not been effectively or "permanently" sequestered.[46]

Changes in vertical mixing rates or the weather can greatly affect carbon transport. For example, in the 1993 IronEx I experiment, an unexpected change in the mixed layer resulted in a cessation of the benefits of the added iron simply because the enriched water was placed out of the photic zone necessary for planktonic growth.[47] Since the HNLC regions, especially the Southern Ocean, are so variable in their physical and biological characteristics, spatially and temporally, the effects of iron fertilization on carbon sequestration will be inconsistent. For example, one model predicted that only 2-44% of the initial carbon sequestered using iron fertilization techniques would be removed from the atmosphere for a full 100 years.[48]

Difficulties with drawdown to the deep ocean are only expected to worsen in the coming years as global warming progresses. As the ocean's temperature rises, its ability to absorb carbon dioxide through the solubility pump will be reduced because gases are less soluble in warmer waters. Furthermore it has been suggested that the warmer waters will result in a shutdown of many of the planet's currents, both across ocean surfaces and between different ocean layers.[49] The shutdown of currents will have obvious negative consequences for nutrient recycling, biological distributions, and water temperatures.

The addition of iron to the ocean is predicted to have a series of other cascade effects, five of which I will briefly mention. First, the goal of the iron addition is to maximize the utilization of nutrients in the HNLC regions. This is beneficial to the life in those HNLC regions but has the secondary effect of

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[44] Hugh. W. Ducklow, Deborah K. Steinberg & Ken O. Buesseler, *Upper Ocean Carbon Export and the Biological Pump*, 14 Oceanography 55, 55 (2001); Powell, *supra* note 28.

[45] T.-H. Peng & W. S. Broecker, *Dynamical Limitations on the Antarctic Iron Fertilization Strategy*, 349 NATURE 227, 229 (1991); K. O. Buesseler et al., *Revisiting Carbon Flux Through the Ocean's Twilight Zone*, 316 SCIENCE 567, 567-570 (2007).

[46] Scott, *supra* note 27, at 59.

[47] Peterson, *supra* note 19, at 74; Powell, *supra* note 28 at 12.

[48] Anderson & Totterdell, *supra* note 17, at 67.

[49] Marinov & Sarmiento, *supra* note 15, at 284.

producing a nutrient deficit in the waters by the time they reach other areas of the world, such as the tropics.[50] Lack of nutrients in these areas will result in significant changes to the ecosystems found there.

Second, the addition of iron is likely to cause hypoxia in non-surface waters.[51] Hypoxia, or lack of oxygen, would result from the iron-induced phytoplankton bloom blocking sunlight to deeper waters, as well as from overloading the bacterial decomposers, which remove oxygen from the water as they consume the sinking, dead phytoplankton.[52] This process is similar to that seen in the Dead Zone in the Gulf of Mexico.[53] In the Antarctic region, it is hypothesized that hypoxia could result in increased mortality rates of many different organisms, but most notably krill eggs, which serve as the foundation of the Southern Ocean ecosystem.[54]

Third, the addition of iron could shift the type of plankton and other species that survive, favoring fast growing species.[55] This shift could adversely effect the natural balance of the ecosystem. For example, some experiments have shown populations of toxic plankton dominating the blooms.[56] If fertilization projects proceed at the scale that some desire, this short-term change could become a long-term one, potentially causing the local extinction of certain species. This shift in species could also adversely influence the positive-feedback, DMS system discussed previously.[57] Instead of supporting a population of phytoplankton that produces DMS, populations could produce greenhouse gases such as methane and nitrous oxide.[58] Since these gases have a greater global warming potential than carbon dioxide, the benefits of iron fertilization would be lost and the global warming situation could actually be

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[50] Peterson, *supra* note 19, at 77; Chisholm et al., *supra* note 18, at 310; Sagarin et al., *supra* note 47, at 5; *See* Powell, *supra* note 40

[51] Jorge L. Sarmiento & James C. Orr, *Three-Dimensional Simulations of the Impact of Southern Ocean Nutrient Depletion on Atmospheric CO_2 and Ocean Chemistry*, 36 LIMNOLOGY & OCEANOGRAPHY 1928, 1948 (1991).

[52] Jed A. Fuhrman & Douglas G. Capone, *Possible Biogeochemical Consequences of Ocean Fertilization*, 36 LIMNOLOGY & OCEANOGRAPHY 1951, 1952 (1991).

[53] In the Gulf of Mexico, the influx of nutrients has come from runoff primarily from agricultural lands in the Mississippi River watershed. The nutrients overload the natural food web, and in the same mechanism described for iron fertilization, a hypoxic or dead zone is created. This phenomenon has been witnessed since the 1970s in the Gulf of Mexico and has reached a maximal size of 8,800 square miles in 2008. David Malakoff, *Death by Suffocation in the Gulf of Mexico*, 281 SCIENCE 191 (1998); Nat'l Oceanic & Atmos. Admin., *NOAA and Louisiana Scientists Predict Largest Gulf of Mexico "Dead Zone" on Record*, July 15, 2008, http://www.noaanews.noaa.gov/stories2008/20080715_deadzone.html.

[54] Peterson, *supra* note 19, at 77.

[55] Kenneth. H. Coale et al., *A Massive Phytoplankton Bloom Induced by an Ecosystem-Scale Iron Fertilization Experiment in the Equatorial Pacific Ocean*, 838 NATURE 495, 499 (1996); ALLSOPP ET AL., *supra* note 23, at 3.;

[56] Scott, *supra* note 27, at 95; ALLSOPP ET AL., *supra* note 23, at 12.

[57] Fuhrman & Capone, *supra* note 52, at 1952.

[58] *Id.* at 1953; Chisholm et al., *supra* note 18, at 310; ALLSOPP ET AL., *supra* note 23, at 3.

worsened.[59]

Fourth, the addition of foreign iron could result in invasive species introductions. The chemical differences between iron that naturally reaches these HNLC regions and that used in executed experiments have already been documented.[60] There is potential that these foreign iron sources also contain unidentified, microscopic organisms that could wreak havoc on the ecosystem in a similar manner as was seen in the Caribbean when microorganisms present in dust blown in from Saharan Africa destroyed fragile coral reefs.[61]

Finally, increasing the amount of carbon dioxide stored in the ocean will harm the creatures that live within it. It has already been documented that the increasing concentration of carbon dioxide in the oceans, termed ocean acidification, has slowed growth rates in calcium carbonate based organisms such as coral reefs and crustaceans.[62]

Beyond these understudied, hypothetical concerns regarding adverse side effects, there have been many measurable failures of iron fertilization experiments to meet their projected results. The first of these failures is the ratio of iron incorporated versus the amount added to the ocean. So much iron is added in the experiments that unless the conditions are perfect, a lot of iron is lost due to clumping and sinking before it can be utilized by phytoplankton.[63] Changes in environmental conditions out of human control such as the amount of sunlight, presence of fronts, and vertical mixing can greatly affect this incorporation rate.

The second failure of the experiments was assuming that bottle experiments accurately reflect natural conditions. The initial large projections of what iron fertilization was capable of were based upon the observed rates of bottled experiments. In general the bottle experiments consisted of adding particulate iron to 1-liter containers of seawater collected from the HNLC regions and observing the phytoplankton growth and change in CO_2 concentration. It does not take an oceanographer to realize that it is not guaranteed that the representation of species within the small experiment bottle would reflect the full range present in the ocean.[64] Additionally, with a bottle, there is no escaping through sinking, so the iron can be more fully utilized than it would be in the real ocean.[65] Thus projections from solely bottle experiments

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[59] Fuhrman & Capone, *supra* note 52, at 1956.

[60] Chisholm et al., *supra* note 18, at 309.

[61] Brian Handwerk, *Tainted African Dust Cloud Harms U.S., Caribbean Reefs*, NATIONAL GEOGRAPHIC NEWS, July 14, 2008, http://news.nationalgeographic.com/news/2008/07/080714-africa-clouds.html; TETRA TECH, INC., OCEAN IRON FERTILIZATION CONCEPTUAL MODEL 5 (2008), http://www.climos.com/imo/Climos/Climos_OIF_Conceptual_Model_Approach.pdf.

[62] Sagarin et al., *supra* note 47, at 6.

[63] Kerr, *supra* note 26, at 1089; Monastersky, *supra* note 30, at 148.

[64] Kerr, *supra* note 26, at 1089.

[65] *Id.*

overestimate the drawdown potential of iron fertilization.[66]

The overestimates from bottle experiments and models have been reflected in the in-situ experiments as well. It was initially hypothesized that iron fertilization could result in the drawdown of 30,000-110,000 tons of carbon for every ton of iron added to the ocean. However, the actual experiments proved less promising, sequestering only about 1000 tons of carbon for every ton of iron added.[67] This was not an isolated or atypical finding; most of the twelve experiments saw less-than-predicted drawdown rates, with only three conclusively demonstrating any sequestration had been achieved.[68] Though part of this lack of demonstration is due to the short period during which the cruises were able to observe the fertilized area (only a couple of weeks),[69] it is troubling that even on the short time scale, very little sequestration activity occurred.[70] If this deep-sea sequestration is not attained through drawdown, then the ultimate purpose of iron fertilization has been lost because the carbon initially absorbed by the phytoplankton bloom will simply be re-released for reasons discussed previously.

Even if iron fertilization did not present all of these problems, it is not a very viable solution to the global warming problem because it would require continual fertilization of the HNLC regions to remove the amount of carbon dioxide necessary to combat climate change. One study suggested that for a removal of 30% of the annual human generated CO_2, a region of a billion square kilometers would have to be fertilized, which is more than an order of magnitude greater than the entire Southern Ocean.[71] Another indicates that fertilization of the entire Southern Ocean for the next 50 years would reduce atmospheric carbon by only 6 ppm, which is 1/14 of what experts believe we need to reduce to stabilize atmospheric concentrations.[72] These are the optimistic models. An earlier model demonstrated that atmospheric CO_2 would not be "significantly reduced" even if iron fertilization worked "perfectly."[73] Models as recent as 2005 have suggested that to mitigate all anthropogenic emissions, fertilization would have to occur on a scale 15 times greater than the total area of all HNLC regions.[74] All of these models are relying on the scaling up of drawdown rates from relatively small-scale (in relation to the entire HNLC

[66] K. O. Buesseler & P. W. Boyd, *Will Ocean Fertilization Work?*, 300 SCIENCE 68 (2003).

[67] Powell, *supra* note 40 at 3.

[68] Coale et al., *supra* note 55, at 495; Boyd et al., *supra* note 29, at 699; Powell, *supra* note 40.

[69] Powell, *supra* note 28.

[70] Chisholm et al., *supra* note 18, at 309.

[71] Buesseler & Boyd, *supra* note 66, at 68.

[72] Email from Jorge L. Sarmiento on April 6, 2008; *See* S. Pacala, R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, 305 Science 968, 968 (2004).

[73] Peng & Broecker, *supra* note 45, at 227.

[74] R. E. ZEEBE, ARCHER, D., *Feasibility of Ocean Fertilization and its Impact on Future Atmospheric CO2 levels*, 32 Geophysical Research Letters, 11 (2005).

regions) iron experiments, however it is unknown if the same rates of drawdown can actually be achieved when scaled up to the necessary level.[75] Moreover, the more iron that is added, the harder the drawdown process becomes because the ocean becomes saturated with carbon dioxide, inducing a cessation of the solubility pump function described in Section II.[76]

C. *Synthesis and suggested action*

Scientific uncertainty, as has dominated the discussion thus far, is typically a rationale for allowing action to proceed unregulated, especially in the international environmental realm.[77] However, in the case of determining whether iron fertilization should be allowed, uncertainty is a valid reason for a ban. "The oceans are a fluid medium, beyond our control;"[78] accordingly it is foolish to assume that we have a full grasp of what the consequences of our actions will be. Nearly all members of the scientific community adopt this stance, regardless of their position on the effects of iron fertilization on climate. They stress that research on iron fertilization is desperately needed and that its application on a large scale should not proceed without more certainty in the science. In other words, they recommend adopting the precautionary principle, which stresses preventative or cautionary environmental protection.

There are numerous examples of how human intervention in natural processes results in disaster. As just one example, humans have eliminated the majority of the earth's wetland systems and are now seeing the effects of reduced water quality and increased damage from storms.[79] It would be irresponsible to ignore the lessons learned from the past experiences of large-scale human perturbation of the natural environment and proceed with this geo-engineering proposal.

Rationality should enter the decision-making process. If eutrophication is normally regarded as a negative consequence of human action,[80] why should we be supporting it now? Should that not be cause for concern? As one scientist said, "attempting to make policy decisions without a good understanding of the science involved (and the associated uncertainties) is positively dangerous."[81] Accordingly, it is unwise to proceed with iron fertilization on a large scale, and its ban should be addressed in an international environmental agreement in order to prevent any irreversible harm.

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[75] Chisholm et al., *supra* note 18, at 309.

[76] Sarmiento & Orr, *supra* note 51, at 1940.

[77] Norman Myers, *Scientific Uncertainty and Public Policy*, ENCYCLOPEDIA OF THE EARTH, Aug. 9, 2007, http://www.eoearth.org/article/Scientific_uncertainty_and_public_policy.

[78] Chisholm et al., *supra* note 18, at 309.

[79] *Gambling with Gaia*, ETC GROUP COMMUNIQUÉ (ETC Group, Ottowa, Ont., Can.), Jan. 2000, *available at* http://www.etcgroup.org/en/materials/publications.html?pub_id=608.

[80] THORNE-MILLER, *supra* note 40, at 25.

[81] Peterson, *supra* note 19, at 64.

III. IRON FERTILIZATION AND INTERNATIONAL LAW

A. *Introduction*

The regulation of iron fertilization is a gray area in international environmental law. It is not explicitly discussed in any agreement, but the nature of the procedure used to engage in fertilization, its effects upon the natural environment, and the proposed locations for fertilization render it within the scope of several existing international agreements. The treaties capable of addressing iron fertilization can be broken into three categories: those dealing with iron fertilization as pollution or dumping, those dealing with iron fertilization as it relates to the biological resources of the environment, and those addressing the climate change mitigation application of iron fertilization. For the purposes of this discussion, I have selected four primary agreements within those three categories to discuss in greater depth.

B. *Coverage under pollution and dumping regulations*

Since iron fertilization takes place in the oceans, it is only natural to turn to the U.N. Convention on the Law of the Sea ("UNCLOS"),[82] the so-called constitution of the oceans, as a first step in determining how iron fertilization could be regulated by existing agreements. As the primary location for iron fertilization projects is in the high seas (more than 200 miles off coasts), it is logical to examine Part VII, the section dedicated to the High Seas, for answers. However, Part VII emphasizes issues of security, passage, and sovereignty without providing much guidance for regulation of iron fertilization. Interaction with the environment of the high seas is only mentioned in the final section, Articles 116-120, and there the focus is on fisheries and not other elements of the environment. It is therefore necessary to focus on Part XII, which contains a much more extensive discussion of regulation of the marine environment beyond fisheries.

Part XII, the section of UNCLOS dedicated to the Protection and Preservation of the Marine Environment, contains obligations for Parties concerning conservation of the ocean. As such it has the best authority to address the cascade consequences that iron fertilization will have on the ecology of the HNLC regions. Article 192 states that nations "have the obligation to protect and preserve the marine environment." In order to accomplish this, Article 194(1) requires Parties to take all measures "necessary to prevent, reduce, and control pollution of the marine environment from any source." In light of these obligations, the primary question becomes whether the iron dust applied in

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[82] United Nations Convention on the Law of the Sea, Dec. 10, 1982, 1833 U.N.T.S. 397 [hereinafter UNCLOS], *available at* http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm.

fertilization projects qualifies as "pollution" and thus is regulated by Article 192.

Article 1 of UNCLOS defines pollution as "the introduction by man, directly or indirectly, of substances or energy. . .which results or is likely to result in such deleterious effects as harm to living resources and marine life." Given the potential negative consequences of iron addition described in the previous section, it would seem relatively easy for iron fertilization to meet the requirements laid out in Article 1. However, proponents of iron fertilization argue that since its addition is intentional and for the benefit of the environment, it does not count as pollution. This places iron fertilization in a unique situation, since items are not usually added to the ocean for good.[83] Consequently there is not a real precedent that can be referenced. Further difficulty will likely be encountered given the uncertainty in the science. UNCLOS does not generally endorse the use of the precautionary principle when addressing pollution,[84] so it could be difficult to make persuasive arguments that iron fertilization is pollution with the lack of hard evidence that dominates the field now.

Article 210 of UNCLOS specifies regulations for pollution resulting from dumping, which is the best category of pollution to describe iron fertilization. Dumping is defined in Article 1(5)(a) as "any deliberate disposal of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea." The addition of iron to the ocean in fertilization projects is indeed "deliberate" but it is unclear whether added iron is "waste." Article 1(5)(b) further complicates the issue by excluding from the original dumping definition the "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."[85] Again, the key to understanding where iron fertilization lies in this debate is to break up the definition. Iron fertilization definitively satisfies the first clause of the exclusion. However, given its negative impacts on the marine environment in combination with the obligation established in Article 192, it fails to satisfy the second clause. Thus it can be argued that UNCLOS could prohibit the use of iron fertilization, but does not do so explicitly with its current language.

The relationship between iron fertilization and its regulation under international marine dumping guidelines can be analyzed in greater depth using the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.[86] More commonly referred to as the London Convention, this agreement establishes international regulations for the intentional dumping of waste at sea. Dumping is defined in Article 3(1) with the exact same language and exclusions as found in UNCLOS, Article 1(5).

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83 Peterson, *supra* note 19, at 79.

84 Scott, *supra* note 27, at 69.

85 UNCLOS, *supra* note 82.

86 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, Dec. 29, 1972, 1046 U.N.T.S. 120 [hereinafter London Convention], *available at* http://www.imo.org/Conventions/contents.asp?topic_id=258&doc_id=681.

Consequently, the same debate over iron's classification remains: if iron dust is considered "waste," London Convention can cover it. However, if it is not "waste" (since it is not added to the ocean as a method of disposal but rather as a precursor for growth), then the Convention is irrelevant.

Assuming the international community was to accept iron's classification as "waste", there would still be challenges presented by the text of the Convention to ban its use in fertilization projects. Since 1996, the Convention has adopted a reverse-list approach by prohibiting the dumping of all wastes except those listed in Annex 1. This list contains two categories of waste that could be interpreted to incorporate the iron dust used in fertilization projects. Annex 1(1.5) allows for the at-sea disposal of "inert, inorganic geologic material," which is precisely what the particulate iron used in fertilization experiments is.

Annex 1(1.7) allows for the disposal of iron explicitly, although in the form of a "bulky" structure. While iron dust is certainly not "bulky," its chemical composition is likely quite similar to that of "bulky" forms. Accordingly, it may be difficult, though not impossible, to persuade Parties that iron dust should not be included in Annex 1. However, given the London Convention's precautionary approach to pollution control,[87] it may be easier than first thought.

Demonstration of the linkages between iron fertilization and the negative consequences it induces might persuade Parties of the need to modify the language of Annex 1 to exclude particulate iron. Furthermore, chemical oceanographers could clarify the differing chemical reactions and impacts on an ecosystem that particulate iron has as compared to larger masses of iron. Thus, bulky iron could remain on the accepted dumping list while particulate iron would be excluded. A modification to this effect would stave off the potential exemption that fertilizing iron might achieve under both the "inert, inorganic geologic material" clause and the "bulky" forms clause.

C. *Coverage under biological conservation regulations*

Stepping back from pollution and dumping issues, iron fertilization has the potential to be regulated under agreements concerning biological conservation and integrity. Similar to the guiding principles of Part XII of UNCLOS, the 1992 Convention on Biodiversity ("CBD") seeks to conserve biological diversity through sustainable use of natural resources.[88] Its emphasis on an ecosystem-based approach to biodiversity,[89] in contrast to a species-based approach, favors the consideration of the potential cascade effects iron fertilization when determining if its use is appropriate. It is hard to directly

[87] LEE A. KIMBALL, FORGING INTERNATIONAL AGREEMENTS: STRENGTHENING INTER-GOVERNMENTAL INSTITUTIONS FOR ENVIRONMENT AND DEVELOPMENT 8 (1992).

[88] The Convention on Biological Diversity, June 5, 1992, 1760 U.N.T.S. 143 [hereinafter CBD], *available at* http://www.cbd.int/convention/convention.shtml.

[89] THORNE-MILLER, *supra* note 40, at147.

connect iron fertilization with the population reduction of a specific endangered or listed species, as would be necessary under a species-based treaty. However, with the broader coverage outlined by the CBD, in which changes in the ecosystem composition as a whole are regarded as an offense, regulation of iron fertilization could be possible.. Furthermore, the CBD advocates a precautionary principle,[90] so direct and scientifically proven links are not necessary to initiate protection or prohibitory measures.[91] Accordingly, the lack of long-term studies and observations on the effects of iron fertilization up the food chain does not necessarily prohibit regulation of iron fertilization under the CBD.

However, despite these positive qualities and potential for coverage, the CBD provides only a weak way to regulate fertilization. For example, Article 7(c) of the Convention calls for each Party to "identify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity" but only requires that the activities be identified and then "monitored." As such, it does not effectively ban the use of detrimental processes and thus would still allow fertilization. Article 14 elaborates on these terms and the requirements of Parties, but has the same effective message: Parties must document changes but are not required to prevent detrimental actions. Thus the provisions of the CBD lack any real enforcement teeth.

Further ineffectiveness arises from the scope of coverage of the CBD; waters are only regulated if they fall in territorial seas.[92] Since the high seas are the regions in which iron fertilization implementation is most hopeful, using the CBD to address fertilization would not be the most appropriate or inclusive approach.

Some experts have suggested that iron fertilization regulation could be addressed from a biological conservation perspective using the treaties governing Antarctica and its waters, namely the Antarctic Treaty of 1959[93] and Commission for the Conservation of Antarctic Marine Living Resources ("CCAMLR"). The Antarctic Treaty of 1959 and its 1991 Madrid Protocol seek to protect "the Antarctic environment and dependent and associated ecosystems and the intrinsic value of Antarctica"[94] through methods similar to those used in the CBD. The same is true of 1980's CCAMLR, which regulates harvesting and associated activities in much of the Southern Ocean.[95] However, given that iron

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[90] *Id.* at 146; Protocol on Biosafety to the Convention on Biological Diversity, Jan. 29, 2000, 39 I.L.M. 1027, Conference of the Parties 6, Decision VI/23, Annex, *available at* http://www.cbd.int/decisions/view.shtml?id=7197.

[91] The preamble of the CBD states that "lack of full scientific uncertainty should not be used as a reason for postponing measure to avoid or minimize" threats. CBD, *supra* note 88.

[92] KIMBALL, *supra* note 87, at 2.

[93] The Antarctic Treaty, Jan. 12, 1959, 402 U.N.T.S. 71, *available at* http://www.scar.org/treaty/at_text.html.

[94] Scott, *supra* note 27, at 100.

[95] Convention on the Conservation of Antarctic Marine Living Resources, May 20, 1980, 19

fertilization prospects are not limited to the Southern Ocean, I have eliminated these treaties as potential remedies, as they will not provide a complete solution to the problem.

D. Coverage under global climate change mitigation regulations

Since the objective of iron fertilization is to mitigate the extent of global climate change, its regulation can also be controlled by climate agreements, such as the Kyoto Protocol. As discussed in the introduction, the Kyoto Protocol provides an implementation scheme to achieve the goal outlined by Article 2 of the UN Framework Convention on Climate Change namely, the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[96] Article 3(3) of the Kyoto Protocol states that the emissions reductions committed to by each Party can be achieved in the first commitment period, 2008-2012, through removals of emissions by "sources" and by "sinks."[97] This means that reductions can either be achieved through increasing efficiency or increasing storage. The wording of the first part of this Article indicates that iron fertilization could be used. However, Article 3(3) goes on to specify that only sinks which result "from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990" will be counted. Accordingly, iron fertilization is excluded. However it is only excluded by default and not by prescription, so its continued coverage in the second commitment period is not guaranteed.

This exclusion of iron fertilization credits has been upheld in the operation of the two carbon markets, the Chicago Climate Exchange and the European Climate Exchange, but has not prevented ocean credits from being sold on the voluntary market.[98] Private iron fertilization companies such as Climos have begun to petition for inclusion under the Clean Development Mechanism ("CDM").[99] To fully prevent the inclusion of iron fertilization credits in future commitment periods, the text of the Kyoto Protocol needs modification and the guidance documents regulating carbon trading and the CDM regimes should be updated to exclude iron fertilization.

I.L.M. 841 [hereinafter CCAMLR], *available at* http://www.ccamlr.org/pu/e/e_pubs/bd/pt1.pdf.

96 United Nations Framework Convention on Climate Change, May 9, 1992, 1771 U.N.T.S. 107 art 2 [hereinafter UNFCCC], *available at* http://unfccc.int/resource/docs/convkp/conveng.pdf.

97 Kyoto Protocol, *supra* note 11, art. 3.

98 Powell, *supra* note 40. This market trades 7 million tons of carbon for a total of $400 million annually.

99 Press Release, Climos, Climos Receives First Methodology for Ocean Iron Fertilization from EcoSecurities, Signs with DNV for Assessment (Dec. 3, 2007), http://www.climos.com/releases/2007/123release.html.

IV. RECOMMENDATIONS

A. Suggested modifications

Iron fertilization regulation is a problem that needs to be addressed at the global level because its negative effects have the potential to be felt worldwide. This viewpoint is shared by both scientists, as demonstrated in the science section of this analysis, and policy makers, as demonstrated in the preamble of UNCLOS, which states "problems of ocean space are closely interrelated and need to be considered as a whole."[100] Furthermore, the most promising locations for iron fertilization are found in the high seas and thus can only be regulated through an international forum. Modifying an existing treaty in such a forum will have the additional benefit of maximized observation and enforcement, which could be lost in a more piecemeal approach afforded by regional agreements or domestic legislation.

It is with this context in mind, as well as the discussion of the existing agreements presented in the previous section, that I recommend that new language be incorporated in both the London Convention and the Kyoto Protocol to regulate iron fertilization in the oceans. The suggested changes are minimal but still provide crucial protection of the ocean's resources by banning the use of iron fertilization at the commercial scale. Scientific exploration of the effects of fertilization could still be explored on a smaller scale, similar to that employed in the twelve experiments to date, but with the intention of further experiments being to ascertain greater information about the dynamics of iron fertilization and its impact on the ecological environment rather than to explore its effects on mitigating climate change. I have selected these two agreements over the others discussed because I believe that a) they provide the strongest route for an iron fertilization ban, and b) they would require the least modification of their existing language. Furthermore, by amending the two agreements at once, the physical action of dumping iron, as well as the motivations behind it, will be addressed simultaneously and thus provide a more comprehensive solution to this emerging problem. The specific recommended modifications are discussed below.

I recommend that Annex 1 of the London Convention be modified to exclude iron dust. This could be done in two different ways. First, Annex 1(1.5) could be supplemented with an additional phrase to indicate the exclusion of compounds that induce harmful cascade effects. The text would then read, "inert, inorganic geologic material, excluding those materials whose addition to the marine environment results in significant ecological impacts." This rewriting has the additional benefit that it would preemptively ban other, future geo-engineering projects involving element addition to the ocean. An alternative way to modify the Convention's Annex would be to include a

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[100] UNCLOS, *supra* note 82.

specific reference to the exclusion of particulate iron from the accepted list. However, given that no other exemption is listed in this manner and that this approach does not address future actions with different elements, this is a less satisfactory alteration.

In addition to a modification to the London Convention, a second set of modifications should also be made to the Kyoto Protocol and/or the guidance documents regulating the operation of the carbon markets and the CDM to exclude iron fertilization credits from the second commitment period. This would remove any financial motivation from the continued use of iron fertilization. As suggested previously, the modification could be accomplished either by retaining the language of Article 3(3), which allows sink credits *only* from land-based sources, or by including a clause specifically excluding ocean sink sources. Additionally, similar restrictions should be added to carbon market guidance documents as well as a complete prohibition of petitions under the CDM for iron fertilization projects.

Since Kyoto's first commitment period is already operational, there is an immediate need to alter the language of the agreements to avert any growth in this field or unintended, ecological consequences.[101] In addition to the aversion of the destruction of a global commons, taking proactive action will avoid a "carbon rush"[102] that otherwise could occur at the start of the second commitment period. Since the verification of sequestration levels and additionality of iron fertilization projects is tenuous at best,[103] it is quite plausible that carbon market regulators will be wary of such credit incorporation and would likely support its explicit exclusion through modification of the Protocol.

B. *Feasibility*

Amending the London Convention and the Kyoto Protocol to fend off this potentially devastating geo-engineering idea will be readily achievable for six reasons. First, there are not very many involved groups; less than a dozen countries have been active in the twelve research experiments that have taken place and no commercial endeavors have been attempted by these host countries.[104] Instead, there are only a handful of private corporations, many U.S. based, that are involved in commercial ventures.[105] These ventures are not very strong, politically or economically, due to their sole reliance on the voluntary

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[101] Sagarin et al., *supra* note 47, at 9.

[102] J. ADHIYA & SALLIE W. CHISHOLM, CTR. ENVTL. INITIATIVES MIT, Is Ocean Fertilization a Good Carbon Sequestration Option? vi (2001), http://lfee.mit.edu/public/LFEE_2001-001_RP.pdf.

[103] Chisholm et al., *supra* note 18, at 310; *See* Sagarin et al., *supra* note 47.

[104] Boyd et al., *supra* note 29, at 612-617; ALLSOPP ET AL., *supra* note 23.

[105] These include corporations such as Planktos, Climos, Ocean Carbon Sciences, and GreenSea Ventures. Chisholm et al., *supra* note 18, at 309.

carbon market[106] and lack of public support. The February 2008 bankruptcy of Planktos, a private fertilization company, is a perfect example; the company's website attributes its collapse to its inability to maintain sufficient funding due to a "highly effective disinformation campaign."[107]

Given this state of few financially impacted groups, it should be relatively easy to garner support for an iron fertilization ban due to its minimal economic impact; a ban on large-scale fertilization will not endanger the livelihood of many people or an entire state. Action must be taken soon, however, because if allowed to enter the mandatory carbon market, ocean fertilization is projected to be worth over $100 billion in the next century.[108]

Second, there are already existing agreements in which iron fertilization can be addressed. It will not be necessary to develop a new framework, a process which can take several years to decades from conception to implementation. Furthermore, the Kyoto and London frameworks are well regarded within the international community and have large participation. The Kyoto Protocol has 169 Parties and the London Convention has 81 Parties.[109] These numbers are quite impressive especially when compared with the total 192 U.N. recognized nations.[110] These Parties are already concerned about iron fertilization; in June 2007, the Scientific Groups to the London Convention and London Protocol issued a Statement of Concern expressing their desire to restrict iron fertilization projects given the uncertainty with respect to its negative effects.[111]

Third, all Parties will be treated the exact same way if an iron fertilization ban is in effect. All Parties would be prohibited from conducting large-scale iron fertilization and all "credits" would not be recognized in markets; there is no grey area of what is or is not allowed. This, in combination with the lack of financial investment in fertilization projects, means that no State is disproportionately hurt by the agreement and the typical North-South tension that plagues many international agreements will be absent.

Similarly, there are no added costs for implementing this ban. It is not in any group's interest to fertilize the ocean if the carbon dioxide reductions are not recognized by carbon crediting and trading schemes. With most other agreements, violations tend to be due to lack of "financial or technical

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106 Sagarin et al., *supra* note 47, at 9.

107 Rachel Courtland, *Planktos Dead in the Water*, NATURE NEWS, Feb. 15, 2008, http://www.nature.com/news/2008/080215/full/news.2008.604.html.

108 Powell, *supra* note 40.

109 HUNTER ET AL., *supra* note 4, at 816 and 825; UNFCCC, Parties to the Kyoto Protocol, http://maindb.unfccc.int/public/country.pl?group=kyoto (last visited Mar. 28, 2009).

110 Press Release, United Nations, United Nations Member States (July 3, 2006), http://www.un.org/News/Press/docs/2006/org1469.doc.htm.

111 Int'l Maritime Org. [IMO], *Statement of Concern Regarding Iron Fertilization of the Oceans to Sequester CO_2*, IMO Ref. T5/5.01, LC-LP.1/Circ. 14 (July 13, 2007), *available at* http://www.whoi.edu/cms/files/London_Convention_statement_24743_29324_30864.pdf; ALLSOPP ET AL., *supra* note 23, at 4.

capabilities to obey the law."[112] This will not be a problem with the proposed changes of the two protocols. Iron fertilization is a small industry that lacks rogue parties; there are no benefits without a market. Accordingly, problems of flag of convenience states[113] will be avoided and thus enforcement or monitoring costs will be non-existent. In addition, since the change will take place in the existing frameworks of the Kyoto Protocol and London Convention, no money needs to be collected for a new Secretariat or other regulatory body.

Fifth, the changes do not affect sovereignty. The loss of sovereignty that accompanies many international agreements can be a stumbling block,[114] but that would be absent from the proposed modifications as enforcement authority remains with the individual countries.

Finally, there are likely to be many Parties who are interested in stymieing this potential carbon mitigation technique and thus would be willing to propose or support the modifications of the Kyoto Protocol and London Convention. While the previous scientific discussion has demonstrated that iron fertilization will not prove to be a reliable source of carbon credits, some nations may still fear its incorporation in the carbon market. They are worried that the inclusion of ocean credits will reduce demand for other terrestrial credits they are able to offer. A study examining meeting Kyoto targets using sinks and trading found that Russia and the Ukraine will suffer the biggest losses of all Annex I countries if ocean credits are included in carbon markets.[115] Thus it would likely not be very hard to convince these countries to initiate the movement to ban iron fertilization, regardless of the preponderance of negative consequences that iron fertilization has on the ecosystem. Furthermore these countries are both parties to the Kyoto Protocol and the London Convention, so they have the legal ability to propose modifications to those agreements.

While those nations which stand to benefit from the inclusion of ocean credits in carbon markets are not likely to put forth the proposed modifications of international agreements, they may support iron fertilization's ban for other reasons, such as concerns about negative cascade effects. For example, the United States stands to benefit from the incorporation of ocean sink credits,[116] so its government would not likely propose a ban, but the U.S. Environmental Protection Agency has already expressed concern about iron fertilization for profit by private companies and conveyed that concern to the Scientific Group of the London Convention.[117] It is likely that many other nations feel the same

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[112] KIMBALL, *supra* note 87, at 43.

[113] Flag of convenience states are those states that have weaker enforcement regimes for environmental regulations and/or may not be part of international environmental agreements. *See* HUNTER ET AL., *supra* note 4, at 808.

[114] *Id.* at 21.

[115] Rehdanz et al., *supra* note 6, at 3523.

[116] *Id.* at 3522.

[117] Letter submitted by United States to the Scientific Groups of the London Convention and the London Protocol, Planktos, Inc., Large-Scale Ocean Iron Addition Projects (June 1, 2007), *available*

way, as there are plans to discuss iron fertilization in the next meeting of the London Convention parties in May of this year.[118] This climate of concern is favorable to getting the necessary votes for the modified treaty language.

It is worth noting that while I am advocating the modification of existing treaties, it is entirely possible that in the next fifty years there will be the development of a new agreement or treaty which addresses geo-engineering as a whole. This treaty could have its foundations in the UN Environmental Modification Convention ("ENMOD"), signed by 34 parties since 1978, which prohibits governments from using weather or climate as a weapon against other states.[119] ENMOD only has language to cover "hostile" environmental modification, while environmental modification for "peaceful purposes" is explicitly permitted in Article 3.[120] Despite the current lack of coverage of climate modification through iron fertilization, which is decidedly not hostile, ENMOD lays the groundwork for the ban of iron fertilization in a similar agreement. The key to this assertion is that ENMOD recognized that any weather alteration is a threat to the international community as a whole.[121] Since the oceans are critical in regulating the planet's climate, it would seem logical that iron fertilization would be prohibited by such an agreement. The actual development of a geo-engineering treaty will likely depend on the prominence and success of other geo-engineering projects in the near future.

CONCLUSION

Iron fertilization is not an appropriate mitigation strategy for climate change. Its projected benefits have not proven themselves in field experiments, nor are they sufficient to outweigh all of the negative consequences that would likely result. It is therefore necessary for its use to be regulated. This regulation needs to occur at the international level because the oceans are a global commons, and thus damage to them has the potential to affect the entire world.

The practice of iron fertilization is not addressed in any existing international agreement explicitly, but it readily could be with slight language modifications of one or more agreements. These agreements include the UN Law of the Sea Convention, London Convention, Convention on Biological Diversity, and the Kyoto Protocol. A simultaneous modification both the Kyoto and London Protocols affords the best solution as it addresses the motivations for iron fertilization projects as well as restricts the actual activity.

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at http://www.cpps-int.org/spanish/planaccion/reunion/Seminario%20Regional%20OMI-CPPS/LC-SG%2030INF.28%202007_.pdf.

118 Email from Ken Buesseler on April 8, 2008.

119 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, May 18, 1977, 31 U.S.T. 333, T.I.A.S. 9614 [hereinafter ENMOD], *available at* http://www.fas.org/nuke/control/enmod/text/environ2.htm.

120 *Id.*

121 *Gambling with Gaia, supra* note 79, at 1.

Iron fertilization presents a unique opportunity for the international community to take a proactive stance on a potential environmental problem. Many environmental agreements cite the precautionary principle as a guiding standard, but rarely do they have an opportunity for its complete application. By taking the recommended steps to include language addressing iron fertilization in the Kyoto Protocol and London Convention, the international community will be responding proactively instead of reacting to human induced negative alterations of the natural ecosystem.[122]

[122] Peterson, *supra* note 19, at 106.