Iron Fertilization in the Ocean for Climate Mitigation: Legal, Economic, and Environmental Challenges

The Nicholas Institute for Environmental Policy Solutions at Duke University

Raphael Sagarin, Associate Director for Ocean and Coastal Policy, The Nicholas Institute for Environmental Policy Solutions, Duke University

Megan Dawson, Assistant Researcher, The Nicholas Institute for Environmental Policy Solutions, Duke University

David Karl, Professor of Oceanography, University of Hawaii

Anthony Michael, Professor of Biological Sciences, University of Southern California

Brian Murray, Director for Economic Analysis, The Nicholas Institute for Environmental Policy Solutions, Duke University

Michael Orbach, Professor, Nicholas School for the Environment and Earth Sciences, Duke University

Nicole St. Clair, Associate Director of the DC Office, The Nicholas Institute for Environmental Policy Solutions, Duke University

Introduction

As public concern about global warming grows, and the need to reduce greenhouse gas emissions is clear, lawmakers, businesses, the public and investors are being presented with a number of new ideas for how to achieve those goals. Recently one such approach, "iron fertilization" of the oceans - the process of "seeding" some parts of the ocean with the essential micronutrient iron in order to grow more plankton and thus remove atmospheric carbon (in the form of CO_2) and store it in the oceans – has been in the public spotlight through news reports and well-publicized announcements of commercial ventures hoping to use iron fertilization to sequester carbon emissions. This process raises a number of questions, however, including its effectiveness as a market-based sequestration system and possible negative effects on the ocean and other environmental systems.

This paper is aimed to provide lawmakers, non-government organizations, the public and business interests with a brief overview of iron fertilization and its potential benefits and risks. We have consulted scientific and legal experts and reviewed literature from these fields in order to outline what is known and unknown about iron fertilization.

What is Iron Fertilization?

The goal of iron fertilization at sea is to stimulate phytoplankton growth in order to draw carbon out of the atmosphere and into the ocean. This would be achieved by spreading iron in the sea in those locations where iron is currently in such low concentrations that it limits phytoplankton growth.

Proponents hope that this will be one method, among many, to *sequester* or store atmospheric carbon, which is currently contributing to the greenhouse effect and global warming. Some investors, including several existing commercial ventures, hope that iron fertilization will be one method to earn carbon credits that can be traded through a market mechanism or sold as "offsets" for existing or planned greenhouse gas emissions. Some scientists, regulators, and non-government organizations, however, have raised concerns about the unknown effects of attempting to manipulate complex marine ecosystems, the feasibility of iron fertilization for carbon storage, and the efficacy of a market mechanism to facilitate these efforts.

As with any issue that combines complex science, policy and economic drivers, different cultural value systems also come to bear on peoples' views about the wisdom of iron fertilization.

For example, even the group of scientists consulted for this report, all of whom have worked directly on different aspects of the iron fertilization question, expressed a range of viewpoints based on their particular cultural value orientation. While all addressed the need to be cautious with large scale ecosystem engineering, some suggested that such engineering projects may be useful as part of a larger portfolio of ideas to reduce greenhouse gas concentrations, while others expressed strong opposition to manipulating ocean ecosystems in this manner. Aside from the specific biophysical, economic, or social effects of such systems, these cultural value orientations reflect personal and organizational attitudes and perceptions regarding the appropriateness of different courses of action. There was broad consensus that any commercial venture that is engaged in selling carbon credits for iron fertilization should be held to a high bar of accountability and responsibility for their actions.

What do we know about iron fertilization?

Our knowledge about the efficacy and side effects of iron fertilization comes from laboratory experiments, computer simulations and a small number of real-world experiments conducted in different isolated parts of the sea understood to be iron limited.

At the very least, if iron fertilization could be successful it would have to meet four criteria:

1. *Appropriate location and timing* It must be targeted at areas of the ocean and times of year where and when iron currently limits phytoplankton growth, so that new phytoplankton growth follows iron fertilization.
2. *Predictability of additional sequestration* It must consistently generate additional carbon storage that is stored for a predictable time period, so that long-term costs and benefits can be determined.
3. *Acceptable atmospheric and ecological consequences* It must not create dangerous direct or indirect consequences that either add more greenhouse gases to the atmosphere than are removed, or cause other detrimental environmental effects.
4. *Verification* The reduction in atmospheric carbon, acceptable environmental impacts, and economic effects must be verifiable.

Here we outline the challenges and opportunities that lie ahead in meeting these criteria.

Location and timing

It is essential to understand that artificial iron fertilization is not applicable in large parts of the world's oceans, and that not even all areas where iron fertilization may be appropriate have been tested experimentally over long time periods to observe the effects of fertilization. In particular, much of the modeling and real world experimental work has been focused on

HNLC (high nutrient low chlorophyll) areas of the oceans such as the equatorial Pacific and the Southern ocean that initially appeared to be promising areas for iron fertilization. Work in these areas has left scientists and business ventures with doubts about their feasibility to provide long-term carbon storage without negative ecological feedbacks as the results showed great variability in the amount and duration of carbon storage as well as high variability in the ecological responses.

While these doubts do provide a window into the types of problems of which we should be aware of in iron fertilization programs, the same problems may not necessarily arise in other oceanic systems that are currently being considered as sites for fertilization programs. For example, the North Pacific Subtropical Gyre features stronger stratification, or layering, of ocean waters so that sinking carbon may be more likely to be trapped for a longer time period in the deep ocean here.

Predictability of additional sequestration

For iron fertilization to provide additional value, carbon taken up by artificially stimulated plankton growth must be transported to a location, such as the deep sea, where it will not quickly return to the atmosphere. This plankton growth and transport must be in addition to what would have occurred naturally to be counted as a true emissions reduction. Any presumed benefit of iron fertilization must be informed by an understanding of the natural background conditions and how much plankton (and carbon storage) would have been produced in that area without any artificial fertilization.

Based on the life cycle of atmospheric carbon dioxide, "permanent" sequestration of carbon is often considered to be 100 years or more. This somewhat arbitrary timetable need not be met from a single intervention, however. If it remains cost effective to repeatedly apply a treatment that stores carbon for a shorter period so that the cumulative effect is continued removal of carbon from the atmosphere, this process may suffice and could be incorporated into a carbon sequestration market. This is analogous to treatments applied in terrestrial carbon sequestration activities such as forest management, which can be used to generate carbon offset credits.

The real concern is to predictably know the *minimum* amount of time that a given amount of iron fertilization will sequester a given amount of carbon. From an economic standpoint, with this information and assumptions about the future price of carbon on a market, it would be theoretically possible to determine an appropriate price for a given amount of fertilization. From a climatological standpoint the concern would still be what the net carbon taken from the atmosphere is and for how long will it remain sequestered? In a well-designed system these two viewpoints would be reconciled. For example, if the possibility of early release of the stored carbon looms large, then accounting provisions should be made to ensure that the crediting is adjusted accordingly.

Actual short-term experiments in HNLC zones have revealed wide variability in the length of time and amount of carbon sequestered per application of iron. Some scientists suggest, however, that other less dynamic sections of the ocean may be less variable and provide more predictable carbon storage.

Unintended Atmospheric and Ecological Feedbacks

As with any human interventions in an ecological system, the act of fertilization sets off a sequence of events that can become complex and difficult to monitor. Results from iron fertilization experiments and computer simulations illustrate this complexity. Of particular concern are modeling results suggesting iron fertilization may create conditions in which additional powerful greenhouse gases, such as nitrous oxide or methane, are released to the atmosphere. In these cases, iron fertilization may actually increase the concentration of climate warming gases in the atmosphere.

Some computer simulations also suggest that long term storage of carbon in an artificially fertilized part of the ocean will significantly reduce the productivity of other parts of the ocean that rely on nutrients from the altered location. This loss of productivity may have negative effects on fisheries in these locations. The potential for these unwanted feedbacks in the real world will also depend on the spatial and temporal extent of the fertilization program and this must be taken into account when reviewing commercial plans for fertilization.

From observations to date, we have little and sometimes contradictory information concerning the indirect effects on ecosystems that follow from the phytoplankton bloom that iron fertilization aims to stimulate. Comparative experiments in the same locations in different years show that completely different organisms may arrive to consume the new productivity, and these organisms may lead to different ecological outcomes, some of which are undesirable, such as toxic algal blooms. To be effective, iron fertilization must, in addition to providing some certainty of generating a plankton bloom and long-term uptake of the stored carbon, also provide some certainty that excessive unwanted ecological feedbacks do not occur.

An emerging concern of ocean scientists is the potential for "acidification" of parts of the world's oceans due to increased absorption of carbon into the sea. Here the concern is that as the pH of the ocean drops (becomes less alkaline) some marine organisms, including many that play key roles in marine food webs, may have difficulty in calcifying shells and skeletons, leading to reduced food sources for fish and other marine organisms. The effects of iron fertilization on the larger problem of ocean acidification will depend on how effective fertilization is. While simply absorbing more carbon in surface waters will exacerbate acidification, transporting carbon to deep sea reservoirs will partially alleviate the acidification problem in surface waters where most of the critical biological processes are occurring.

Verification

As with all carbon sequestration projects, the ability to verify additional carbon storage and lack of unwanted ecological feedbacks due to iron fertilization will be essential. Because these criteria cannot be precisely predicted, insurance contingencies may need to be provided in the case, for example, that carbon storage does not last as long as expected.

This uncertainty can lead to heavy discounting on the current price of carbon sequestration schemes. It is in the best interest of both carbon offset providers, their buyers, and citizens concerned about the positive and negative effects of iron fertilization to have the ability to verify these effects once the market is underway.

Scientists who were consulted for this paper have mixed opinions about the ability to verify that iron fertilization has stimulated new and lasting carbon storage. Both computer models and experiments focused on the HNLC areas reveal the difficulties of verifying long term storage in parts of the world's oceans. In particular this may be due to the physical dynamics of these systems. Some scientists expressed the view that with improved remote networked sensors, especially when deployed in more quiescent areas of the ocean that are the focus of future iron fertilization efforts, we could achieve capability to track the effects of iron additions.

Most of the consulted scientists did agree that the capacity for an effective verification method would need to be built up through a combination of realistic oceanic models, controlled experiments specifically designed to track effects of iron additions over large areas, and better monitoring systems.

The Legal Future of Iron Fertilization

No current legal structure has been used to actively regulate either the activity of iron fertilization or the selling of carbon credits based on iron fertilization, although various existing treaties are likely to be brought to bear on future fertilization efforts. Most areas of interest for iron fertilization activity are in the high seas, outside of national waters. Yet the most important treaties and conventions designed to regulate activities on the high seas were developed before carbon sequestration projects were being considered, and none of them deal directly with this issue.

On the one hand, several international treaties and declarations prohibit dumping of pollutants at sea or disturbance of ocean ecosystems, while on the other hand several treaties and conventions (sometimes the same treaties) appear broadly to encourage enhancement of greenhouse gas sinks or ecosystem improvements. The UN Convention on the Law of the Sea (LOSC) - to which the United States has not acceded as of September 2007 regulates some activities that could pose harm to the sea, and recently parties to LOSC have approved the idea of deep sea carbon sequestration in geological reservoirs. Even with that approval, it is not clear how LOSC applies to iron fertilization, which is conducted at the sea surface. Other conventions, such as the London Convention and London Protocol which address pollution at sea, might someday be brought to bear on iron fertilization but thus far legal scholars have only speculated as to how or if these treaties will be applied.

Despite this uncertainty, the United States government did submit an agenda item on June 1, 2007 to the Scientific Group of the London Convention and Protocol expressing its concern about the activities of Planktos, Inc. a U.S.- based company that had plans to test iron fertilization in the equatorial Pacific from a U.S.-flagged vessel, the *Weatherbird II.* According to the submitted agenda item, the U.S. Environmental Protection Agency (EPA) warned Planktos that such activity, if conducted under the U.S. flag, could potentially violate the U.S. Ocean Dumping Act (the U.S. statute implementing the London Convention) and requested additional information on several requested items related to environmental impacts such as the potential to produce anoxic conditions, additional greenhouse gases, and harmful algal blooms. Planktos reportedly responded by claiming the test would no longer be conducted under a U.S.- flagged vessel but did not provide information on the environmental impacts[1]. The EPA action and U.S. contribution to the Scientific Group suggests a future course of scrutiny that federal regulators in the U.S. may apply to iron fertilization schemes by other companies as well.

Iron Fertilization on the Market

Any market mechanism set up to trade carbon credits based on either the presumed increased productivity of the ocean environment of carbon sequestration potential would have to be based on the ability to tie economic value to the specific effect of the fertilization. Otherwise, the economic value of the financial instruments would be tied purely to the speculative market as opposed to any verifiable value-added. Both suppliers and purchasers of carbon credits will benefit from a system that provides independent verification that fertilization activities indeed result in long-term carbon storage, that activities are conducted in areas with a high probability for permanent storage and low probability of even indirect environmental damage, and that activities are backed up by contingency plans should storage fail to be permanent or yield unwanted environmental feedbacks.

Given the inherent uncertainties, commercial ventures to sell carbon credits based on iron fertilization must be held to a high bar. At present, at least one company is actively selling carbon credits online that appear to be based in part on iron fertilization[2]. It has not been demonstrated that these credits are in any way related to long-term storage in the ocean of additional carbon dioxide removed from the atmosphere.

Despite the uncertainty that any iron fertilization scheme at present will be able to meet the criteria identified above, business ventures are emerging that are working to reduce these uncertainties and bring verifiable fertilization-based credits to the market.

[1] U.S. EPA Submission to IMO Scientific Group of the London Convention, "Planktos Inc., Large-scale Ocean Iron Addition Projects", June 1, 2007, available via IMO website

[2] www.planktos.com

Including iron fertilization credits in existing carbon markets

At this juncture, no formal markets exist for carbon credits from iron fertilization. Even the major existing carbon trading markets such as the Chicago Climate Exchange and the European Climate Exchange that allow for tradable carbon offsets have no provisions for carbon trading based on oceanic sequestration.

The main driver of carbon credits globally, the Kyoto Protocol, allows terrestrial carbon sinks as creditable offsets that can be sold to emission sources regulated under the Protocol, but does not allow such offsets from ocean sinks. The provisions of the Kyoto Protocol will remain in effect through 2012, so inclusion of ocean sinks in this regime could not happen until after that time. The existing rules for carbon offsets under the Kyoto Protocol only allow projects in another country's "territory," ruling out iron fertilization locations that fall outside of territorial waters. Clearly if such a determination remains on the books in a post-Kyoto climate agreement, this would greatly diminish the potential for iron fertilization credit generation.

In general, any ocean sinks that are allowed under a post-2012 agreement should be subject to the strict rules that apply to terrestrial carbon sinks projects in land use, land use change, forestry and agriculture under the Clean Development Mechanism (CDM) and Joint Implementation (JI) provisions. These rules address issues such as permanence, additionality (the assurance that the carbon sequestration project wouldn't have happened anyway) and ancillary co-effects referenced above. By and large they have been applied fairly rigorously to ensure the credits are valid.

Until or unless regulatory regimes such as Kyoto allow ocean sinks as credits, any role they play will be relegated to voluntary carbon markets, which may not have as strict a set of quality controls and buyer protections as a regulatory system would impose, though efforts are now underway to develop quality standards for voluntary markets.

Conclusions and Key Points

Iron Fertilization is an intriguing but controversial option for mitigating atmospheric greenhouse gases. The controversy arises primarily because the full climatological, ecological and economic implications of iron fertilization are not well-understood by the scientific community. Moreover, what is understood raises concern about possible undesirable consequences on marine ecosystems and climate systems. Yet, commercial ventures see an opportunity to develop iron fertilization as an economically viable climate mitigation option. This mixture of strong economic interest and scientific concern calls for a rigorous assessment of the benefits and risks of iron fertilization. As prelude to the more extensive assessment needed, this paper seeks to frame the key scientific, legal, and economic issues surrounding iron fertilization and give a preliminary view of their importance. Toward that end, several key conclusions arise.

- While models and experiments on scales from laboratory bottles to hundreds of square kilometers in the ocean show in some cases that adding iron to some parts of the ocean can influence the carbon cycle and lead to carbon storage, it is important to recognize that the effectiveness of this process will depend on the location in the ocean, the environmental consequences of iron additions, and the ability to verify carbon storage and the ultimate fate of carbon in the ocean and atmosphere.

- Currently, there is very little ability to predict either the short-term or long-term effects of iron fertilization beyond a clear relationship between iron additions (in iron-poor waters) and a plankton bloom, but results taken from one type of oceanic system where most studies have been focused may not necessarily apply to other areas of the ocean where future iron fertilization efforts may be targeted.

- Responses to iron fertilization will be highly *context-specific*, meaning that there will be different responses based on the location in the ocean, the time of year, and the existing ecological conditions (temperature, water chemistry, species composition, etc.), which are themselves constantly changing.

- There are potential risks of further environmental damage through alteration of marine food webs, alterations of deep ocean chemistry (especially acidity), and feedback mechanisms that result in greater atmospheric concentration of greenhouse gases.

- As with any offset program, nothing about iron fertilization lowers emissions of greenhouse gases. Most experts agree that avoiding dangerous climate change will require a reduction in atmospheric concentrations of greenhouse gases, which can be accomplished with a mix of *emission* reductions and permanent removals through sinks. An offset program which substitutes enhanced sinks for emission reductions can only be effective if the sinks are real, verifiable, and adjusted for any forms of impermanence.

- Increased investment in ocean observing systems, especially remote networked sensors in the oceans, will help resolve questions about iron fertilization while providing multiple benefits for understanding ocean ecosystems in general

- There is little active regulation of either iron fertilization activities at sea or carbon offset programs based on iron fertilization credits. There is the potential and the need to include discussions of iron fertilization in post-2012 Kyoto Protocol negotiations and in future provisions of the UN LOSC and the London Convention.

- Lacking formal regulatory constraints, commercial ventures to sell carbon credits through iron fertilization should be held to a high bar with regard to permanence, verifiability and ancillary environmental impacts. Currently, standards in these areas are being developed for the voluntary carbon offset market.

- Different cultural value systems underlie the debate on iron fertilization, ranging from an approach that disfavors altering one ecosystem to repair damage humans have created in another, to an approach that argues that some forms of ecosystem engineering will be necessary to deal with the magnitude and direction of the climate crisis.

Acknowledgements

The Nicholas Institute for Environmental Policy Solutions is committed to presenting the latest science and research to give decision makers the information they need to analyze their efficacy, risks and potential benefits.

We are grateful to the following scientists and legal scholars who advised on this project.

Ken Caldeira, Faculty, Department of Global Ecology, Carnegie Institution of Washington, Stanford University
Anand Gnanadesikan, Oceanographer, Atmospheric and Oceanic Sciences Program, Princeton University
Sheril Kirshenbaum, Associate in Research in Ocean and Coastal Policy, Nicholas Institute for Environmental Policy Solutions, Duke University
Marian Westley, Oceanographer, Geophysical Fluid Dynamics Laboratory, NOAA
Patricia Yager, Associate Professor, Department of Marine Sciences, University of Georgia
Brigham Daniels, Nicholas Institute for Environmental Policy Solutions, Duke University

In addition, several anonymous reviewers provided critical feedback on earlier drafts of this paper.

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