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Iron fertilization of the Oceans: Reconciling Commercial Claims with Published Models

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Abstract

Box model studies of geochemists have led to the conclusion that iron fertilization of the Southern Ocean would not significantly reduce atmospheric CO_2. Yet Michael Markels, an entrepreneur set on using ocean fertilization to sequester CO_2, believes he can solve the fossil fuel CO_2 problem with iron fertilization. In this paper, we take a simple-minded carbon accounting approach to examine Markels' claims and reconcile them with the conclusions of the modelling studies. We show that the discrepancy comes partly from flawed assumptions in the calculations, but largely from different interpretations of similar results. At best, iron fertilization would make only the smallest of dents in atmospheric CO_2 if fossil fuel burning continues to grow exponentially.

Introduction

The proposal to manage global warming by fertilizing vast areas of open ocean with iron first gained prominence in the late 1980s, when oceanographer John Martin declared "Give me half a tanker of iron and I'll give you an Ice Age"[1]. This stimulated a suite of biogeochemical modelling studies that investigated whether a large-scale fertilization of the ocean with iron would, indeed, make a significant dent in atmospheric CO_2 levels. Two of these studies published in Nature in 1991[2,3] concluded that even under ideal circumstances, iron fertilization of the Southern Ocean, the ocean area deemed most important for the control of atmospheric CO_2[4], would not significantly reduce the atmospheric CO_2 content. The idea of a quick fix to climate change was dismissed.

Meanwhile, oceanographers have continued to be fascinated by the control of primary production and ecosystem structure by iron in certain parts of the ocean, and have studied the effects of iron fertilization in medium scale *in-situ* experiments several times[5,6,7]. These experiments have confirmed the central role that iron plays in controlling the ecosystem in certain areas, and entrepreneurs have been paying attention to the results. The many articles in the popular press[8,9] that have covered the results of these experiments generally also mention the commercial side of iron fertilization: entrepreneurs who want to take advantage of this oceanographic peculiarity for profit. The entrepreneur who has received the most press by far is a man named Michael Markels, Jr. Markels has formed a company called GreenSea Venture, Inc[10], which aims to benefit from anticipated carbon reduction requirements by selling carbon credits obtained from iron fertilization of the ocean[8,11]. Markels claims that he can zero out the world contribution to atmospheric CO_2 increases from burning fossil fuel, 2.2 Gt C/yr[12], by fertilizing 16 million square miles of the Southern

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Ocean with 8.1 million tons of iron[8]. Additionally, he claims that this CO_2 will be sequestered for 1,000 to 10,000 years[13]. He wants to do a technology demonstration experiment in which he claims the fertilization of 5,000 mi^2 of the Equatorial Pacific with iron will sequester between 160,000 to 550,000 t C[14].

What about the results of the modelling studies mentioned above that concluded that fertilizing the ocean with iron could not significantly reduce CO_2? Who is right? In this paper, we examine Markels' claims, and try to reconcile them with the conclusions of the modelling studies of Peng and Broecker[2] and Joos et al.[3]. We show that the discrepancy comes partly from the calculations, and partly from different time-scales for which iron fertilization is being assessed.

Carbon Sequestration Calculations

Iron fertilization proposals target areas that have persistent high levels of major nutrients such as nitrate, phosphate, and silicate, termed HNLC (High Nutrient Low Chlorophyll) regions[6]. The lack of iron in these regions prevents marine phytoplankton from accessing the major nutrients, keeping levels of nutrients high and phytoplankton low. To determine the amount of carbon that may be sequestered from iron fertilization, most calculations assume that the addition of iron allows phytoplankton to completely deplete the levels of phosphate and nitrate in a specified area in surface waters[2,3]. This depletion of phosphate and nitrate can then be related to a carbon depletion through the Redfield ratio: plankton have been found to have a fairly constant ratio of carbon to nitrogen to phosphorus (C:N:P=106:16:1)[15], so the incorporation of nitrate and phosphate into organic matter will be associated with a corresponding incorporation of carbon into organic matter. The carbon for this organic matter comes from a vast pool of dissolved inorganic carbon, or DIC, in the surface water, which equilibrates with atmospheric CO_2 through air-sea gas exchange. The particulate organic carbon, or POC, thus formed represents the maximum amount of carbon biomass that can be formed from an iron addition in a specified area.

If we look at Markels' claims as examples, fertilizing 16 million square miles of Southern Ocean, which has a surface phosphate concentration of about 1.5 μM and a mixed layer depth of about 65 m[7], and using a ratio of C:P=130:1[16], would generate a maximum of 6.3 Gt C as particulate organic carbon, or POC. Similarly, fertilizing 5,000 square miles of the Equatorial Pacific, with its surface phosphate concentration of about 1 μM[4] and a mixed layer depth of about 25 m[6], would generate a maximum of about 500,000 t C as POC. Recall that Markels claimed to be able to sequester 2.2 Gt C in the Southern Ocean and between 160,000 and 550,000 t C in the Equatorial Pacific.

The final step in carbon sequestration calculations is to relate the amount of POC generated to how much and for how long carbon will be sequestered. This is the most crucial part of the calculations, but it is also the most difficult and the source of the largest uncertainties. It is also the step in which the methods of Markels and the geochemists diverge. The uncertainties come in not fully understanding the fate of this POC. Both biological and physical processes act on POC—biological respiration converts it back into CO_2 in a process known as remineralization, and ocean circulation transports POC or CO_2-rich water away from where it was produced.

As a generalization, the deeper the remineralization, the longer the sequestration of carbon. Studies have shown that most POC is remineralized in near-surface waters, however, with 50% of the newly produced POC remineralizing at depths of less than 300 m, 75% remineralizing by 500 m, and 90% remineralizing by 1500 m, suggesting carbon sequestration of the order of tens of years or less[17]. The exact depth dependence of remineralization is not well understood and probably changes with location. Complicating the effect of biological respiration is the added effect of ocean circulation, which can transport water in any direction. For example, POC may sink out of the surface layer and get remineralized in intermediate waters, but an ocean current can then bring this water rich in CO_2 back to the surface, releasing the carbon back to the atmosphere. Circulation thus affects the length of time CO_2 is sequestered from the atmosphere. The interaction between the depth of remineralization and the direction and strength of the ocean currents near the location of fertilization is therefore crucial in determining the fate of POC produced at the surface.

To look at this interaction, Peng and Broecker[2] and Joos et al.[3] used simplified two-dimensional box-advection-diffusion models to predict how much and for how long CO_2 might be sequestered by iron fertilization of the Southern Ocean. They estimated a 10-21% reduction in atmospheric CO_2 after 100 years of iron fertilization. Because of the simplifications in their model, their studies were designed to obtain upper limit estimates of ocean uptake of CO_2.

Markels, on the other hand, uses a single parameter to determine how much of the iron-induced POC is sequestered. In his calculations, he assumes that 53% of new production is sequestered permanently. Markels takes this number from a mass balance study of the upper 40 m of the Eastern Equatorial Pacific, in which 53% of carbon removed from the surface layer was calculated to be from sinking organic particles[18]. This value merely estimates how much newly produced carbon makes it out of the surface 40 m, and makes no predictions about what happens to the particles beyond the 40 m, thus it is not appropriate to use this value to calculate how much POC is permanently sequestered. Further, this value was calculated for the Eastern Equatorial Pacific, and cannot be applied to any other location.

Markels claims that his proposed iron fertilization technology will sequester carbon in the deep ocean for 1,000-10,000 years[12]. Since he does not incorporate ocean circulation into his calculations, and ocean circulation is crucial for determining the length of time CO_2 is sequestered from the atmosphere, the origins of this claim are not clear.

Framing the Claim

Criticizing Markels' use of the 53% value, while strictly appropriate and methodologically correct, does not resolve the apparent discrepancies between his claims and the conclusions made from the geochemical models. Markels still thinks he has a solution to global warming, whereas the geochemists concluded that iron fertilization would not make a significant dent in atmospheric CO_2. The resolution to this comes in different interpretations of similar quantities.

Although both groups of geochemists concluded that iron fertilization is not the most effective strategy to reduce future increases in atmospheric CO_2, it turns out that they were also getting carbon sequestration numbers on the order of several Gt C[2,3], right around what Markels claims he can sequester in the Southern Ocean. The reason Markels proclaims he has a solution to climate change and the geochemists say iron fertilization won't make a significant dent in CO_2 is a question of timeframe.

Markels' proposal sounds most compelling because he claims that he can wipe out fossil fuel CO_2 completely with his iron fertilization scheme, *i.e.*, he claims to have a solution of our problem of rising CO_2. The amount of carbon that he says needs to be sequestered to solve our CO_2 problem is 8 Gt CO_2, or 2.2 Gt C, which conveniently falls in the range of upper limit estimates for carbon sequestration from iron fertilization of the Southern Ocean.

The sequestration of around 2-3 Gt C is in the ballpark of the yearly amount of fossil fuel carbon that ended up in the atmosphere[12], but as a result of fossil fuel burning *back in the 1980s*. Business-as-usual scenarios predict exponentially increasing levels of atmospheric CO_2 in the future from steadily increasing rates of emissions. The reason the geochemists' iron fertilization effect looks so small (cf. Figure 2, ref. 3) is because they are comparing a somewhat *constant* “best-case” iron fertilization effect (for the sake of argument, say 2 Gt C/yr) to *increasing* levels of CO_2 emissions. So, although a hypothetically perfect iron fertilization implementation may reduce CO_2 of a magnitude roughly similar to the 1980s fossil fuel CO_2 contribution to the atmosphere, the ever-increasing rate at which CO_2 is being emitted means that iron fertilization will be incapable at making a dent in the future. In fact, rather than catching up with emissions, the geochemists’ models[2,3] indicate that iron fertilization becomes *less* efficient at sequestering CO_2 with time.

Conclusions

This paper has focused only on carbon accounting as a means of evaluating the feasibility of the commercial iron fertilization proposal of Markels. There are many other considerations, some of which, such as the unpredictable nature of the ecosystem response, may result in far more serious consequences than merely not sequestering any carbon. Still, the take home message from this carbon-centric analysis is this: even if iron fertilization were fully optimized to sequester the maximum amount of carbon, it will make only the smallest of dents in atmospheric CO_2 if fossil fuel burning continues to grow exponentially. Markels may still convince people to pay him for his carbon credits, but he will not solve the problem of climate change with a few tankers of iron.

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[10] GreenSea Venture web site: www.greenseaventure.com

[11] Markels, Jr., Michael. U.S. Patent #6,056,919. Method of Sequestering Carbon Dioxide, 02 May 2000.

[12] Markels arrives at this 2.2 Gt/yr number from the following assumptions (cf. ref 15): In the 1980s, total CO_2 emissions from fossil fuel burning were about 5.5 Gt C/yr. An additional 1.1 Gt C/yr are estimated to have come from land use change. Of the total 6.6 Gt C/yr of anthropogenic CO_2 being added to the atmosphere, about 85% came from fossil fuel burning and about 15% came from land use change. Terrestrial and ocean sinks took up about half of these anthropogenic emissions, and the other half stayed in the atmosphere. If we make the simplistic assumption that about ~85% of the ~3.3 Gt

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C/yr atmospheric increase was due to fossil fuels, then the observed atmospheric CO_2 increase in the 1980s that was attributable to fossil fuel burning was about 2.8 Gt C/yr. Markels calculates a slightly lower value of 2.2 Gt C/yr by letting the natural sinks only take up fossil fuel-derived CO_2 and not CO_2 from land-use change.

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