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Ocean Fertilization as an Effective Tool for Climate Change Mitigation

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Introduction

Ocean fertilization is a technique to permanently sequester carbon dioxide into the deep ocean by stimulating phytoplankton growth. Oceanographers have known for decades that biologic productivity in much of the open ocean is not limited by the supply of macronutrients such as nitrates and phosphates. Since the early 1990's, twelve open ocean experiments have shown that adding iron to these regions results in large blooms of phytoplankton[1]. These experiments mimic the effect of natural iron delivery from large dust storms which deposit tens of millions of tons of iron to the ocean annually and thus provide essential nutrients for phytoplankton growth.

Early on, oceanographers recognized that ocean iron fertilization might sequester large amounts of carbon from the atmosphere. Within the global carbon cycle, 45% of annual carbon turnover is driven by the primary productivity of ocean phytoplankton. As these organisms bloom and mature, they can be eaten or die throughout a 60-day cycle; a significant fraction of the dead organisms or fecal pellets aggregate into falling particles and sink towards the deep ocean. Over geologic time this "Biological Pump" has been the primary mechanism responsible for the concentration of approximately 86% of the planet's surface carbon into the deep ocean (see Figures 1-2). Recent research, modeling studies and experimental results have produced a wealth of new information and insight with which to better understand the carbon sequestration effectiveness and the expressed environmental concerns of ocean fertilization.

Now, several private corporations are beginning the work necessary to enable carbon markets to fund what could be a significant form of carbon mitigation, ultimately allowing emissions targets to be advanced more rapidly. This paper will discuss how ocean fertilization projects can generate verified carbon reductions according to an independently validated methodology. This paper will also cover a proposed "Code of Conduct" for fertilization projects, which covers carbon measurement and market elements, addresses potential environmental concerns and could form the basis of voluntary or regulatory standards relating to the quality and integrity of such projects.

Part 1: GHG Project Accounting for Ocean Fertilization

For ocean fertilization projects to be funded by the carbon markets, they must be analyzed according to industry standard greenhouse gas accounting protocols.

Real Carbon Reductions

The biological pump drives carbon sequestration from the atmosphere into the deep ocean reservoir, bypassing the surface ocean. The improvements in measurement techniques and modeling have increasingly shown that carbon export to the deep ocean is significantly greater than previously thought, and that up to 50% of the carbon in a phytoplankton bloom is sequestered below 500 meters[2]. At this depth, the permanence of carbon storage is 100 years or more over much of the world's oceans[3]. Additionally, recent modeling has shown that the majority of the carbon exported from the surface ocean is replaced by atmospheric CO2[4], therefore ocean fertilization can result in real reductions of carbon dioxide. Early ocean fertilization experiments were usually too short to observe the bloom termination, or too small-scale to effectively track the export of carbon[5]. More recent experiments, such as EIFEX (2004) in the Southern Ocean, measured sequestration efficiency of 50% below 1000m in concurrence with observations of natural blooms and model results[6].

There is reason to believe that natural iron fertilization contributed substantially to the reduction of ice age atmospheric CO2 levels. It has been known for some time that iron dust flux to the ocean has at least quadrupled during glacial stages of the past one million years[7]. Now, a recent synthesis of measurements and modeling by Cassar et al. shows that "airborne Fe increases production of sub-Antarctic waters, strengthening the link between enhanced Fe delivery and lower CO2 during the ice ages." Their research shows that observed increases in iron flux would have resulted in a 40ppm reduction of atmospheric CO2, which is equal to half of the total CO2 difference between warm and glacial conditions[8].

Applicability Conditions

Ocean fertilization projects should be conducted in the deep, open ocean to address the potential environmental concerns noted below. Projects should be conducted away from coastal zones and sensitive ecosystems. Furthermore, SF6 should not be used as a tracer to track the project area.

Additionality

Other than the sale of carbon reductions, there are no other current or contemplated revenue streams from an ocean iron fertilization project. Further, there are no policies compelling these projects. Therefore the additionality of these projects should be assured under virtually any additionality test.

Immediacy

Ocean fertilization projects are completed quickly. The plankton bloom ends within approximately 60 days of the first application of iron. The sequestration of carbon occurs rapidly, with ships expected to remain on station for approximately 60 total days to complete measurements. Permanence and Monitoring of Sequestered Carbon Ocean mixing is a slow, regular process that occurs on a time scale of hundreds to a thousand years. The ability to associate the depth of a water parcel in the water column with an age of that parcel is well-established in the oceanographic community. Measurements of the intrusion of manmade tracers (e.g. CFCs) and radioactive elements into world oceans provide calibration data for circulation models. These models can then produce a "residence time vs. depth profile" curve for any area of the ocean in which ocean fertilization is conducted[3].

To be consistent with the established practice of Global Warming Potential calculations and of LULUCF policy, a depth corresponding to a >100-year residence time is recommended for measuring the carbon credits claimed by the project. The Kyoto Protocol uses 100 years as the arbitrary time horizon for which the GWP of the six regulated GHGs are normalized[9]. Likewise, the IPCC recommends that 100 years be considered the permanence threshold with regard to LULUCF carbon sequestration projects[10]. Carbon reductions from ocean fertilization measured at the 100-year depth should be considered permanent, with no qualifications. Monitoring the project in the years after completion is not necessary.

Measurement

Measurement of sequestered carbon requires placement of sediment traps at the 100-year depth horizon. These traps measure the downward flux of carbon throughout the duration of the bloom. A comprehensive review of the techniques for using and calibrating sediment traps for the purpose of measuring sinking carbon was published in 2007[11].

Baseline

There are two types of baseline considerations for ocean fertilization projects: spatial baseline and temporal baseline. Spatial baseline reflects the background rate of carbon sequestration while the project is under way. These measurements are taken outside of the fertilized patch. The difference between in-patch and out-of-patch measurements gives the net carbon flux attributable to the fertilization project.

A temporal baseline recognizes that the rate of natural carbon sequestration can vary on a seasonal basis, as natural phytoplankton blooms typically occur in the late spring or early summer. An ocean fertilization project should initiate after the natural peak bloom has passed to avoid using the non-iron nutrients that would have been used anyway by the natural bloom. In some areas with high nutrients but low phytoplankton (called "High-Nutrient, Low Chlorophyll" or HNLC regions), natural blooms do not use all available nutrients. Thus, the temporal baseline may not be relevant in HNLC regions.

Leakage

Because the greenhouse gases (GHGs), methane and nitrous oxide, are products of biological metabolism, there has been concern that enhancing phytoplankton productivity might not result in a net benefit of GHG reductions[12]. More recent coupled physical/biogeochemical ocean models have shown that substantial N2O generation is some regions (e.g. the tropics), and very little generation in other regions (e.g. North Pacific and Southern Ocean)[13]. Measurements during two ocean fertilization experiments in the Southern Ocean confirm these results. One experiment showed a small amount of N2O[14], the other showed none[15].

From the methodology standpoint, leakage from the generation of non-CO2 gases, such as N2O and CH4, can be quantified through measurements during the project. The CO2-equivalent amount can then be subtracted from the total sequestered carbon. In the North Pacific and Southern Ocean, High-GWP gas leakage is estimated to be 5% or less of the total CO2 reductions. Leakage from the burning of fossil fuels to power the ships and from other direct operations will be deducted and is estimated to be approximately 1% of the total CO2 reductions.

Ancillary Effects: Potential Environmental Concerns

From the beginning of ocean fertilization research, oceanographers have studied the potential environmental concerns of ocean fertilization. These concerns are discussed in detail below, and either seen not to be relevant or can be effectively addressed through project design as discussed in the Applicability Conditions section above.

Eutrophication is persistent excessive primary productivity that can lead to low oxygen conditions possibly harmful to ocean life. Eutrophication occurs in coastal ocean waters from the continuous abundant supply of nitrate and phosphate from land, and rarely occurs in open ocean surface waters where macronutrient supplies are limited. Every phytoplankton bloom stimulated during ocean fertilization experiments has died out due to limited macronutrients, including experiments that applied iron to the ocean multiple times 1. Thus, eutrophication is very unlikely to occur with ocean fertilization in non-coastal waters.

Anoxia. The export of substantial amounts of organic carbon to deep waters will result in the decomposition of that material over time by microbial respiration. This will consume oxygen in deep waters. Some early models assumed that ocean fertilization would be used at large, basin-wide scales (e.g. the entire Southern Ocean) for at least a century, and these reasonably suggested that the deep waters of the ocean might become anoxic[16]. More realistic models that look at fertilization of more moderately sized patches of the ocean for a period of one or two decades suggest reduction in deep water oxygen, but no anoxia[17].

Changes to the species composition of phytoplankton. Natural blooms result in temporary changes to the overall species composition compared to non-bloom conditions[18]. After the bloom, the species mix is similar to pre-bloom conditions. There is no evidence that individual fertilized blooms will cause lasting changes to species composition. Common sense would also suggest this, given the large variability of natural iron delivery over both annual and geologic time scales.

Toxic algae. Ocean fertilization experiments stimulate the same species that bloom under natural conditions, generally diatoms. While algae capable of producing toxins exist in most of the ocean, the production of toxins rarely dominates natural blooms in the open ocean. Blooms dominated by algae capable of producing toxins generally occur in coastal waters where nutrient levels are high. Ocean fertilization activities should be conducted in the open ocean where the risk of harmful algal blooms is small, and the presence of abnormal levels of toxins should be monitored.

Ocean acidification. Ocean fertilization provides a net benefit to surface ocean acidification by accelerating the transport of CO2 out of surface waters to the deep ocean bicarbonate reservoir. This local decrease in surface ocean acidity will occur for approximately eight months before atmospheric CO2 re-equilibrates with the surface ocean 4. The effect on deep ocean acidity is very small because of the relative size of the deep ocean carbon pool. To put this in perspective, if the historic total of human CO2 emissions remaining in the atmosphere (~750 GtCO2) were sequestered to the deep ocean, this would increase the deep ocean carbon pool by less than 1%. Therefore ocean fertilization does not exacerbate deep ocean acidification.

Ancillary Effects: Potential Benefits

Ocean fertilization is likely to have some positive ecological effects. For instance, stimulating phytoplankton creates more food for higher trophic level consumers. Recent examples of this come from Antarctic icebergs, where observed increases in marine life density are the result of ocean fertilization from the release of iron-containing mineral dust entrained in the melting ice[19]. These effects were observed for several kilometers around the icebergs and at many higher levels of the food chain.

A second transient benefit of ocean fertilization is an increased production of clouds over the ocean. Phytoplankton naturally produce dimethyl sulfide gas (DMS), a primary source of cloud condensation nuclei over the open ocean. However, this effect only lasts several weeks at most.

Long Term Effects of Ocean Fertilization

The geologic record tells us that iron addition to the ocean has happened many times in the past for extended periods (2000-3000 years at a time). Sediment cores and ice cores worldwide have shown multiple order-of-magnitude increases in iron delivery for sustained periods over the past million years (see Figure 3). As iron increased, so did biological productivity of bloom species associated with iron. When previous levels returned, productivity relaxed as before. Further research will use experimental observations as well as computer modeling to identify an appropriate scale as well as any long term effects of sustained fertilization.

Part 2: The Climos Code of Conduct for Ocean Fertilization

Notwithstanding the discussion above, Climos recognizes that concerns have been raised about the potential impacts of this activity on the marine environment, about the lack of clear global regulatory guidance applicable to these activities, and about the difficulty of applying regulatory standards to activities on the high seas in areas beyond national jurisdiction.

In response to these concerns, Climos has proposed the elements of a Code of Conduct[20] that would address the major concerns about ecological protection, CO2 sequestration effectiveness, and regulatory requirements. This Code would provide a starting point for voluntary carbon credit certification standards, because a project following the Code will produce certified carbon reductions consistent with the protocols of GHG project accounting. The Code would also require compliance with all applicable laws relating to ocean environmental protection, and would require operators to take steps described above to minimize the impact of the scientific environmental concerns. Finally, the Code would require that all commercial operators conduct their projects in an open and transparent manner with the participation of the oceanographic community; in this way, the carbon market can provide a driving force for the advancement of ocean fertilization science.

Climos presented an overview of ocean fertilization to delegates at the International Maritime Organization London Convention on November 5, 2007, and will be working to bridge the compatible ideas of effective regulatory control and the need for continued evaluation of this technique.

Conclusion and Recommendations

Ocean fertilization has the potential to be an effective tool for anthropogenic CO2 mitigation that should be considered in combination with other strategies such as energy efficiency, renewable energy, LULUCF, and carbon capture with geologic storage (CCS). The magnitude of the CO2 problem suggests that we evaluate every available option. Ocean fertilization could remove quantities of CO2 that are comparable to these other strategies. Most oceanographers agree that the next step is to increase the scale of project patches to a moderate size to learn how much carbon can be sequestered[21].

While ocean fertilization is not a "silver bullet," the weight of scientific evidence suggests that well-designed projects at moderate scale can effectively reduce atmospheric CO2 levels without harm to sensitive marine ecosystems. It is also apparent that responsible projects would result in permanent, fully additional carbon reductions. The carbon market was established to accelerate emissions reductions as well as fund high quality carbon reductions. Ocean fertilization has the potential to be a vital tool in the effort to mitigate climate change, and verified projects based on rigorous validated methodologies should be considered for voluntary markets now and regulated markets in the future.

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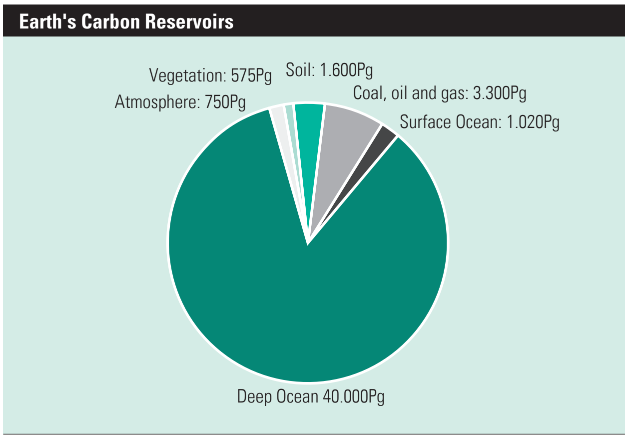

▲ **Figure 2.** Comparison of the Earth's carbon reservoirs. The deep ocean reservoir dwarfs all other carbon reservoirs. The biological pump is the primary mechanism for carbon sequestration into the deep ocean. (1 PgC = 1 GtC = 3.66 GtCO2e)

Climos

is a company dedicated to removing carbon from the atmosphere. Founded in California's Silicon Valley by entrepreneurs Dan Whaley and Richard Whilden, Climos scientific research is overseen by Dr. Margaret Leinen, former Assistant Director of Geosciences at the National Science Foundation (NSF). Climos is guided by a Scientific Advisory Board that includes some of the world's experts in ocean, earth and climate science.

IETA has no position on the role of ocean fertilization in addressing climate change, but believes that any possible mechanism should be investigated and debated in a responsible manner, with all due consideration given to the principle of environmental integrity. IETA is pleased to provide a forum for this process.

The Biological Pump

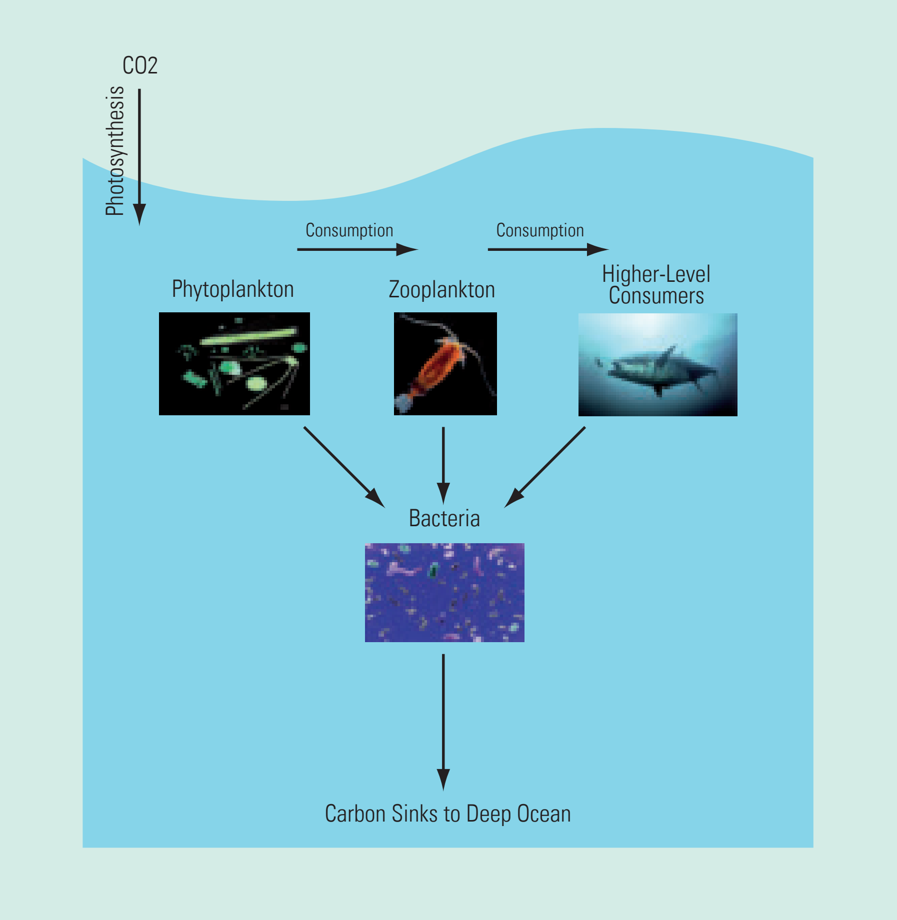

Figure 1. Biological Pump schematic shows pathways for carbon into the deep ocean. This is a natural process by which plankton grow at the surface, and then lose buoyancy after they die. Carbon is exported to the deep ocean from the "marine snow" composed of sinking plankton bodies and the fecal pellets from higher level consumers that eat plankton.

Iron vs Biogenic Silica (Opal) in the Equatorial Pacific

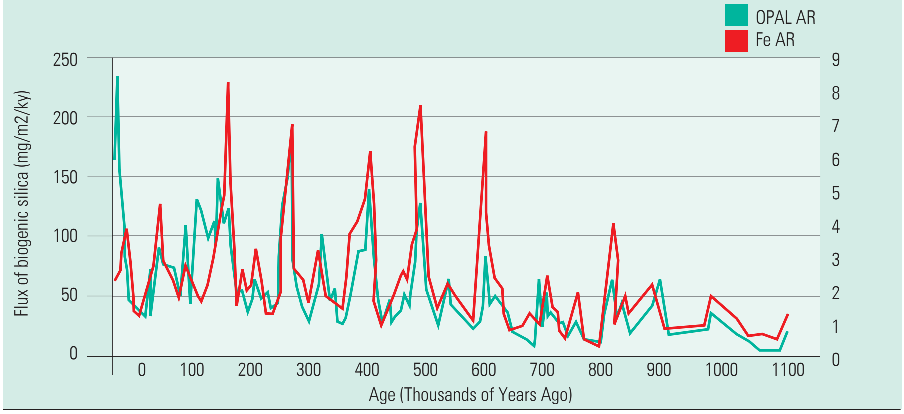

Figure 3. Biological productivity ("Opal AR") mirrors changes in iron dust flux ("Fe AR") over the last 1 million years. (Source: Knowlton and Leinen, 2007, Pre-publication)

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