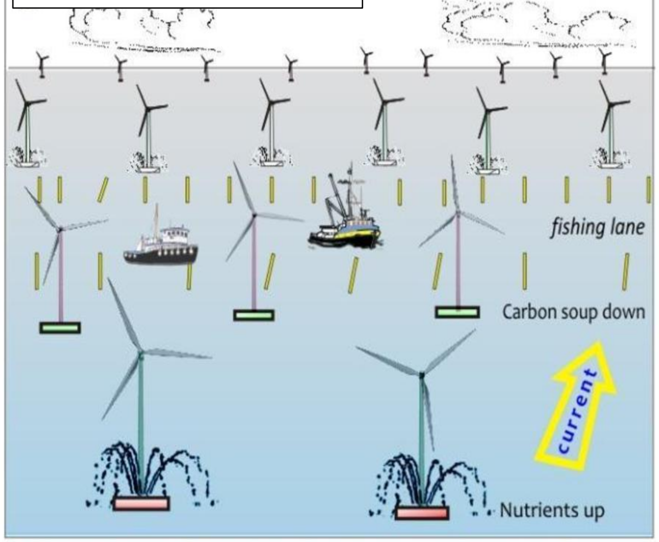
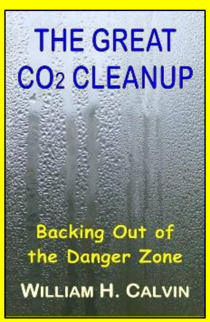
# Plowing Under a Carbon-fixing Crop

## Right-sizing a Plankton Plantation

The Plankton Plantation




The quick cool-down.

**Fast Enough** is complete by 2040. **Big Enough** probably means using one percent of the ocean surface and getting the project's power from wind and wave.

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An appropriate goal for our emergency repair would be to **"Put the genie back in the bottle"**—to remove nearly all of the excess $CO_2$ and put it back into long-term storage—and to finish retiring this carbon debt within the next twenty years.

This emergency repair would need to recapture most of the 350 GtC fossil emissions between 1750 and 2009. On top of that, extrapolating the emissions trend suggests we should allow for capturing another 250 GtC to counteract addit-ional fossil fuel use during the drawdown. A giga-ton of carbon (GtC), when oxidized into $CO_2$, weighs 3.7 gigatons.

If we could remove 30 Gt of circulating carbon each year via carbon dioxide removal, then in twenty years we could recapture an amount equal to all 600 GtC of the fossil fuels burned. Another 25 percent will be needed to offset deforestation and forest fires. Additional amounts could offset such $CO_2$ heating equivalents as methane leaks and albedo (brightness) reductions.

But remember: **the cool-down does not begin until the continuing emissions of $CO_2$ have been countered.**

## Why sink the $CO_2$ in the oceans?

To avoid competing with the world's food product-ion and supplies of fresh water, most sequestered carbon must come from new biomass grown in new places. Here I explore how paired ocean pumps might uplift nutrients and then sink the new organic carbon back into the ocean depths.

Instead of sinking only the debris that is heavy enough to settle out, as in iron fertilization, we would be using bulk flow to sink the entire organic **carbon soup** of the wind-mixed layer (organisms plus the hundred-fold larger amounts of dissolved organic carbon) before its carbon reverts to $CO_2$ and equilibrates with the atmosphere.

The $CO_2$ later produced in the depths by the sunken carbon soup will reach the surface 400-6,000 years later. Smearing it out over that return period greatly reduces the damaging peaks in ocean acidification.

If we fertilize via pumping up and sink nearby via bulk flow (a push-pull pump), we are essentially burying a carbon-fixing crop, much as farmers plow under a nitrogen-fixing cover crop of legumes to fertilize the soil. Instead of sinking only the debris that is heavy enough, we would be sinking the entire organic carbon soup of the wind-mixed layer.

## How much ocean acreage?

Algaculture minimizes respiration $CO_2$ from higher up the food chain and so allows a preliminary esti-mate of the size of our undertaking. Suppose that a midrange 50 g (as dry weight) of algae can be grown each day under a square meter of sunlit surface, and that half is carbon. Thus it takes about $10^{-4}$ $m^2$ to grow 1 gC each year. To produce our 30 GtC/yr draw down would require 30 x $10^{11}$ $m^2$ (0.8% of the ocean surface, about the size of the Caribbean).

But because we pump the surface waters down, not dried algae, we would also be sinking the entire organic carbon soup of the wind-mixed surface layer: the carbon in living cells plus the hundred-fold larger amounts in the surface dissolved organic carbon. Thus the plankton plantations might require only 30 x $10^9$ $m^2$ (closer to the size of Lake Michigan).

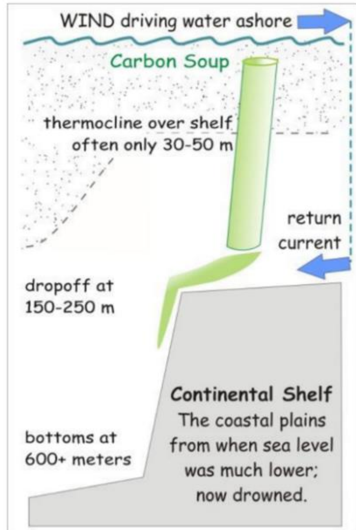
The space requirement might be more because down pumps will not capture all of the new plankton; it might be less because the relevant algaculture focuses on oil-containing algal species and on harvesting a biofuel crop, not on plowing under the local species as quickly as possible. The ocean pipe spacing, and the volume pumped down, will depend on the outflow needed to optimize the organic carbon production. [The chemostat calculation.]

Only field trials are likely to provide a better estimate for the needed size of sink-on-the-spot plankton plantations, pump numbers, and project costs.

Though ocean fertilization is usually proposed for low productivity regions where iron is the limiting nutrient, another strategy is to boost the shoulder seasons in regions of seasonally high ocean productivity. For example, ocean primary productivity northeast of Iceland drops to half by June as the nutrients upwelled by winter winds are depleted. Continuing production then depends on recycling nutrients within the wind-mixed layer. However, to the southwest of Iceland, productivity stays high all summer.

Because not all of the new plankton will be successfully captured and sunk, fertilization will stimulate the marine food chain locally. Most major fisheries have declined in recent decades and, even where sustainable harvesting is practiced, it still results in fish biomass 73% below natural levels. At least for fish of harvestable size, there is niche space going unused.

Locating the new plankton plantations over the outer continental shelves is more likely to supply a complete niche for many fish species, whereas deep-water plantations will lack variety. (The main commercial catch in deep water is tuna.) Also, down-pumping near the shelf edge would deposit organic




carbon in the bottom's offshore "undertow" stream, carrying it over the cliff and down the Continental Slope into deeper ocean.

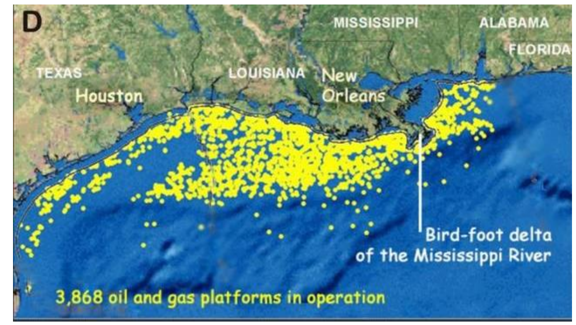
Note that pumps would be tethered to the bottom so that ocean currents are always creating a plume downstream: a plume of fertilizer near the surface and a second plume of carbon soup in the depths. (Pumping up from a different depth than pumping down will prevent the interaction that characterizes the oceanographers' box models.) While the water might come back around in a thousand years, the plumes for the clean-up will only be decades long and well spread out by that time.

## It's time to do a proper estimate

So far, this is only an order-of-magnitude estimate of the kind one does on a scratch pad. It demonstrates that it is well within our means. Next, one would proceed to a simulation. The state of the art looks good for this but in the ordinary pace of basic science, I'd estimate it would take a decade for several rounds of improvements, what would ordinarily come before field trials.

Time is so short that we must accelerate that. We need to start field trials simultaneously, discovering any problems with pumping and working out an efficient layout for a plankton plantation. Even more emphatically, we need field trials of competing designs for carbon removal. We once had time for doing a carbon removal project in a more economical way, but we wasted it.

## Where to do field trials




Testing the design need not wait for floating windmills. Oil and gas platforms can house ordinary pumps and supply their power during field trials.

## Overview

Most civilizations of the past have proven fragile, snuffing out their own candle. Climate change was usually the final blow, once they had made themselves vulnerable via explosions in population and resource consumption. Thanks to both history and science, we're the first society to understand what's going on, both with resource issues and climate change.

But some political parties make one wonder if human intelligence is mature enough to avoid committing collective suicide—even though we're still technologically and economically capable of repairing the rot we have caused in the foundations.




**Series home:** Print, and find additional handouts at, [*WilliamCalvin.org/climate*]

**Reading:** *The Great $CO_2$ Cleanup*, WilliamCalvin.org

C. H. Greene et al. *Earth's Future,* via doi.org/10.1002/2016EF000486

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