Reversing Ocean Acidification with a 20-year Drawdown of Excess CO2 via Push-Pull Ocean Pumps

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Pull up sunken nutrients to create CO2-capturing plankton blooms, then push new organic carbon down into ocean depths before it reverts to CO2, thereby keeping it out of the air for millennia.

A drawdown of atmospheric CO2 would address all three big issues: global overheating, ocean acidification, and excess methane. Here I discuss a class of solutions that should be big, quick, and sure-fire, suitable for both cleaning up the excess CO2 and countering out-of-control emissions. I provide an idealized example, while cautioning that a Second Manhattan Project is needed to get it right.

How big? Aim at removing all 350 GtC emitted since 1750. That would cool things off and reverse the acidification of the ocean surface layer.

How quickly? Aim for 20 years. During the project period, another 250 GtC are likely be emitted from business-as-usual, so make that goal 600 GtC, or –30 GtC/yr.

How secure? Our initiative needs to be sure-fire, since we must avoid having to make an even bigger effort later (perhaps after an economic crash or when resource wars have started).

Once the drawdown is complete, half of the sequestration capacity might still be needed for decades to continuously counter out-of-control emissions and those from essential uses of liquid fuels; the other half goes on standby for future emergencies.

Sequestration Candidates

Most of the desirable candidates for long-run improvements will be too small, too slow, or too iffy for an emergency drawdown. And we have already sped past some exits without noticing: even fertilizing the ocean surface enough to settle out –30 GtC/yr of the usual debris into the depths will now require an unachievable 3x increase in ocean productivity worldwide.

The proposed push-pull pump plantations are far more efficient than settling. In consequence, they might need less than 1% of the ocean surface:

- Pump up sunken nutrients from the depths to enhance plankton production (what winter winds do).
- But also imitate the natural downwellings; bulk flow works far better than settling at moving carbon into the depths. Pump down the green surface waters within a week, before the new organic carbon reverts to CO_2.
- Pumping down also sinks the 240x larger amounts of organic carbon from feces and decomposition that are dissolved in surface waters (DOC).

Just as farmers grow a nitrogen-fixing crop of legumes and then plow it under, we would be growing a carbon-fixing crop of plankton and then pumping it (and its DOC) under.

This push-pull pumps proposal has some unique advantages compared to current climate strategies:

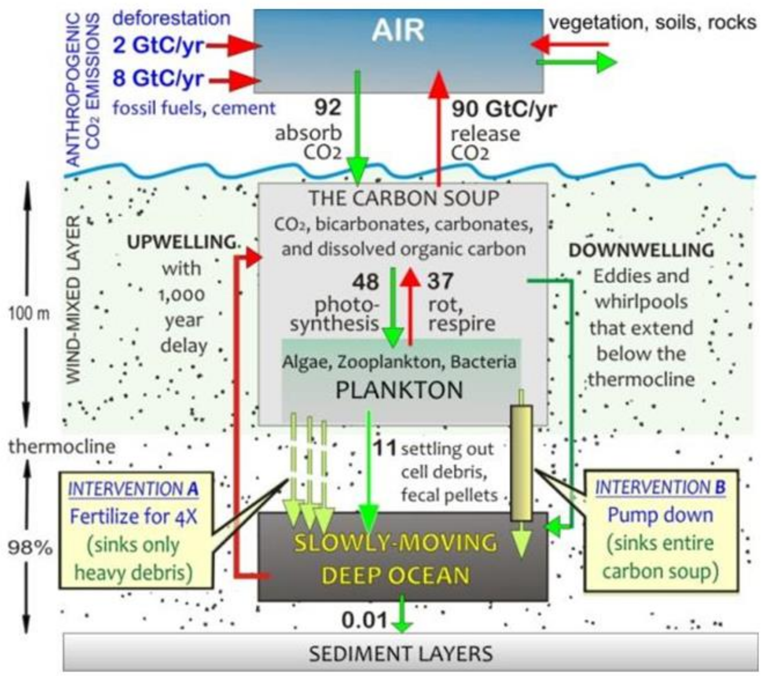
- It subtracts from the problem, not merely slowing down its worsening (which is all emissions reductions do, given that even partial CO_2 scrubbing by natural processes takes centuries).
- It is big, quick, and secure against backsliding.
- It is impervious to drought and holdout governments.
- It does not compete for land, fresh water, fuel, or electricity.
- It runs on wind power, augmenting the natural up- and down-welling of oceans.
- It also locally cools the ocean surface, by pulling up cool water and pushing down warm water.

Charge the **Second Manhattan Project** to deploy something like this within four years. A decade later, the climate threat could be half gone.

Idealized push-pull pumps and plankton plantations

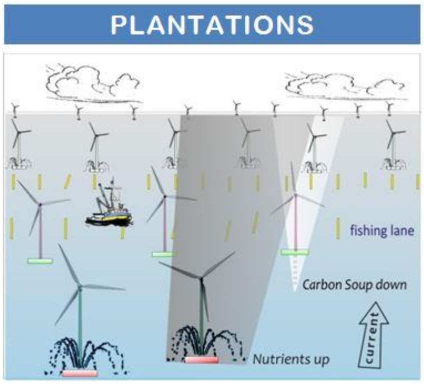
Nature's scrubbing system, on this time scale, mostly uses leaves and phytoplankton to remove carbon dioxide from the air. Photosynthesis releases the oxygen from the CO_2 molecule while incorporating the carbon into sugar and such. Unlike leaves, microalgae can double and redouble their numbers in 24 hours.

But the prospects for fertilizing enough blooms of algae have not looked good. Only about one-fourth of the new life manages to settle into deep waters before decomposing ("11" in illustration below). Removing the excess carbon via settling alone would require a 3x increase in productivity for 20 years in all the oceans, 70 percent of the earth's surface.

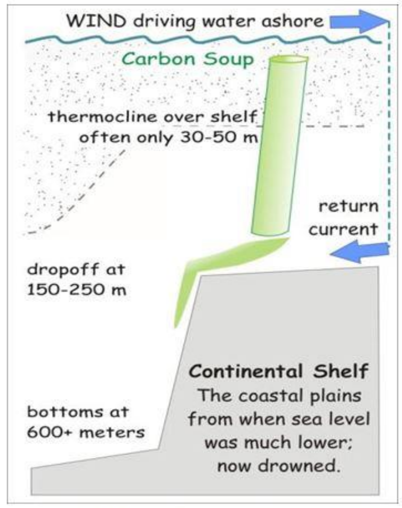


The Organic Carbon Soup

The ocean's carbon budget and how to keep 30 GtC/yr from becoming atmospheric CO2. Iron fertilization experiments have been aimed at settling more cell debris into the depths (*Intervention A*) but 30 GtC/yr would require 4X the natural settling worldwide, as would achieving fertilization by pumping nutrients up to the surface. Pumping down (*Intervention B*) can be done at many sites and sinks the entire "organic carbon soup" of surface waters—unlike *A*, where only the larger particulate matter settles quickly enough for its pending CO2 to be sequestered. (Source for fluxes: Houghton, 2007)



A plankton plantation design using windmill pumps, including a fishing lane free of anchor cables. Shading shows the plume of nutrients from a single pump and the plume of organic matter dispersed in the depths. One advantage of windmills is that compressed air can be generated to aerate surface waters and can be pumped into the depths to reduce hypoxia. The spacing of windmills, however, is subject to the usual limitations created by downwind vortices.



Locating Plankton Plantations at the edge of the Continental Shelf has many advantages, including shorter pipes. Staying on the Shelf also allows one country to quickly proceed in its own waters without lengthy international negotiations.

An easy-to-visualize method to do push-pull pumps uses floating windmills. Long pipes hang 15 to 30 stories down into the slowly moving depths. One windmill operates traditionally, pulling deep water up to the surface. The nutrients in this cold water create a sustained bloom of algae (and algae thrive in cooler water).

The other windmill pump pushes the enriched surface water down to where it cannot resurface for millennia. Pumping down stores the carbon in the brand-new algae as well as canceling out whatever carbon dioxide was first pulled up from below the thermocline.

Even more importantly, it sinks the 240x larger amounts of dissolved organic carbon (DOC) from the feces and cell debris. DOC ordinarily becomes carbon dioxide within a week or two and then escapes into the air as winds stir the surface layer. Stashing it as well is the second big step up in efficiency achieved by push-pull pumps.

Running the numbers

Green-water plantations might require less than one percent of the ocean surface. This comes from the following argument (more details in Calvin 2013b):

> Coastal upwelling zones can have a productivity of 500 to 2000 $gC/m^2/yr$. Algaculture yields can be 50 g (as dry weight) of algae grown each day under a square meter of sunlit surface, and half is carbon, or as much as 8000 $gC/m^2/yr$. Thus it takes about 1 x

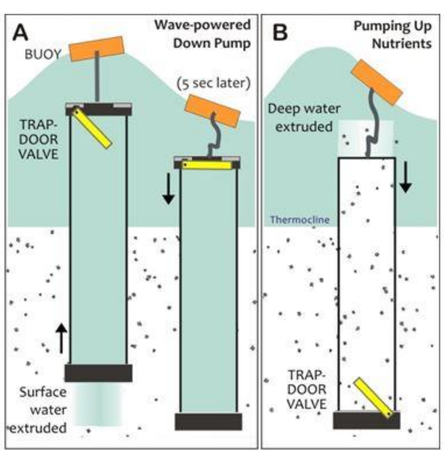
10^{-4} m² to grow 1 gC each year. To produce our 30 x 10^{15} gC/yr drawdown rate would require 30 x 10^{11} m² (0.8% of the ocean surface, about the size of the Caribbean).

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 much larger amounts in the surface DOC. Thus sink-on-the-spot plankton plantations might require as little as 30 x 10^{9} m² (closer to the size of Lake Michigan).

Apropos location, pumping down to 150 m near the edge of the continental shelf in mid-latitudes would deposit the organic carbon where it could be carried into the slower-moving deep ocean.

The ocean pipe spacing, and the volume pumped down, will depend on the outflow needed to optimize the organic carbon production (the *chemostat* calculation). Sufficient aeration may be needed to move enough CO_2 into surface waters to maintain high productivity. If wave action is insufficient, bubblers are an alternative, as is locating in high southern latitudes.

What is the needed size of plankton plantations, pump numbers, and project costs? While simulations can address some aspects of plantation design, *only field trials are likely to illuminate many biological issues* such as yield and side effects.



WAVE-POWERED PUMPS

Isaacs' buoyed one-way pipes. A less expensive pump can be constructed that uses wave power and allows closer packing. They would be more effective in the Antarctic Circumpolar Current because of the large wave heights.

From Calvin 2008, after Isaacs et al and Kithil

The Salter Sink uses a meter-high lip on a large floating ring to capture wave tops. This builds up enough hydrostatic pressure to push down warm surface water, kept enclosed by a tubular skirt.

Detail from figure in Intellectual Ventures white paper.

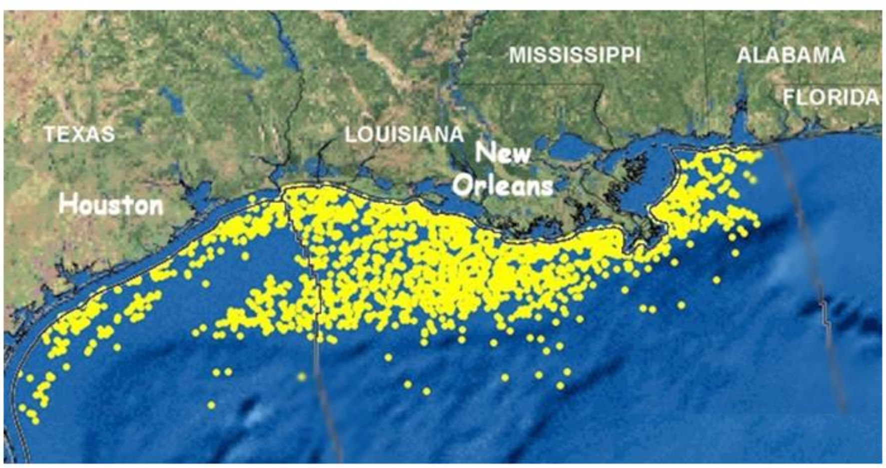
There are a number of alternative ways to achieve wind-or-wave-powered pumps, both up and down, such as Isaacs' buoyed one-way pipes and Salter's elevated ring to capture wave tops and create a hydrostatic pressure head for pushing surface waters into the depths. Combinations will need exploring; for example, a Salter Sink might be used for the down pump with a windmill for pumping up and aeration, thus concentrating the nutrients and production inside the ring.

A Second Manhattan Project

This idealized push-pull ocean pump is meant to provide a concrete example, easy to remember, that defines the response ballpark by being big, quick, secure, powered by clean sources, and inexpensive enough so that a country can implement it on its own continental shelf without endless international conferences. Other drawdown schemes need to pass those same tests.

To do the evaluation and planning job right is going to take a Second Manhattan Project of various experts to design cleanup candidates and evaluate side effects. To field test their plantation designs, let them instrument the many abandoned oil platforms in the North Sea and the Gulf of Mexico. Then quickly deploy the best designs, using the abilities of the offshore services industry.

If a government-scale Second Manhattan Project is delayed, field trials might be done with foundation-scale funding.



Test bed possibility

Existing drilling platforms in the Gulf of Mexico could support a field trial for pump and plantation design. Map (adapted from NOAA.gov) shows about 4,000 active platforms; there are another 3,000 inactive. A similar opportunity exists in the North Sea.

***Statement of expected impact (500 characters max.):**

Physical Impacts: The CO_2 drawdown should promptly reduce ocean surface acidity and air temperature. As ocean surface temperatures drop more slowly, sea level will mostly come down.

Hope: “What’s the use?” is a real danger on our current trajectory. The psychological prospect of actually reversing much of climate change should help sustain efforts for longer-term goals such as conservation and clean energy. It might also head off the disruptive economic impacts of reduced valuation (and loss of credit and insurance) in regions especially threatened by climate change. (I suspect this lies behind the US Chambers of Commerce extensive lobbying promoting climate denial.)

***Expected duration of work to make progress:**

First year for a 2nd Manhattan Project. Begin ocean survey at likely sites, studying the entire water column for a year, including flow direction and rate. Simulate plantation layouts and need for aeration; decide if the whitewater of the high southern latitudes will be needed. Deploy existing pump designs among oil and gas platforms.

Second year. Deploy six push-pull pump designs and evaluate. Field test the plantation layouts that emerge from the simulations; continue water column studies.

Third year. Partially deploy the best three plantation layouts with the most promising pumps.

Fourth year. Fully deploy 30 GtC/yr sequestration capacity.

***Expected total cost:**

US$ 1 billion minimum for full deployment, much less for field trials.

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*Author biography or biographies (3000 characters max. for each author bio):

- Born in Kansas City, Missouri USA, 1939.
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Climate books:

WILLIAM H. CALVIN (2008). *Global Fever: How to Treat Climate Change*. University of Chicago Press. See *Global-Fever.org*.

WILLIAM H. CALVIN (2013a). *The Great Climate Leap: A Climate Surprise is like a Heart Attack*. ClimateBooks. See *WilliamCalvin.org/bk15*.

WILLIAM H. CALVIN (2013b). *The Great CO2 Cleanup: Backing Out of the Danger Zone*. ClimateBooks. See *WilliamCalvin.org/bk16*.

More generally:

WILLIAM H. CALVIN (1994). The emergence of intelligence. *Scientific American* 271(4):100-107 (October; special issue *Life in the Universe*; reprinted in a Scientific American book of the same name, 1995). Many translation editions. Revised in 2006 for a Scientific American special edition on human evolution.

WILLIAM H. CALVIN (1990). *The Ascent of Mind: Ice Age Climates and the Evolution of Intelligence*. New York: Bantam.

WILLIAM H. CALVIN (1998). "The great climate flip-flop," *The Atlantic Monthly* 281(1):47-64. See also *WilliamCalvin.org/1990s/1998AtlanticClimate.htm*

WILLIAM H. CALVIN (2002). *A Brain for All Seasons: Human Evolution and Abrupt Climate Change*. University of Chicago Press. Winner of 2002 Phi Beta Kappa book prize for a scientist's contribution to literature. *faculty.washington.edu/wcalvin/BrainForAllSeasons/*.

Note to reviewers:

1) Engaging in a quick ballpark check on the numbers with the usual two-compartment equilibrium model has led a number of people astray because the water is flowing a la Heraclites but the pumps are tethered. Pumping up creates a downstream plume of nutrients at the surface. Pumping DOC, POC, and new greenery down creates a slower plume (and at a different depth than any downstream up-pump's intake); a laminar plume has a high surface-to-volume ratio and is surrounded by water with the usual oxygen content. The plumes are only 20 years long, about 1

percent of recirculation time. Thus input and output will not mix as in two-box models unless the project is continued for many millennia.

2) A frequent objection is that pumping up will bring up unwanted CO_2. And it does. But push-pull pumping means that much more potential CO_2 is pushed down than brought up, overcoming this objection to up-only pumping.