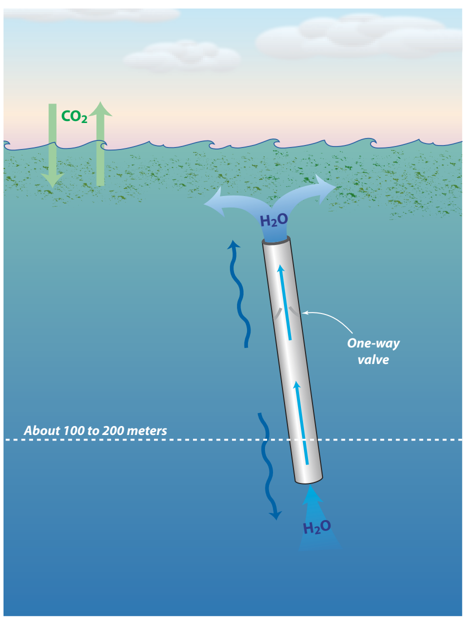
A Rash of Proposals Emerges to Transfer

It's sort of the planetary equivalent of moving clutter accumulating in the attic to other storage space in the basement: transferring excess heat-trapping carbon dioxide from Earth's atmosphere into the deep ocean. A combination of forces—including rising public awareness and concern about climate change, international treaties, and growing carbon trading markets—has combined to spark so-called geoengineering proposals to do that. Ocean iron fertilization is just one of several of these ideas. Here are a few others that apply to the oceans:



Jack Cook, WHOI

TUBING THE OCEAN—Increasing urgency about climate change has spurred proposals, which may have seemed radical not too long ago, to reduce atmospheric carbon dioxide levels. In a recent issue of the journal *Nature*, scientists James Lovelock and Chris Rapley proposed putting thousands of giant plastic tubes in the ocean (see next page). Wave motion and a one-way valve would push deep water through the tubes to the surface, bringing up essential nutrients to stimulate blooms of tiny marine plants. These phytoplankton would help draw down heat-trapping carbon dioxide from the air and also emit a chemical called dimethyl sulfide, which stimulates the formation of clouds that would block solar radiation and help cool the planet, the scientists say.

Injecting CO_2 into the Depths

Scientists from MIT, Columbia, and Harvard universities have suggested that carbon dioxide from industrial plants could be captured and piped into seafloor sediments—a variation of older proposals to dump CO_2 into ocean depths greater than 3,000 meters (almost 2 miles). Freezing temperatures and intense pressure would turn the carbon dioxide gas into a dense liquid heavier than the water above, so that it would stay in deep-sea storage and out of the atmosphere.

The idea would also capitalize on unused real estate. Undersea sediments along the U.S. coastline, for example, may be sufficient to store the nation's annual carbon dioxide emissions for thousands of years, researchers said in the August 2006 issue of the *Proceedings of the National Academy of Sciences*.

Opponents of the idea argue that adding billions of tons of carbon dioxide into the ocean in large, concentrated doses would alter the oceans' water chemistry, have detrimental impacts on sensitive marine organisms, and send harmful ripples through the food chain. Also, possible leakage back to the surface remains a question.

Industrial plants would need to be retrofitted with devices to harness emissions (something that would be required also for other proposals to store CO_2 underground). Additional costs would come from injecting the CO_2 via pipes, likely from a ship or a platform (similar to those used with ocean drilling) through nearly two miles of salt water into the seafloor.

Fertilizing the Ocean with Nitrogen

The Ocean Nourishment Corp. (ONC) in Australia has proposed injecting large amounts of urea—a nitrogen compound found in mammalian urine and fertilizers—into low-nitrogen seas to stimulate phytoplankton blooms and draw down excess CO_2 from the air. Like land plants, phytoplankton require (along with sunlight, water, and CO_2) not just iron but nutrients such as nitrogen to grow, but most tropical and subtropical ocean regions have too little of this essential nutrient, resulting in low productivity.

In ONC's plan, coastal factories using tanker-supplied natural gas would produce urea, pump it through pipelines, and release it at the edge of the continental shelf to stimulate phytoplankton blooms. In theory, phytoplankton growth would both pull CO_2 out of the atmosphere and also provide abundant food for zooplankton and fish, increasing fish stocks for people. Carbon "locked" in dead plankton and fish tissue may eventually sink and be sequestered in the ocean depths.

To be effective, the proposal would have to be worldwide. It would require at least 1,000 times more nitrogen than iron to fertilize equivalent blooms. Several unresolved issues make the idea complicated: Increased coastal nitrogen could promote blooms of toxic algae ("red tides"); the altered ocean chemistry could lead to unanticipated and permanent ecosystem changes; it remains unproved that more carbon-containing debris will sink to the deep ocean; and the factories and ecosystem changes would be disproportionately in poor tropical countries.

ONC is a commercial venture eager to sell rights to use its licensed method in tropical regions to obtain carbon-offset credits. The company reportedly has conducted at least one small-scale experimental release of one ton of urea in the Sulu Sea, bounded by the Philippines and Borneo, and has further plans to test a release of 1,000 tons. The first release was near a highly biodiverse area and a World Ocean Heritage site, prompting protests, partly because ONC may not have secured adequate Philippine government permission.

Excess Carbon into the Ocean

Speeding Up Chemical Weathering

Researchers from Harvard and Pennsylvania State universities have outlined a process that mimics the natural weathering of rocks, but accelerates the process—transferring carbon from air to sea over decades, rather than millennia.

Carbon dioxide (CO_2) in the atmosphere naturally dissolves in fresh water (H_2O) such as rain, forming weak carbonic acid (H_2CO_3). As rainwater percolates down through volcanic rocks, chemical reactions produce bicarbonate (HCO_3^-) salts that flow into the ocean. Bicarbonate dissolves readily in seawater, allowing the ocean to retain and store more atmospheric CO_2.

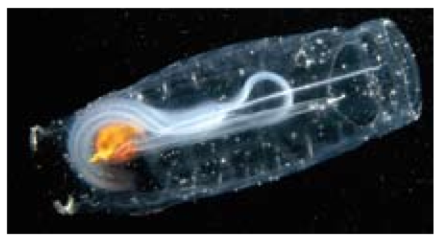
In an article published Nov. 7, 2007, in the journal *Environmental Science and Technology*, the researchers propose building dozens of solar-powered plants in remote volcanic islands, such as in the South Pacific or the Alaskan archipelago. The plants would split seawater to get hydrogen ions that would be combined electrochemically with the chlorine in salt to produce hydrochloric acid, which is stronger than carbonic acid. The hydrochloric acid would then be sprayed on nearby rocks to react with alkaline materials before flowing back into the ocean—as occurs in nature, only much faster. (As a side benefit, the researchers say, the process could also combat the growing acidification of the ocean, as excess atmospheric CO_2 reacts with seawater to produce carbonic acid.)

Scaling this method up to billions of tons of CO_2 per year would require lots of acid, island real estate, money, and energy. (The energy used to split water might better be fed right into the grid to offset building coal-fired plants, critics say.) Opponents also warn that the exact environmental consequences of producing highly alkaline seawater, particularly on local marine life, are not clear.

Promoting the Growth of Salps

A company called Atmocean, Inc. has suggested a plan to stimulate large populations of small gelatinous marine animals called salps, which eat phytoplankton and produce large, heavy fecal pellets. The pellets sink fast, essentially pulling carbon out of surface waters and ferrying it to the depths.

The plan calls for stimulating phytoplankton blooms that, in turn, would spur the proliferation of salps, which can multiply rapidly into dense swarms covering hundreds of square kilometers of ocean. But instead of adding fertilizer to the ocean, Atmocean proposes to bring deep, nutrient-rich water up to low-nutrient surface regions to stimulate phytoplankton blooms—by a novel means. It would place 200- to 1,000-meter (600- to 3,000-foot)-long open-ended, flexible plastic tubes, manufactured by Atmocean, into the ocean, where they would unroll and hang vertically. Surface wave action, aided by one-way valves in the tubes, would pump high-nutrient water to the surface to promote blooms.



Laurence Madin, WHOI

SAVED BY THE SALPS?—Another proposed scheme to reduce CO_2 levels would promote swarms of transparent animals called salps, whose heavy fecal pellets sink fast, ferrying carbon to the depths.

The company has tested one tube and planned a larger test of 25 tubes off Bermuda. The plan calls for arrays of thousands of tubes connected with lines, drifting with sea anchors, deployed over most of the world ocean. Atmocean would also generate and make available carbon offset credits.

Objections to the plan center around hazards to shipping and marine life from the tubes and linking lines, as well as the feasibility and legality of deploying such large tube arrays in the world ocean. In addition, salp blooms are unpredictable; their presence alone near the tubes does not guarantee they will bloom. Such ocean manipulations may also change ecosystems in undesired ways.

Using Tubes to Enhance Mixing

British scientists James Lovelock and Chris Rapley have proposed an idea for ocean fertilization using long open-ended tubes, based on a similar proposal by Atmocean Inc. Lovelock's and Rapley's plan, published Sept. 27, 2007, in the journal *Nature*, emphasizes growth of clouds as well as phytoplankton and would use the ocean to "help the Earth cure itself" of global warming, the authors say.

Thousands of plastic tubes—100 to 200 meters (300 to 600 feet) long and 10 meters (30 feet) in diameter—would be deployed in the oceans, extending from the nutrient-poor surface to nutrient-rich, cold waters about 200 meters (656 feet) down. Wave motion and a one-way valve would pump deep water through the tubes to the surface, bringing up nutrients that plants need. Like fertilizer on a lawn, the nutrients would promote phytoplankton growth, decreasing CO_2 levels in the water as carbon is incorporated into plankton tissue.

At the same time, phytoplankton would produce dimethyl sulfide, a compound that escapes to the atmosphere and aids cloud formation. More phytoplankton would mean more clouds to reflect solar radiation away from Earth, decreasing global warming, the scientists say.

Critics of the plan say it simply won't work and that deeper waters brought up by the pipes would also contain large amounts of dissolved CO_2 that would be released to the atmosphere and worsen the problem. In addition, any phytoplankton blooms stimulated would reuse carbon that had already been drawn into the ocean, rather than remove additional CO_2 from surface water. Cooler water brought up from the deep could also have impacts on ecosystems.

—Kate Madin and Amy E. Nevala