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Iron versus the Greenhouse

Oceanographers cautiously explore a global warming therapy

By RICHARD MONASTERSKY

Nothing had prepared Kenneth Coale or his shipmates for the color of the water. The oceanographers watched in awe as the *R.V. Melville* plied Pacific waves dyed a soupy green by a bumper crop of tiny ocean plants.

The tint was abnormal. Only a day before, this patch of water near the Galapagos Islands had sparkled with electric blue clarity, a quality owed to the general absence of microscopic plants called phytoplankton. Coale and his colleagues had transformed this marine desert into a garden simply by sprinkling a dilute solution of iron into the water.

"We had predicted the response, but none of us was really prepared for what it would look or feel like," says Coale, a researcher at the Moss Landing (Calif.) Marine Laboratories. "There were some of us who were quite pleased and others of us who would walk out on the fantail and burst into tears. It was a profoundly disturbing experience for me. We had deckhands come up to us and ask, 'Did we do this?' "

Indeed they had, and some of the scientists feared that the repercussions would ripple far beyond this small sector of water. Although designed to test basic theories about marine ecology, the Pacific experiment had demonstrated all too dramatically the effects of adding iron to the ocean—a scheme known as the Geritol solution to global warming. By spreading just half a ton of iron across 100 square kilometers of the Pacific, the oceanographers had stimulated enough plant growth to sop up some 350,000 kilograms of carbon dioxide from the seawater. If performed on a grand scale, iron fertilization of ocean water could absorb billions of tons of carbon dioxide from the air, enough to slow the rate of greenhouse warming, according to some rough estimates.

The Geritol solution, named for the venerable iron supplement, represents only one of many geoengineering quick-fixes dreamed up to stave off global environmental problems. The proposals range from low-tech to Star Trek, from planting trees to stationing a huge filtering screen between Earth and the sun. Some people promote these megaprojects as a planetary salve, easing the pain of global warming without requiring society to address the root cause, its dependence on fossil fuels. Others view them as last-ditch efforts that could save Earth should efforts to reduce pollution prove ineffective.

Coale and many others who witnessed iron's tremendous greening effect loathe the idea of tinkering with the globe in such a heavy-handed way. But he admits that the overwhelming success of the iron experiment could well generate a wave of support for geoengineering proposals.

"We have demonstrated that we have the key now for turning this system on and off," says Coale. "I think some will be encouraged by these findings. Therein lies the dilemma."

The idea of stimulating plankton growth with iron grew out of the fertile mind of the late John H. Martin, an oceanographer at Moss Landing. Martin sought originally to explain a long-standing mystery concerning barren waters in the Antarctic, subarctic, and equatorial Pacific Oceans. With the abundant concentrations of nutritious nitrate and phosphorus in all three regions, phytoplankton should thrive. But it doesn't.

Martin became convinced in the late 1980s that lack of iron keeps the phytoplankton from making use of the nutrients and that a little extra iron would trigger rapid growth of the plants. He calculated that it would be feasible to fertilize the ocean on a massive scale, eventually drawing carbon dioxide out of the atmosphere and deep-sixing the greenhouse gas into the nether reaches of the ocean. Want to slow global warming? Just add iron.

He announced this possibility somewhat facetiously in July 1988 at a lecture at the Woods Hole (Mass.) Oceanographic Institution. "Putting on my best Dr. Strangelove accent, I suggested that with half a shipload of Fe [iron] . . . I could give you an ice age," he recalled 2 years later in the newsletter of the Joint Ocean Global Flux Study.

Martin lobbied extensively for conducting a field experiment of iron fertilization—a plan that some oceanographers considered anathema. Nonetheless, the National Research Council's Board on Biology backed Martin's call for field research to test the iron hypothesis. It estimated that iron fertilization could remove 2 billion tons of carbon in the form of carbon dioxide from the atmosphere each year. That's about 1.5 times the U.S. carbon dioxide emissions each year.

Always one to inspire controversy and debate, Martin remained vague about his feelings on actually using iron fertilization to limit global warming. Oceanographer Sallie W. Chisholm of the Massachusetts Institute of Technology often argued with him about the ethics of geoengineering, or even of conducting research toward that goal.

"He was cynical about humankind," she says. "He felt that obviously this would be a foolish way to go, that humans should get their act together and stop emitting so much carbon dioxide. But he didn't believe that we would get our act together."

Whatever his thoughts about actually implementing the Geritol solution, Martin used the idea to his advantage. The controversial notion attracted interest to his pet hypothesis about iron deficiency in phytoplankton, which other oceanographers roundly criticized as too simplistic. At the time, prevailing theories held that various combinations of light limitations, cold temperatures, and predator populations kept the phytoplankton from using up the ready supply of nutrients. When Martin broached the issue of geoengineering, what had been basic science instantly acquired social relevance.

The charismatic oceanographer convinced his colleagues and the National Science Foundation to stage a small-scale experiment that would add iron to 64 square kilometers of ocean near the Galapagos Islands. Though Martin died of cancer shortly before the expedition, his colleagues carried out the first iron addition in the fall of 1993.

The experiment vindicated Martin's hypothesis. As predicted, the iron supplement stimulated plant growth, verifying that at least some phytoplankton species suffered from iron deficiency.

But the anticipated drawdown of carbon dioxide never materialized. Tiny animals known as zooplankton flocked to the region and consumed the new plant growth, releasing the carbon dioxide before it could sink into the deep ocean. Other factors also limited the iron's effectiveness (SN: 3/5/94, p.148).

In June, Coale and company ventured back out to the eastern Pacific to fertilize another parcel of ocean, this time spreading the iron additions out over a week's time. Given the results of the first experiment, the oceanographers were not prepared for the overwhelming bloom they created in the normally barren ocean. "It would be like driving through the Mojave Desert and coming on a rain forest," says Coale.

Phytoplankton grew so successfully that concentrations of the photosynthetic pigment chlorophyll increased by a factor of 30 to 40 in the water, accounting for the green color. This time, scientists measured a marked decrease in the carbon dioxide concentration of the water. Because this part of the Pacific normally vents carbon dioxide into the atmosphere, the experiment reduced the natural flow of the greenhouse gas into the air (SN: 7/22/95, p.53).

The second fertilization produced a much more powerful response because of slight changes in experimental procedure and natural conditions. In 1993, the oceanographers added all the iron at once, whereas in the more recent outing, they split the supplement into three doses, prolonging the time it took the iron to sink. Ocean currents also kept the iron-doped water at the surface longer during the second experiment, giving phytoplankton more time to grow and absorb carbon dioxide.

Coale is quick to distance the iron experiments from the topic of geoengineering, noting that the team set out only to test the validity of Martin's basic hypothesis. But he acknowledges that the recent results could help those who want to pursue large-scale iron fertilization.

"We are conducting research that may be used toward geoengineering and that does make me feel a bit uncomfortable. I don't feel we have the same dilemma as the scientists who worked on the Manhattan Project [building the first atomic bomb], but there are some similarities," he says.

Despite Coale's personal feelings, his lab at Moss Landing has turned into a mecca for geoengineering supporters. Sitting on a shelf in his office is a bottle of Japanese scotch, a present from visiting researchers connected with the Japanese electric power industry, which seeks to conduct experiments aimed at iron fertilization. The benefits are clear for producers of electricity, who face the specter of increased regulation and potential limits on profits should nations start imposing controls on greenhouse gas pollution.

Coale has yet to open the bottle. "It's sort of ironic that the scotch is sitting there unopened after two experiments, and we don't know whether it would be a good idea to toast these results or not."

Coale and others associated with the more recent experiment argue vigorously against using these findings to support the Geritol solution to global warming. For starters, they raise the issue of efficacy. No one knows exactly where the carbon dioxide goes once incorporated into the phytoplankton tissue. The gas could stay in the ocean, or it could leak out into the atmosphere just as quickly as it is absorbed.

After the recent Pacific experiment, the waters returned quickly to their natural condition. This indicates that any geoengineering plan would have to add iron to the water quite frequently, says Coale. Even if the technique worked, it would offset only about one-third of global carbon dioxide emissions.

Then there is the question of side effects. Promoting the growth of certain phytoplankton species on a massive scale will alter the ecology of these ocean areas, with unknown consequences, says Chisholm. Considering that most researchers laughed off the iron hypothesis as recently as 8 years ago, oceanographers feel wholly unprepared to predict how the ocean will respond to iron fertilization.

To succeed, a geoengineering scheme would have to spike an area of ocean the size of Asia, nearly 500,000 times the size of the experimental patch. The bloom of plants could enrich the whole ecosystem. But the decay of all that organic matter could rob the surface waters of oxygen, generating huge anoxic zones—the equivalent of a giant swampy layer in the ocean—that would kill marine life there. It is even possible that the organic matter could exacerbate global warming by generating methane, a greenhouse gas much more potent than carbon dioxide.

"I think it's folly. It would just cause another environmental problem," says Chisholm. "It's so naive to think that we can do one thing and it's going to have a predictable effect. The arrogance of human beings is just astounding."

A controversial report by the National Academy of Sciences in 1992 looked at iron fertilization, among other geoengineering options. Although the NAS noted some caveats, it concluded that iron fertilization does have one attractive feature: a relatively cheap price tag. Running 360 ships full-time to fertilize 46 million square kilometers of ocean would cost somewhere between $10 billion and $110 billion a year.

Not much for altering the global climate. In comparison, the United States spends close to

$2 billion each year on global change research.

But would the money be well spent? Michael MacCracken, director of the Office of the U.S. Global Change Research Program in Washington, D.C., examined geoengineering schemes for the upcoming report by the Intergovernmental Panel on Climate Change. He argues that society would benefit more from investing in new energy technologies than from manipulating the environment.

"The trouble with most geoengineering options is that it's sort of money down the drain," says MacCracken. "If you are going to go to all of this effort, why don't you just build some alternative power sources? Why not use the same amount of money to build solar-powered satellites and beam the energy back?"

MacCracken also warns that, once started, the geoengineering path would become an addiction. "All of these become a continuing commitment for society in order to keep temperatures down. And if you ever stopped doing that for some reason, you suddenly get this very large warming influence upon you."

But society may need geoengineering options, no matter how unpalatable, says Gregg Marland of the Oak Ridge (Tenn.) National Laboratory, who worked on the NAS report. He also helped organize a symposium on the topic at last year's annual meeting of the American Association for the Advancement of Science.

Marland says his job—compiling the global inventory of carbon dioxide emissions—has made him skeptical about the prospects of making deep cuts in greenhouse gas pollution. "Per capita emissions in the U.S. are 5 tons per year of carbon. The global average per capita emissions are 1.1 tons per year. It's inconceivable in any kind of an equitable world that those emissions won't increase. Population is increasing, for one thing. The growth taking place in Asia right now is phenomenal."

Society may simply lack the political will to reduce greenhouse gas emissions, says Marland. "If we don't, somewhere down the line geoengineering may be our only choice. . . . I think we'd be foolish to walk away from geoengineering, and we'd be equally foolish to count on it right now or to start trying it."

Against this backdrop of divergent options and emotionally charged arguments, many scientists take the safe route, calling for more basic research on climate. In a book submitted for publication, *The Engineering Response to Global Climate Change*, a panel of scientists and engineers, which includes Marland and MacCracken, argues that scientists must learn how the climate works and develop the skill to predict it before evaluating strategies to control nature.

To that end, Coale and his colleagues are trying to secure funding for a small-scale fertilization experiment in the Antarctic Ocean, another area seemingly affected by iron limitations. Although he has conflicting feelings about how people might use the results of this research, Coale believes the issue won't disappear. Oceanographers should therefore explore the iron hypothesis further so society will have the necessary information for making sound judgments.

"As John Martin once said, 'The cat's out of the bag.' I feel compelled to carry out this research in a way which is environmentally responsible," Coale says.

Can science whip up a salve for global wounds?

The idea of continent-sized algal slicks in the ocean may strike some people as unappealing. If so, scientists and engineers have dreamed up a wide array of alternatives for keeping the globe's temperature out of the red zone. In 1992, a panel of the National Academy of Sciences studied several so-called geoengineering schemes. Among them:

- Sending 110 mirrors, each 100 square kilometers in size, into orbit to reduce the amount of sunlight reaching Earth's surface. The mirrors would roughly offset the heating caused by U.S. carbon dioxide emissions, at a cost of perhaps $120 billion. But collisions between mirrors or with other space debris could require frequent replacements, drastically increasing the cost. Other scientists have noted that the mirrors would cause undesirable shadows on Earth's surface, similar to those caused by eclipses.
- Shooting dust or tiny sulfur droplets into the stratosphere, where they would block sunlight. Existing naval rifles could launch enough material to offset U.S. carbon dioxide emissions at an annual cost of only $0.25 billion to $0.50 billion. This so-called human volcano would mimic the effect of giant eruptions, which spew sulfur into the stratosphere. But the particles could speed up destruction of the already weakened stratospheric ozone layer.
- Stimulating the formation of reflective marine clouds. Because ship exhaust encourages the growth of cloud particles, a fleet of ships or power plants built in the middle of the ocean could generate enough clouds to offset the doubling of atmospheric carbon dioxide expected by the middle of the next century. Producing this amount of sulfur-rich exhaust would require the equivalent of 365 coal-burning power plants. Acid rain produced by the sulfur would clearly cause problems if it reached land, but members of the NAS panel disagreed over whether the acid rain would harm the ocean.
- Planting trees in unforested areas of land. A 1990 study by the U.S. Forest Service concluded that reforestation could offset up to 56 percent of U.S. carbon dioxide emissions, at a cost of $20 billion. But the NAS panel questioned some of that study's optimistic assumptions. Taking a more conservative approach, the NAS panel estimated a cost of $1.7 billion for balancing 10 percent of U.S. emissions.

A committee of scientists and engineers explores several other proposals for controlling climate in The Engineering Response to Global Change (in preparation). One of the more expensive options would be to install a giant solar deflector, built from materials on the moon, at a point 1.5 million miles from Earth in the direction of the sun. Thinner than a human hair, the diaphanous sheet would stretch 2,000 kilometers across and deflect 2 percent of the radiation headed toward Earth. Estimated cost: $1 trillion to $10 trillion.

Michael MacCracken, director of the Office of the U.S. Global Change Research Program in Washington, D.C., says that it is difficult to find cheap geoengineering options that do not threaten the environment. "It turns out the ones that have the least side effects have the most up-front costs, and the ones that have the most side effects have the least up-front costs." □