Researchers, Other Experts Examine Climate Engineering Issues

■ ***Among the questions: Can Earth's climate be deliberately engineered to mitigate human impact? Should it be?***

The feasibility of deliberately engineering Earth's climate—and the social, economic, political, and ethical issues raised by such projects—were explored by two panels at the annual meeting of the American Association for the Advancement of Science (AAAS), held in late February in San Francisco.

A surprising number of such schemes have been proposed over the past decade. They share the common theme that human technological intervention might be able to reverse or mitigate the effects that human economic activities are inadvertently exerting on Earth's atmosphere.

Two such effects are targets of climate engineering strategies. One is the projected increase in Earth's temperature due to emission of greenhouse gases, principally carbon dioxide from fossil fuels. The other is the documented depletion of the planet's protective stratospheric ozone layer by chlorofluorocarbons (CFCs).

Dreams of climate engineering have a longer history than many people realize, according to Stephen H. Schneider, a biology professor at Stanford University. Schneider told the AAAS symposium that, in 1960, two Soviet authors, N. P. Rusin and L. Flit, published a pamphlet entitled "Man Versus Climate." In it they wrote that, for northern nations, "the Arctic ice is a great disadvantage, as are the permanently frozen soil (permafrost), dust storms, dry winds, water shortages in the deserts, et cetera."

Rusin and Flit argued, "If we want to improve our planet and make it more suitable for life, we must alter its climate." Their grandiose proposals included providing Earth with a ring of highly reflective particles similar to the rings of Saturn and diverting rivers to create a vast "Siberian sea."

C&EN staff photos

Schneider: cure addiction to polluting

Climate engineering projects proposed more recently have a firmer scientific and technological basis. These projects include dispersal of sulfate particles in the stratosphere to reflect sunlight, fertilizing the southern oceans with iron to stimulate phytoplankton growth, and injecting ethane or propane into the stratosphere over Antarctica to counteract ozone-depleting chemical reactions. The feasibility of such projects was the focus of the first panel.

Two ideas for climate engineering that initially seemed to have potential appear less likely to work than was originally thought, according to two scientists on the panel. Three years ago, Ralph J. Cicerone, a geosciences professor at the University of California, Irvine, and coworkers suggested that annual injections of about 50,000 tons of ethane or propane into the Antarctic stratosphere could suppress the CFC-mediated ozone loss that produces an "ozone hole" over the continent each austral spring [*Science*, **254**, 1191 (1991)]. Their idea was to mop up ozone-destroying chlorine atoms through the rapid reaction of Cl with a simple alkane to produce HCl.

Cicerone and coworkers performed a series of calculations that indicated such a strategy might work. Now, Cicerone says the idea is "no longer as encouraging as when we published the paper." The problem is rooted in the staggering complexity of stratospheric chemistry. The 150 or so reactions that affect stratospheric ozone concentrations are simple in themselves, but when they interact with each other, they are an intricate and difficult-to-analyze matrix. Including two reactions, heretofore thought unimportant in Antarctic atmospheric chemistry, changes the predicted effect of a hydrocarbon on ozone.

When Cicerone published his hypothesis, some environmental activists criticized the work because, they said, even broaching the possibility of climate engineering could weaken the resolve of government and industry to solve the root problem—CFC use, in the case of stratospheric ozone loss—endangering the atmosphere. In San Francisco, Cicerone countered such arguments, saying that it is only through the peer review process that the validity

Cicerone: new reactions change prediction of climate engineering strategies can be examined.

Cicerone adds that preventing the appearance of the Antarctic ozone hole meets criteria that should apply to any climate engineering scheme. "The ozone hole is well documented and the situation is getting worse by several measures," he says. "And industry and government have dealt with the root problem by reaching agreements that will severely limit the emission of CFCs. However, the atmosphere will require several decades to clean itself, so the ozone hole will reappear well into the next century."

Another climate engineering hypothesis that has been tested and found wanting is fertilizing southern oceans with iron to increase phytoplankton growth, an idea first proposed by the late John H. Martin, who was director of the Moss Landing Marine Laboratories in Moss Landing, Calif. (C&EN, July 2, 1990, page 21). Martin believed that low levels of iron limit the biological productivity of nutrient-rich southern oceans. He suggested that adding iron to these waters would increase the growth of phytoplankton, thus reducing CO_2 levels in the seawater and thereby altering the CO_2 balance between seawater and the atmosphere.

At the meeting, Richard T. Barber, Harvey Smith Professor of Biological Oceanography at Duke University, reported on experiments in the South Pacific Ocean designed to test Martin's ideas. Results showed that iron probably is the limiting nutrient for phytoplankton in these waters—iron fertilization resulted in "spectacular" increases in the phytoplankton growth rate, Barber says.

Nevertheless, the strategy probably won't much affect atmospheric carbon dioxide levels, Barber continues. One reason is that increased amounts of phytoplankton—which are plants—turn out to stimulate increased grazing by zooplankton—which are animals. "We grew a lot of phytoplankton and wound up with a lot of happy little animals," he says. Because zooplankton respiration releases carbon dioxide, the inorganic carbon levels in the seawater did not change significantly as a result of the iron fertilization.

Another scientist, Joyce E. Penner, of Lawrence Livermore National Laboratory, described studies of natural and anthropogenic sulfate aerosols that suggest that these chemical species reduce the solar flux reaching Earth's surface. The research indicates it might be possible to counteract greenhouse warming, at least in part, by injecting sulfate aerosols into the stratosphere.

Should such an approach be used to counteract greenhouse warming? Should any climate engineering project be considered? These sorts of questions were the focus of the second panel.

Not surprisingly, the answers varied widely. Thomas Schelling, an economist at the University of Maryland, College Park, conceded that "some people may not take global warming as seriously if they think there will be successful technological intervention to counter it." However, he added, "I expect technological intervention 50 years from now will be less dangerous than the worst case global warming scenario. I think there will be relatively benign technological approaches to controlling global warming that will create fewer economic problems than significantly reducing the use of fossil fuels."

By contrast, Dale W. Jamieson, a philosopher at the University of Colorado, Boulder, told the symposium, "If we have learned anything from the environmental movement, it is that technological interventions have unforeseen consequences." Coupled with the fact that the climate is an extremely complex system and the reality that engineers "generally overstate their expertise," the public should be very wary of climate engineering, he said.

Jamieson's first, enthusiastic conclusion was: "We should not now engineer the climate." On the issue of whether research on climate engineering should go forward, Jamieson reached a second, unenthusiastic conclusion: "Steve Schneider argues that climate change could become so severe that climate engineering is the only hope for humanity. The problem is that research can lead to inexorable development. I think the feasibility of engineering the climate should be studied. But there is a terrible risk of inappropriate application."

Schneider is opposed to climate engineering schemes. "The following metaphor comes to mind," he said. "Better to cure heroin addiction by paced medical care that weans the victim slowly and surely from addiction than by massive substitution of methadone. In my value system, a more rapid implementation of energy-efficient technologies; alternative, less polluting energy or agricultural production systems; better population planning; wildlife habitat protection; and commodity pricing that reflects not simply the traditional costs of labor, production, marketing, and distribution, but also the potential for a modified environment, are the kinds of lasting measures that can cure 'addiction' to polluting practices without the side effect of geoengineering—planetary methadone in my metaphor."

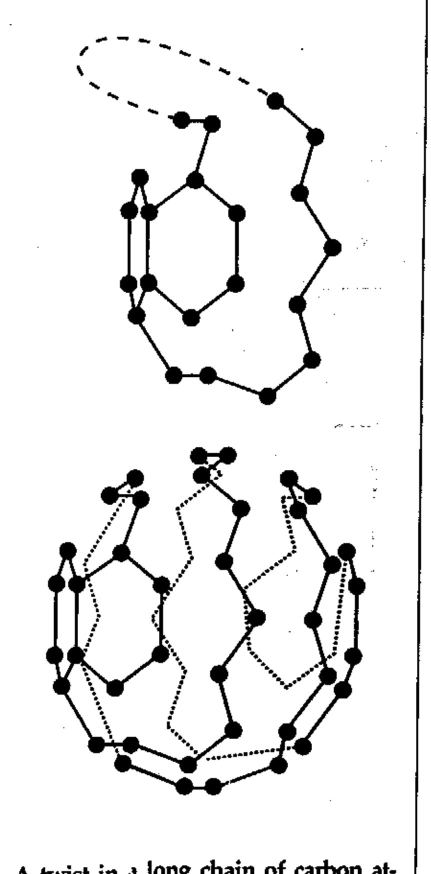
Schneider concluded, "I'd prefer to get unhooked from our need for carbon than to try to cover the effects with sulfuric acid injections into the stratosphere."

Rudy Baum

Mechanism for fullerene formation proposed

A research group at Northwestern University has proposed a mechanism for the formation of fullerenes from large planar carbon rings.

Martin F. Jarrold, a professor of chemistry at Northwestern, Evanston, Ill., has reported the results of his group's work in *The Journal of Physical Chemistry* [98, 1810 (1994)]. The group included chem-



A twist in a long chain of carbon atoms might lead to a species intermediate to fullerene.