COPING WITH CHANGE

by Steven Lagerfeld

Ever since Rachel Carson's *Silent Spring* (1962), Americans have been repeatedly alerted to tangible threats—dirty water, polluted air, toxic waste dumps, pesticides—to what is now called "the environment." In recent years, environmentalists, federal officials, and scientists have shifted their attention to "invisible" threats, from airborne asbestos particles in schools to cancer-causing radon gas in the basements of suburban homes. And this autumn, after several summers of drought and record-breaking heat waves, American headline writers rediscovered two unseen phenomena miles above the surface of the Earth: the depletion of the protective ozone layer in the atmosphere and the rise of the "greenhouse effect."

The thinning of the Earth's ozone shield, which screens out harmful ultraviolet light, has been discussed, off and on, since the 1970s. [See box, p. 124.] The hot 1988 summer and some strong rhetoric have focused far more attention recently on the greenhouse effect, which appears to be gradually making the planet grow warmer.

At an international conference on "The Changing Atmosphere" sponsored by the Canadian government in Toronto last June, some 300 reputable scientists and government officials warned that "Humanity is conducting an uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war." A "greenhouse doomsday scenario" by author Jeremy Rifkin conjures up images of the Netherlands disappearing under the waves like a latter-day Atlantis, Bangladesh swept by floods claiming millions of lives, and the Mississippi River transformed into a "vast earthen plain"—while Manhattan's West Side Drive is lined with palm trees.

Exaggerations aside, there is a growing consensus among climatologists and other researchers that both the greenhouse effect and ozone depletion are not simply alarmist fantasies.

Last June, James E. Hansen, a senior physicist at the National Aeronautics and Space Administration (NASA), found himself on the network television news when, noting that the mean global temperature has increased by one degree Fahrenheit during the last century, he told a congressional committee that "the greenhouse effect has been detected and is changing our climate now." On Capitol Hill, Senators Timothy E. Wirth (D.-Colo.) and Robert T. Stafford (R.-Vt.) have each introduced legislation calling for improved energy conservation, more research, and tighter environmental regulation to combat the greenhouse effect.

Scientists are not totally certain that the greenhouse effect is the sole cause of the warming. The hot summers of the recent past could well be, at least in part, the result of natural climatic fluctuations. "Climate is a complicated thing," notes Roger Revelle of the University of California, "and the changes seen so far may be due to some other cause we don't yet understand." Indeed, even the rising temperatures of the past century were punctuated by an unexplained cool period between 1945 and 1975, when some scientists began to worry about the eventual onset of a new Ice Age.

Hubert H. Lamb, a leading British climatologist, is also wary. While the greenhouse effect is real, Lamb believes, the long-term global warming may also have natural causes. Even scientists, he cautions, follow "fashions." A particular theory "catches on and gains a wide following, and while that situation reigns, most [researchers] aim their efforts at following the logic of the theory and its applications, and tend to be oblivious to things that do not quite fit."

Bubbles in the Ice

Nevertheless, *most* scientists now agree that the greenhouse effect will warm the Earth during the decades ahead. Sometime between the year 2025 and 2050, average global temperatures could be as little as three degrees Fahrenheit above current levels, or as much as nine degrees higher—unless nature intervenes and suddenly cools the planet. Some of this change we may be able to avert; some of it we will have to adapt to.

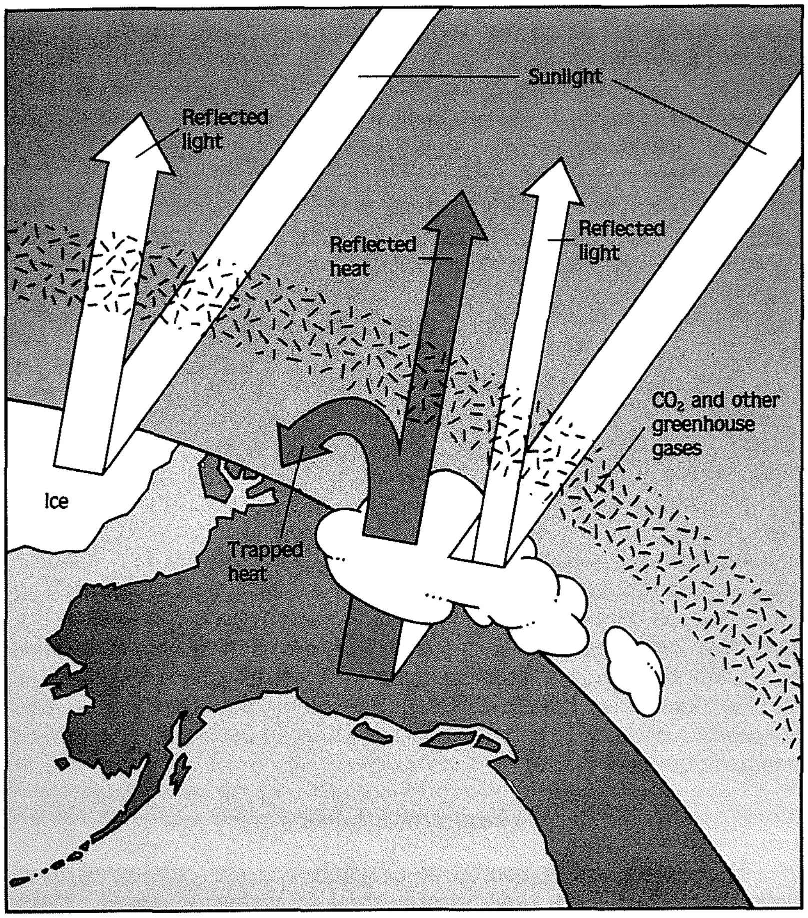
The greenhouse effect is a natural phenomenon. The Earth's atmosphere, consisting chiefly of nitrogen and oxygen, but including many other gases, is almost transparent to sunlight. The Earth's surface reflects some of the sunshine, but much of it is absorbed, only to be emitted later as infrared radiation. That is where the greenhouse effect comes in. While most sunlight easily passes through the atmosphere on its way to the planet's surface, some of the outbound radiating infrared is trapped by gases in the lower atmosphere before it can escape into space. These "greenhouse gases," chiefly water vapor and carbon dioxide (CO_2), then warm up, heating the Earth's atmosphere.

The greenhouse gases occur naturally; by regulating temperature, precipitation, and soil moisture, they make life on Earth possible. A paucity of CO_2 leaves Mars frigid and dry, while an overabundance of it makes Venus a furnace.

Carbon dioxide is also the raw material of photosynthesis in plants. Trees, shrubs, grasses, and other plants return some of the CO_2 they absorb to the atmosphere through respiration, but they store vast quantities (in the form of carbohydrates) in their cells. Only after the plants die and decay or are burned is that carbon transformed into CO_2. The

Steven Lagerfeld, 33, is senior editor of the Wilson Quarterly.

THE GREENHOUSE EFFECT



The Earth's atmosphere functions much like a giant greenhouse, admitting sunlight from outer space, but preventing heat from escaping. About 50 percent of all incoming sunlight penetrates to the Earth's surface. As this simplified diagram suggests, clouds reflect (and absorb) much sunlight; so do haze and dust in the air. The Earth's surface, especially where it is covered by snow and ice, also reflects some light. The remaining sunlight is absorbed by the land and oceans. As the Earth warms, it emits heat in the form of invisible infrared radiation. About 15 percent of this heat ultimately escapes from the atmosphere. The rest is "trapped" by a layer of clouds, water vapor, carbon dioxide, and various other "greenhouse gases" that extends from ground level up to 10 miles above the planet's surface—thus providing the warmth that supports, but at higher levels could disrupt, life on Earth.

emitted carbon is continuously reabsorbed by the Earth's "sinks"—the oceans and the "biomass" (all plant and animal matter). But carbon dioxide has been building up in the atmosphere faster than it can be reabsorbed by these "sinks."

Only in relatively recent times have scientists gained the ability to measure the gases that are responsible for the greenhouse effect.

In 1980, by examining air bubbles trapped in the glacial ice of Greenland and Antarctica, researchers discovered that CO_2 concentration in the atmosphere before the Industrial Revolution (circa 1750) was about 280 parts per million (ppm). In 1958, as part of the International Geophysical Year, scientists began the first systematic readings of current levels of atmospheric CO_2 at an observatory atop Mauna Loa, an 11,000-foot peak in Hawaii. At that time, the level had increased to about 315 ppm. By the end of 1986, it had risen to 345 ppm.

Thus, the Earth's atmosphere now contains about 25 percent more CO_2 than it did at the beginning of the Industrial Revolution, and 10 percent more than it did a mere quarter of a century ago. Today, the concentration of CO_2 in the atmosphere is increasing by about 0.4 percent per year. That is fast enough to produce a doubling of the preindustrial level within 35 to 60 years.

Why is this buildup occurring? During the 19th century, loggers, farmers, and ranchers cleared vast tracts of virgin forest throughout the United States, New Zealand, Australia, South Africa, and Eastern Europe, thus releasing vast amounts of CO_2 into the atmosphere. Since World War II, logging (of teak, mahogany, and other tropical woods) and land clearance have largely shifted to Africa, South America, and Asia. This source probably accounts for about 10 to 20 percent of the world's manmade emissions of CO_2.

Winners and Losers

The largest single source of CO_2 today is the burning of fossil fuels—coal, petroleum, and natural gas—in factories, power plants, home furnaces, and automobile engines. Between 1950 and 1979, worldwide fossil fuel use quadrupled. Higher oil prices and greater fuel efficiency in industry and autos have since slowed the rate of increase. But, this change has been accompanied by a shift to coal, which produces far more CO_2 than either oil or natural gas.

Carbon dioxide is not the only greenhouse gas. Methane (CH_4) and nitrous oxide (N_2O) are naturally occurring substances that also have "greenhouse" properties, as do the manmade chlorofluorocarbons that have been implicated in the destruction of the ozone layer. As a result of rapid population growth, increasing affluence, and industrial expansion, they have been increasing even more rapidly than CO_2.

Nitrous oxide rises into the atmosphere from automobile exhausts, factory smokestacks, and the decomposition of the chemical fertilizers

Amid last summer's heat waves, "Washingtoon" cartoonist Mark Alan Stamaty poked fun at attitudes toward the "greenhouse effect."

that the world's farmers are using in ever-increasing amounts.

As for methane, cows are among the chief culprits. Beef and dairy cattle (along with other ruminant animals) release the gas from their digestive tracts. The global cattle population has surged during the past century, partly to satisfy the appetites of affluent Americans and Europeans for steaks and hamburgers. Methane is also produced by bacteria in the world's swamps (thus, the term "swamp gas") and the rice paddies of Asia, which have been expanded dramatically since World War II to feed growing populations. Termites, especially numerous in the savannahs and forests of Africa, where they feed on grass and felled trees, emit the gas from their digestive tracts.

Together, the buildup of nitrous oxide, methane, and other "trace gases" makes a major contribution to the greenhouse effect. "These are the little guys," observed Stephen Schneider, of the U.S. National Center for Atmospheric Research. "But they nickel and dime you to the point where they add up to 50 percent of the problem."

The ill effects of an eroded ozone layer are fairly narrow and easy to predict—an increase in the incidence of skin cancer, crop damage. But the consequences of a strong greenhouse effect are less certain. Climatologists use computerized "general circulation models" to predict how and where the world's climate will change in a greenhouse atmosphere.* The models have serious limitations: Scientists do not yet know

*The federal government now spends about $195 million annually on climate-related research under the nine-year-old National Climate Program. A variety of federal agencies are involved, including the departments of Agriculture, Energy, and Commerce, and the National Science Foundation. The leading U.S. researchers in the field are concentrated at about 10 universities, from the University of Alaska, Fairbanks, to Florida State University, Tallahassee.

exactly how temperature, winds, precipitation, and other elements of climate interact and alter one another.

Even so, climatologists seem to agree on the *outlines* of change in a "greenhouse world." They believe that the tropics will warm slightly, but land surfaces in the high latitudes in both hemispheres, especially the Northern Hemisphere, will heat up considerably more. A warmer atmosphere would hold more water, resulting in greater rainfall overall—although some regions would be drier.

But there is very little agreement among the five or six major climate modeling teams in the United States and Western Europe on how *specific* regions might be affected, especially by changes in rainfall. One thing is clear: around the world, there would be winners and losers.

A Boon to Farmers?

For example, some scientists predict that the midlatitudes of the Northern Hemisphere continents (the Great Plains in the United States, Central Europe, parts of the Soviet Union) are likely to become hotter and much more drought-prone than they are today. Others disagree. They add that the Sahara and other dry regions could get *more* rainfall. Changes in the circulation of monsoons might augment the annual rains in India, Pakistan, and Bangladesh, helping to avert the periodic droughts and famines that have cost thousands of lives in these populous lands. On the other hand, the sometimes catastrophic annual monsoon floods in Bangladesh could become more dangerous.

One much-publicized doomsday vision raises the specter of huge chunks of the Antarctic ice sheet breaking off and melting to engulf the world's coastal cities. That is highly unlikely. Scientists now know that Antarctica was largely unaffected by rapid global warmings in the distant past. But some increase in sea levels is quite possible, due to "thermal expansion" of water molecules as the oceans' waters warm. Already about five inches higher than they were a century ago, the oceans could rise by an additional five to 15 inches within the next four decades, according to the Environmental Protection Agency. Bangladesh and other low-lying countries could lose valuable coastal croplands and suffer much greater damage from storms and hurricanes. Throughout the world, beaches, marshes, and coastal farmland would be endangered. Just a one-foot rise in sea level would wash away most recreational beaches in the United States and destroy large portions of the coastal wetlands where many birds and fish breed.

In many places on Earth, even minor changes in temperature, rainfall, and water levels of streams and rivers could wipe out innumerable small plant and animal species that have adapted to very narrow local ecological "niches." A lower water level in one river, or increased flooding in another, might wipe out isolated species of birds or fish.

The rising level of CO_2 in the atmosphere could have one important positive result. Biologists have long known that bigger doses of CO_2 speed up plant photosynthesis and reduce water consumption. (Indeed, some agronomists maintain that increases in CO_2 in the air helped western U.S. wheat farmers achieve their remarkable tripling of crop yields between 1920 and 1980.) Thus, in a "greenhouse world" of the future, there might be some overall increase in farm productivity. But the most important result might be the expansion of farming in areas of the world, notably Africa's Sahel region, where lack of rainfall now limits crop production—assuming, of course, that other unforeseen climatic changes do not cancel the benefits.

These predictions are based just on the *warming* due to the greenhouse effect. Other features of the global climate may also be affected—for better or worse. The amount of sunshine reaching field crops may vary because of changing cloudiness. Winds and humidity may also shift. As always, the complex interaction of such fluctuations makes it difficult to predict exactly how the world's overall climate may be transformed. As physicist S. Fred Singer and others have noted, for example, heavier cloud cover might *cool* the globe, counteracting some of the greenhouse "warming" effect.

Most scientists agree that a worldwide temperature increase of at least three degrees Fahrenheit during the next few decades seems inevitable. But they also agree that human beings can do much to slow the rate of increase, to prevent even more severe temperature increases, and to adapt to the climatic changes that we cannot stop.

Hanging Together

Many scientists and politicians favor international efforts to restrain emissions of CO_2. (No one is quite sure what to do about the methane emitted by cows and some of the other greenhouse gases.) But effective agreements will be hard to produce. Today's global efforts to control ozone depletion, a threat with much clearer causes and effects, reveal some of the pitfalls.

In September 1987, after two years of difficult negotiations under the aegis of the United Nations Environmental Program (UNEP), representatives of 24 nations and the European Economic Community, meeting in Montreal, signed an agreement to cut production and consumption of certain chlorofluorocarbons by 50 percent by 1998. But, despite all the cheering that greeted the agreement, it was really only, as David D. Doniger of the Natural Resources Defense Council recently put it, "a major half-step forward."

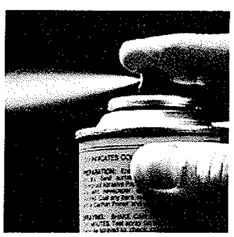
The pact's many compromises foreshadow the difficulties that will hamper any international effort to deal with the greenhouse effect. Only the industrialized nations are required to reduce production and consumption of chlorofluorocarbons; the world's poorer nations are permitted to increase output until 1999; and the Soviet Union is allowed a two-

THE EARTH'S ERODED SHIELD

Ordinary Americans probably first heard about the ozone layer some 20 years ago. During the late 1960s and early '70s, scientists and environmentalists warned that emissions from the supersonic transport (SST) favored by President Richard M. Nixon would gradually destroy ozone in the upper atmosphere. Such fears, along with high cost estimates, led Congress to kill the SST in 1971.

Three years later, in *Science*, chemists Mario Molina and F. Sherwood Rowland discussed another possible threat: chlorofluorocarbons, manmade chemicals then used chiefly as propellants in aerosol cans. In the upper atmosphere, they suggested, chlorofluorocarbons decompose, liberating chlorine molecules that then destroy ozone. Official reaction was swift. In 1977, the United States joined several other nations in banning the use of chlorofluorocarbons in aerosols—"the first time," note Stephen H. Schneider and Starley L. Thompson, "a substance suspected of causing global harm had been regulated before the effects had been demonstrated."

Meanwhile, however, chlorofluorocarbons grew into a $750 million industry in the United States alone. They were used increasingly as refrigerants, as propellants in making styrofoam, and as industrial solvents. Another class of chemicals with similar effects, the halons, were used in fire extinguishers. And it was discovered that methane and other trace gases also destroy ozone.



Why worry about the ozone layer? About 21 percent of the Earth's atmosphere is composed of oxygen, mostly in the two-atom molecule, O_2, but a tiny fraction exists as ozone, O_3. When it envelops major cities, ozone is considered a pollutant; in the frigid stratosphere (six to 30 miles above the Earth), it screens out the most harmful portions of the sun's ultraviolet rays. When it is absorbed by DNA, ultraviolet light can inhibit the human immune system and cause skin cancer and cataracts; it also appears to retard plant growth and reduce crop yields.

After chlorofluorocarbons in aerosol cans were banned in 1977, public concern about the ozone layer dissipated. Then, in 1985, a team of scientists led by Joseph Farman of the British Antarctic Survey discovered a massive "hole" in the ozone layer—a 40 percent drop since 1979 in the atmospheric concentration of ozone over the frozen continent. Since then, new studies have documented a less drastic, but worldwide erosion of the ozone layer.

"We have strong evidence that change in the ozone is wholly or in large part due to manmade chlorine," declared Robert Watson of the National Aeronautics and Space Administration last March. There are other possibilities: It could be that the past decade's cyclical decline in solar activity (indicated by sunspots), which has curtailed the production of fresh ozone in the stratosphere, is partly responsible. But the ozone loss is greater than can be explained by temporarily reduced solar activity. Day by day, the evidence is growing that Watson is correct; man is the villain.

thirds increase before it must begin cutting back.

Evaluating the agreement recently, the U.S. Office of Technology Assessment estimated that it might cut chlorofluorocarbon emissions by 45 percent at best—but could also permit an *increase* of 20 percent. In part because chlorofluorocarbons remain in the atmosphere for about 100 years, even a 45 percent reduction of emissions, Doniger observes, "will only reduce the *acceleration* of [ozone] depletion."

Meanwhile, the scientific studies on which the 1987 pact was based have become outdated. Just a day after the U.S. Senate approved the agreement, a new study indicated that the planet's ozone shield has eroded by 1.7 to 3 percent since 1970—even more rapidly than had been predicted. Last September, the U.S. Environmental Protection Agency called for a worldwide ban on production of chlorofluorocarbons.

Dealing with the greenhouse effect is going to pose a considerably greater political and financial challenge. The causes are much more numerous, and many are not under man's control; the costs of various proposed remedies could be much higher; and the benefits (relief from unfavorable shifts in climate) will very likely be unequally distributed among the world's regions.

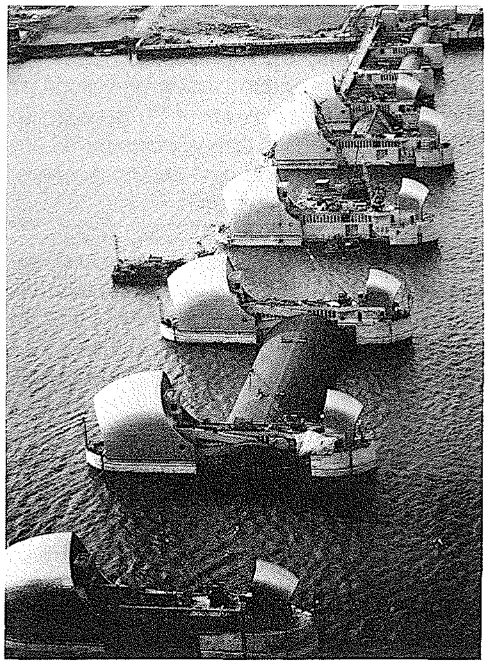
Nuclear Power Revisited

The United States and the Soviet Union now produce nearly half of the world's CO_2. Yet, much of the increase in CO_2 emissions during the decades ahead will be produced by industrializing Third World nations, such as South Korea and Brazil. "How do you get rapidly developing, hand-to-mouth nations to give up their first taste of economic security in the name of some vague and distant scare scenario?" *The New Republic* asked recently. "Environmentalism is a luxury they can't afford." Mainland China, for example, with its immense population and relative poverty, is not likely to slow the exploitation of its vast coal reserves unless scientists can point with near certainty to dire consequences for China's farmers. They cannot. In fact, China now plans to virtually double its burning of coal by the year 2000.

Similarly, as steel, autos, and other energy-intensive industries continue to shift production to the Third World, these poorer nations are not likely to take kindly to the suggestion that they cut back on the use of coal and oil—unless the West somehow finds a way to compensate them for the sacrifice of economic opportunity.*

Neither is the West eager to reduce its standard of living to combat a vaguely perceived global threat. Coal use in the United States and

*A creative experiment by Conservation International, a private organization, suggests one way this might be done: so-called debt-for-nature swaps. Using private contributions, the Washington-based group bought up (at a discount) $650,000 worth of Bolivia's international debt, then turned it over to the Bolivians. In return, the Bolivian government pledged to limit development of four million acres of Amazon lands, thus preserving a valuable CO_2 "sink." Yet, it remains to be seen whether the leaders of Bolivia and other Third World nations will be able to exert strict control over the development of such remote areas.



Adapting to climate: London's $765 million Thames Barrier, a pivoting dam, was completed in 1982. The slight rise in sea levels caused by the planet's warming during the 20th century, along with certain geological anomalies, have left the city vulnerable to flooding from once-a-century North Sea "storm surges."

Western Europe is likely to grow well into the next century. The chief "alternative" energy sources—wind and solar power, biomass conversion—are a long way from being practical (or economical) enough to make a difference. Synthetic fuels, the great energy panacea of the 1970s, are even "dirtier" than coal. The only major energy source that does not create CO_2 is nuclear power, but it faces vehement political opposition in the United States and much of Western Europe. Attitudes toward the atom may be changing. Senator Timothy Wirth's pending "greenhouse" bill includes $500 million for research into "safe" forms of nuclear power. America, said the Colorado Democrat, must get over its case of "nuclear measles."*

Stronger efforts to conserve energy would help reduce CO_2 emissions somewhat. According to the World Resources Institute, the latest electrical appliances, light bulbs, and building designs are twice as energy-efficient as older versions. Greater fuel economy in automobiles is also possible. The average new car in the United States now gets 25

*Since the Three Mile Island reactor accident in 1979, American utility companies have ordered no new nuclear power plants, and have canceled earlier plans for 65 reactors. Even so, 46 new nuclear reactors have gone into operation since Three Mile Island, serving such major cities as Houston, Phoenix, Pittsburgh, and Chicago. Today, 109 reactors across the United States supply 18 percent of the nation's electricity. Nuclear power generates 70 percent of all electricity in France, 50 percent in Sweden, and 44 percent in Taiwan.

miles per gallon, up from only 13 in 1973, but still only half of what some existing cars achieve. Even so, as S. Fred Singer notes, more conservation "can only nibble" at the CO_2 problem.

A few scientists are beginning to think about exotic schemes to combat climatic change. They range from covering the world's oceans with white styrofoam chips to reflect vast amounts of sunlight back into space, to launching huge solar power stations into orbit around the planet, to lobbing frozen "bullets" of manmade ozone into the atmosphere. As Princeton physicist Thomas H. Stix concedes, however, such ventures remain "mighty speculative."

A simpler way to slow the buildup of CO_2 is simply to plant more trees. A vast forest of fast-growing sycamores or poplars—covering approximately 1.2 million square miles, roughly twice the area of Alaska—might contain enough trees to absorb all of the excess CO_2 that man is producing today (about three billion tons annually). But even such a dramatic effort would only postpone the day of reckoning. When trees reach maturity, after about 40 years, they stop absorbing CO_2.

Living in the Greenhouse

Cutting down and replanting such vast forests would present new problems. Burn the wood as fuel, and you liberate the carbon within it (creating CO_2); sell it as lumber and you threaten the lumber industry and the woodlands that it controls.

Whatever mankind does, it now seems inevitable to most scientists that the greenhouse effect will change the world's climate somewhat—more heat waves and droughts in some areas, heavier rains and milder temperatures in others. In some locales, the shifts may be extreme. But, overall, a three-degree increase in temperatures is well within man's ability to cope. We have, after all, barely noticed the one-degree warming during the past century. And, during the so-called Little Ice Age of 1400–1850, when average annual temperatures dropped by about two degrees below today's levels, the far less sophisticated societies of Europe suffered only scattered disruptions. "If we have 20 or 50 years to plan," observes Paul Portney, a researcher at Resources for the Future, "we can take steps to mitigate the adverse effects."

Levees can be erected to contain rising seas and rivers; if need be, people and industries can gradually move, as they always have, to follow the weather.

Surprisingly, the world's farmers may find it relatively easy to deal with change. They have always been pawns of the weather, and so have learned to respond quickly to year-to-year changes in temperature and rainfall. In the past, agricultural scientists and farmers have overcome severe local handicaps caused by climate. Since the 1920s, for example, plant breeders have helped American farmers expand the range of hard red winter wheat from Kansas and Oklahoma, south to Texas and as far north as the Canadian prairies. This kind of wheat now grows as well in Sidney, Montana, as it does in Sidney, Nebraska, although the Montana town's growing season is 10 days shorter, rainfall is 20 percent less, and annual temperatures are more than seven degrees cooler. Unlike traditional spring wheat, winter wheat is planted in autumn, quickly establishes a root system, and then lies dormant under the winter snows. It begins to grow again as the soil warms in spring, normally flowers and sets seed after the spring frosts, and is harvested before the extreme heat and drought of summer.

Farmers can shift to improved, drought-resistant plant varieties or to entirely new crops. They can employ new water-conserving tillage techniques, and irrigate more acres only at critical stages of plant growth rather than fewer acres all the time, as they do now. In short, farmers in the United States and elsewhere ought to have little trouble feeding the world in a moderately warmer climate.

This relatively optimistic view reflects the assessments of many specialists who have studied the ways in which farmers and agronomists have responded to normal weather fluctuations—drought, extremely cold winters, heavy rainfall. Scientists are by no means unanimous in rejecting more sombre scenarios. That mankind has managed to adapt to climate as it has changed in the past, however, seems to justify a fair degree of confidence in our ability to cope with a moderate warming of the globe during our lifetime.

But even the optimists warn that if the peoples of the world do not begin to restrain their output of CO_2 and other greenhouse gases, global temperatures could *eventually* climb by nine degrees, and by much more in some places. That, they say, would take us far beyond the bounds of any climatic change that mankind has experienced in its short history, and possibly beyond our ability to cope.