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Global Climate Research to Be Proposed by U.S.

Los Angeles Times

The Bush administration will propose next week an international research program on the "greenhouse effect" and the threat of global warming.

The proposal will be offered at a White House-sponsored conference Tuesday and Wednesday, where economic and scientific research on climate change will be assessed by science, environmental, and finance ministers from 17 countries and the Organization for Economic Cooperation and Development.

President Bush will open and close the gathering, which will consider not only what is known about the greenhouse effect, but also "more importantly what we don't know, what the uncertainties are, and how we might reduce those uncertainties," presidential science adviser D. Allan Bromley said.

Critics of the administration's response to evidence of global warming have charged the agenda will focus on uncertainties rather than addressing response strategies, such as conservation and renewable energy sources.

"The president is using this conference as a leadership facade," Ruth Caplan, executive director of the Environmental Action Foundation, said yesterday.

"When he should be leading the international call for action, he is using debate to buy time and delay action," Caplan said.

Washington Post
Apr. 12, 1990

How climate changes

ONLY two things are certain about the world's climate—and one of them is that it will always be unpredictable. The forces that govern it are preposterously intertwined, linking the chemistry of the deep oceans to the physics of the stratosphere, the ice-fields of the Arctic to the forest canopies of the tropics. It is as difficult to find a single cause for a climate change as it is to pinpoint the sneeze on which to blame an epidemic of influenza. Such complexity leads to the other certainty about climate: it is in perpetual flux.



The change that concentrates the minds of politicians and scientists today lies in an abundance of carbon dioxide. This colourless, tasteless and non-toxic gas, constantly produced by every animal around, seems an unlikely source of worry. But it has special talents: it is a much better trapper of heat than are the gases that make up the bulk of the atmosphere. That much is a certainty of molecular physics. There is no doubt that carbon dioxide—as well as several other gases, including methane and the man-made CFCs—enhances the atmosphere's greenhouse effect. Because its level has been rising ever since people took to burning wood, coal and what-have-you in industrial quantities, the amount of heat being trapped by it must be increasing.

This greenhouse effect is not controversial. Neither is it synonymous with global warming. Evidence from the ice ages shows that the carbon-dioxide greenhouse has always played a crucial role in shaping the climate, but only as one part of a symphony of effects which few people pay attention to (see pages 95-100). Other factors may redistribute extra heat in the atmosphere so as to leave temperatures at ground level unchanged. Spreading high wispy clouds might reflect sunlight back into space. Other mechanisms may need study, too, as climatic theories evolve. New discoveries always bring in their wake modish theories to explain them.

The politicians who will gather in Washington in the coming week for President Bush's meeting on climate change will hear the climatologists' current estimates: a warming of between 2°C and 6°C before 2100. They will also hear how utterly uncertain those estimates are. The uncertainties will not go away: political decisions about global warming will always be made on a teetering balance of probabilities. If and when the warming starts (it is not clear that any greenhouse-caused warming has taken place so far) its future rate and effect will remain in doubt. Arguments about whether greenhouse warming is already happening miss the point. It does not matter whether this May's darling buds are shaken by greenhouse winds or ordinary ones. What matters is whether future

droughts will kill the trees they bloom on.

People who seek to shape the climatic future should bear in mind the past. This reveals that climate change, once triggered, tends to gather a momentum of its own. Falls in atmospheric carbon dioxide—smaller than the rises predicted for this century and the next—appear to set off ice ages. Once carbon-dioxide levels are up, they stay up for centuries. Another message from the past is that even if a "greenhouse world" in which many places are warmer and damper may be attractive, getting there will not be. Most environments do not take kindly to sudden changes. Forests take time to migrate, deserts do not bloom overnight. Even a couple of degrees Celsius of warming in a century would still be much quicker than anything since the end of the most recent ice age. Rich countries may be able to ride out such ecological upheavals. Poor ones may not.

Such lessons from the past need to be mixed with tomorrow's uncertainties: it may never happen. For now, the wisest course is to let the risk of global warming act as an extra spur for doing only those things that would be wise even if there were no such risk. These include banning the ozone-chomping CFCs, encouraging cleaner and more efficient engines, saving tropical forests from the torch and saw, exploring energy sources like the sun and the wind, and improving nuclear power. To go beyond such prudence is a large step, betokening the beginning of a new endeavour: planet management.

The one-millennium manager

Man has often changed nature—wiping out a species here, stripping a region of woodlands there—but in a piecemeal sort of way. Now people wonder whether to wield the power that two centuries of technology have given them and have a shot at global air-conditioning. Waging war on carbon dioxide by cutting down on the use of fossil fuels would be only a first step. The climate changes constantly, and once man thinks he has seized the controls to avert some disastrous man-made alteration, he will be forever jiggling them to steer his world through natural changes that will follow.

If today's politicians worry about the greenhouse effect, their successors the day after tomorrow will have to worry about ice ages. The next ice age is probably nearer in time than the death of Julius Caesar, perhaps closer than the coronation of Charlemagne. Such stretches of time sound thankfully huge to politicians. But if they start to play at planet management, they will need to learn to think in centuries.

White House Balks at Hosting Talks on Global Warming

WP 10/25/89 A2

By Michael Weisskopf
Washington Post Staff Writer

White House advisers have rejected a bid by Environmental Protection Agency Administrator William K. Reilly to invite representatives of other nations to the United States next year to begin negotiating an international convention on global warming, administration sources said yesterday.

Reilly had sought to extend the invitation at an upcoming conference in the Netherlands, but it did not become clear until yesterday that he will be allowed to attend.

Last May, President Bush committed the nation to an international convention to identify the problems posed by global warming as the first step toward a possible treaty to limit the man-made gases that trap solar heat like a greenhouse and raise the Earth's temperature.

But when a working group of the White House Domestic Policy Council met Friday, most participants opposed Reilly's suggestion that the United States host the first session, sources said.

The sources added that most members of the group, chaired by the president's science adviser, D. Allan Bromley, also expressed opposition to U.S. participation at the meeting of 70 environmental ministers next month in the Netherlands, where proposals are expected on limiting the burning of fossil fuels. Only Reilly and the State Department representative said a U.S. delegate should attend.

The group was expected to ask Bush to referee. But reporters' calls to the White House yesterday appeared to hasten a decision.

According to White House spokesman Steven Hart, "The decision is Mr. Reilly's to make."

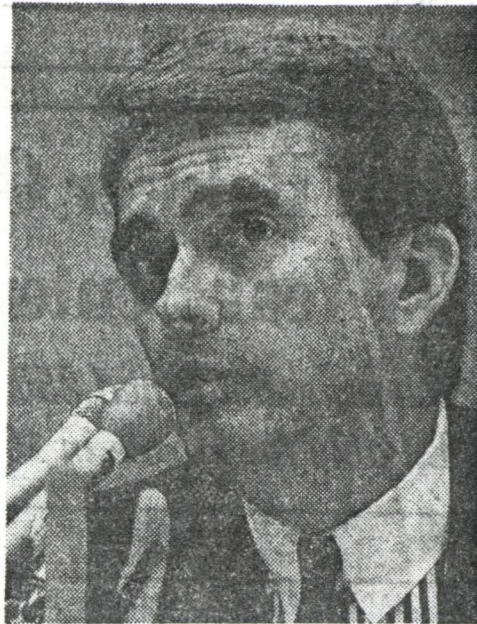
Last week, Reilly said he would attend the conference.

Hart would not comment on other decisions at Friday's meeting, which was attended by top officials from the Departments of Energy, Interior and Commerce, Office of Management and Budget, Council of Economic Advisers and Council of Environmental Quality.

Environmentalists are closely watching administration moves because such key players as White House Chief of Staff John H. Sununu are known to question the scientific consensus on global warming and the economic wisdom of curbing use of fossil fuels, including coal and oil.

Sununu originally opposed U.S. support for an international convention last May.

In addition, Bromley raised concerns among environmentalists when he sug-



WILLIAM K. REILLY

... wanted to issue invitation at Dutch session

gested at his confirmation hearing that dramatic temperature changes would only occur after atmospheric levels of carbon dioxide—the principal greenhouse gas—more than doubled from concentrations that existed before the industrial revolution. Most scientists predict that lower levels of carbon dioxide would result in significant warming.

At the Nov. 6-7 meeting in the Netherlands, the Dutch government is expected to propose an international freeze on carbon dioxide at current levels by the year 2000.

Sen. Timothy E. Wirth (D-Colo.), noting the administration's indecision on participating in the conference, said in a floor speech that the United States should be the "point man in the drive to summon a global will" and that staying home would be "disastrous."

Sen. John H. Chafee (R.I.), ranking Republican on the Senate Environmental and Public Works Committee, wrote Bush last week with four other Republican senators, urging that Washington propose a "forceful and specific agenda" at the conference.

NEWS AND VIEWS

CLIMATE CHANGE

Wetter clouds dampen global greenhouse warming

Tony Slingo

VARIATIONS in cloudiness can significantly affect the Earth's radiation budget — the absorbed solar energy and the thermal energy radiated back to space. This conclusion is supported by various modelling studies of the 'greenhouse' effects of increased CO₂ concentrations¹⁻³. In these studies, the CO₂ forcing induces changes in the cloud coverage and liquid-water content, which alter the radiation budget further and thus modify the original perturbation. On page 132 of this issue⁴, Mitchell *et al.* add a new twist to the story, showing how changes in the relative amounts of ice-crystal and water-drop clouds substantially reduce the sensitivity of their model to changes in concentration of CO₂. Indeed, it is becoming apparent that uncertainties in the treatment of clouds severely undermine model prediction of climate.

Mitchell *et al.* used various versions of the UK Meteorological Office atmospheric general circulation model coupled to a 50-m ocean mixed layer. Replacing the standard cloud prediction scheme based on relative humidity by a more sophisticated prescription including liquid water and ice virtually halves the average equilibrium surface warming due to doubled CO₂ — from 5.2 K to 2.7 K. They argue that this spectacular sensitivity to details of the cloud scheme is caused by the replacement of ice clouds by water clouds near the freezing level. In the new cloud scheme, the fall-speed assumed for water drops is much smaller than that for ice crystals, so that liquid-water clouds can dissipate more slowly than ice clouds. According to Mitchell *et al.*, this leads to the predicted relative increase in water clouds near the freezing level, which consequently reduces the amount of solar energy absorbed in the system (more is reflected back into space) and hence gives a smaller warming. When, in addition, cloud radiative properties are allowed to depend on the liquid-water content of clouds, the surface warming drops still further, to only 1.9 K.

The strong dependence of the magnitude of cloud feedback in this work on the details of the model parallels results presented recently⁵ by a large *ad hoc* group (including Mitchell and myself) led by Robert Cess of the State University of New York. We compared 14 general circulation models and found a three-fold variation in global climate sensitivity, caused largely by differences in the cloud feedbacks. The models disagreed not only as to the magnitude but also the sign of the net cloud feedback. For this reason, it is

clear that uncertainty in how to formulate clouds represents a formidable obstacle to reliable climate prediction.

This underlines the continuing need for physical parameterizations to be compared with results from field studies. This is particularly important now that models are becoming increasingly complex. Mitchell *et al.* argue that the assumptions in their model are 'at least qualitatively realistic', but if climate change simulations are to be believable, then all parts of a model must be validated quantitatively, and important processes that are ignored must be identified. Of particular relevance to the cloud problem is the FIRE programme (first regional experiment of the international satellite cloud climatology project), both in its stratocumulus⁶ and cirrus⁷ field phases. Several papers are in preparation that highlight the complexity of the meso-scale dynamical structure of cirrus, so that the fall-speed of ice crystals is only part of the story. It is also interesting that two cases of highly supercooled liquid-water altostratus clouds at temperatures around -30 °C were observed (A.J. Heymsfield *et al.*, personal communication), which suggests that the transition from water to ice clouds is more subtle than Mitchell *et al.* assumed for their model.

The substantial sensitivity of climate models to the details of their formulation,

and the fact that 14 models give 14 different answers for the cloud feedback, show that we are far from the goal of accurate predictions of future climate change. Sensitivity studies such as that reported by Mitchell *et al.* and comparisons between models as done by Cess *et al.* are now the bread and butter of climate modelling. But at the present rate of progress, it will be several years before reliable predictions of global and regional climate change are available from the models. That underlines the need for comprehensive monitoring that is capable of unravelling the climate change signal from the noise and of providing enough data on the state of the atmosphere, the Earth's radiation budget and clouds for the feedbacks to be determined by observation. Such an analysis may well yield the fifteenth answer but at least it will have come from the real world and will permit a much needed test of the models. □

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ECOLOGY

Just proportions in food webs

Joel E. Cohen

IN FOOD webs of natural communities with varying numbers of species, the number of green plants and other species that consume no prey in the web (basal species) is nearly proportional, on average, to the number of species that have both predators and prey in the web (intermediate species), according to studies reported over the past dozen years¹⁻³. Empirical rules⁴ of that type describe structural or anatomical properties of food webs. An important question in community ecology is whether parallel regularities exist in the way in which food webs function⁵. On page 142 of this issue⁶, McNaughton *et al.* report remarkable regularities in measures of food web function. Their findings indicate the existence of a physiology of food webs that generalizes across natural communities. Their report opens up the distant, but highly attractive, prospect of linking the previously known structural regularities

with new functional patterns.

McNaughton *et al.* show that the biomass, consumption and net secondary productivity (NSP) of herbivores are all related to the net above-ground primary productivity (NAP) of a natural habitat by simple power laws. Particularly striking is that the exponent of the power law that relates NSP to NAP is not significantly different from 1: to a first approximation, NSP and NAP are directly proportional. In effect, the energy converted into herbivores per square metre of surface area per year is, on average, about one-thousandth of the energy that is converted into plants per square metre of surface area per year. The ecological energy pyramid has a much larger base than second storey.

This proportionality would be a triviality if secondary productivity were passively controlled and limited by primary productivity. But this trickle-down view of

LETTERS TO NATURE

TABLE 2 Newtonian error and signal strength

Distance r (m)	Maximum 1- μm shape error		Fifth force	
	Displacement $f^2 S$ (m s^{-2})	Strain $f^2 h$ (s^{-2})	Displacement $f^2 S A^2/\alpha$ ($\text{m}^3 \text{s}^{-2}$)	Strain $f^2 h A^2/\alpha$ ($\text{m}^2 \text{s}^{-2}$)
2	4×10^{-12}	2×10^{-17}	1.1×10^{-13}	3×10^{-13}
4	1.3×10^{-10}	3×10^{-18}	1.4×10^{-14}	2×10^{-14}
8	4×10^{-21}	5×10^{-21}	1.8×10^{-15}	1.3×10^{-18}

The results detailed here show that it may be feasible to use the asymmetric monopole to test the fifth-force hypothesis, although the experiment is obviously not easy, and practical problems remain to be examined in detail. For example, there are small elastic distortions in a rotating body as a result of centrifugal forces. The shape defined by Table 1 is the shape that must be achieved at the final rotation speed. A numerical calculation would give the correct initial shape for a given material. Advantages of the experiment are that the experiment is a null one and one can adjust the shape to find the null, and that only octupole-patterned deformations give rise to error signals as large as in Table 2. Also, the parameters I have chosen (size, distance, tolerance and material) are nominal. There is also the possibility that a refinement of this idea, or an incorporation of the mathematical idea into other experimental techniques (such as torsion balances) may prove effective. I note that the experiment would not depend on any variation of the fifth force with chemical composition, as do many of the recent experiments. □

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CO₂ and climate: a missing feedback?

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THE potential of changes in cloud properties to modulate climate perturbations is well known^{1,2}. Changes in cloud amount and cloud height³, cloud radiative properties⁴ and cloud condensation nuclei⁵ (CCN) have all been recognized as possible sources of climate feedbacks. Here we report results of simulations that indicate that the changes of state of cloud water may provide a substantial negative feedback on climate. The feedback is concentrated in mid-latitudes and affects both the magnitude and distribution of the climate change expected from increases in 'greenhouse' gases. Improved measurements and parameterizations of cloud processes are needed to quantify this process.

The model is an 11-level atmospheric general-circulation model on a $5^\circ \times 7.5^\circ$ (latitude $\times$ longitude) horizontal grid coupled to a 50-m mixed-layer ocean with a prescribed seasonally and geographically varying oceanic heat convergence to represent heat advection by ocean currents⁶. In the standard

model⁶ cloud cover is a function of relative humidity. A second version of the model was constructed with an explicit cloud-water variable for all but deep convective cloud⁷. A balance is maintained between cloud water content and water vapour, which is altered by dynamical, convective and boundary-layer processes. Cloud water content is depleted by precipitation at a rate dependent on the phase of the cloud water, which is a function of the local temperature of the layer. For water cloud the rate of conversion to precipitation increases as a function of the in-cloud water content and is marginally enhanced in the presence of precipitation from higher layers. The transition from water cloud to ice cloud occurs between -15°C and 0°C as a smoothly varying function of temperature. Ice-cloud particles are assumed to start falling as soon as they form, with a fixed fall speed of 1 m s^{-1} . The rate of precipitation of ice is, on average, an order of magnitude greater than that of water even in the presence of precipitation from the layer above. Cloud radiative properties were prescribed. Note that although the revised cloud scheme is more detailed, it is not necessarily more accurate than the less sophisticated scheme. Our work highlights how different parameterization schemes can affect the sensitivity of the climate to CO₂.

Two simulations, with CO₂ concentrations of 320 and 640 p.p.m., were performed for each version of the model. The results shown here are averaged over five years after the simulations reached equilibrium. On replacing the relative-humidity cloud scheme⁶ (henceforth referred to as RH) with the model based on cloud water content⁷ (CW), the global annual average surface warming is reduced from 5.2 K to 2.7 K. The largest fractional reduction in the warming occurs in higher latitudes (Fig. 1a) where the large decreases in total cloud cover with RH have been replaced by much smaller reductions or slight increases (Fig. 1b).

With RH, reductions in cloud cover are found throughout the depth of the mid-latitude troposphere (Fig. 2a), as in earlier studies². With CW, the main differences in response occur near the freezing level (Fig. 2b) where, in the warmer doubled-CO₂

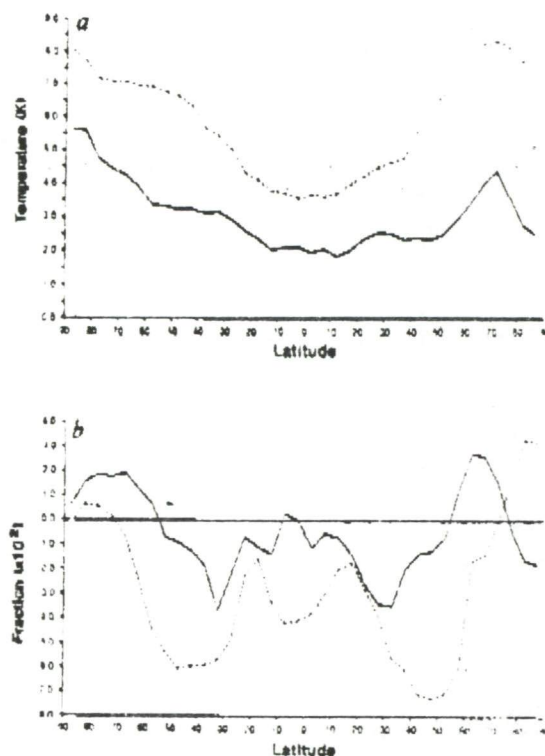


FIG. 1. Zone-averaged equilibrium changes in a surface temperature and b, fractional cloud cover on doubling CO₂ (five-year means). Solid line, simulation with CW. Dashed line, simulation with RH.

simulation, ice cloud which is depleted rapidly by precipitation is replaced by water cloud which is depleted more slowly, so that cloud cover increases. This can be seen more clearly in the height-latitude distribution of the changes in cloud liquid water and cloud ice (Fig. 3). Also shown are the mean 0 °C and -15 °C isotherms in the control simulation. Because of the increases in cloud, the enhanced absorption of solar radiation in mid-latitudes found with RH is greatly reduced when using CW (Fig. 4).

One can define a climate sensitivity parameter λ ($=\Delta Q/\Delta T$) where ΔQ is the change in radiative heating at the tropopause on doubling CO_2 and ΔT is the equilibrium change in surface temperature. Assuming¹⁰ $\Delta Q = 4 \text{ W m}^{-2}$, λ is increased from 0.77 to $1.48 \text{ W m}^{-2} \text{ K}^{-1}$ on replacing RH by CW. Thus changes in the phase of cloud water provide a strong negative feedback on climate, cancelling almost all the previous strong positive feedback from cloud in RH¹¹. Although our model does not allow for this process in deep convective clouds, these have a small areal coverage and a relatively high liquid-water content,

however, suggesting that any radiative feedback from this type of cloud would be small.

The lower-cloud increases in the simulations arise from the assumption that under similar conditions ice is removed more efficiently from cloud than water. In real water clouds, relatively few droplets become large enough to fall out, as the available condensed water is spread over many cloud condensation nuclei (CCN)¹². Very few CCN act as ice nuclei¹³, so in ice clouds the cloud water is spread over fewer, larger particles, all of which have appreciable fall speeds¹⁴. The microphysics of mixed-phase clouds are complex and not fully understood. Although our model does not explicitly represent them it effectively includes their most important aspect, the continual rapid conversion of water to ice¹⁵. A more complex representation would certainly change the pattern in Fig. 2 locally, but the vertically integrated response would probably depend primarily on the overall change from pure ice cloud to pure water cloud. Thus our assumptions concerning the relative fall-out of ice and water are at least qualitatively realistic.

As 1 m s^{-1} may be a large value for ice fall speed, we have rerun experiment CW using a parameterization of fall speed in terms of ice-water content based on observations¹⁴ (experiment CWH). For typical simulated ice-water contents, this gives fall speeds of 0.2 m s^{-1} for high ice cloud and 0.7 m s^{-1} for ice cloud near the freezing level. Cloud changes (Fig. 2c) are qualitatively similar to Fig. 2b and the global warming is 3.2 K, only slightly larger than in CW. The similarity between CW and CWH is to be expected, given that the depletion rate of ice relative to water is large near the freezing level in both experiments.

It has recently been suggested that changes in cloud radiative properties may contribute an important feedback to climate^{4,5,16}. In a warmer climate, greater cloud water content would increase cloud albedos (a negative feedback) and emittances (a positive feedback). A further experiment was carried out using the revised version of the model with an additional modification to

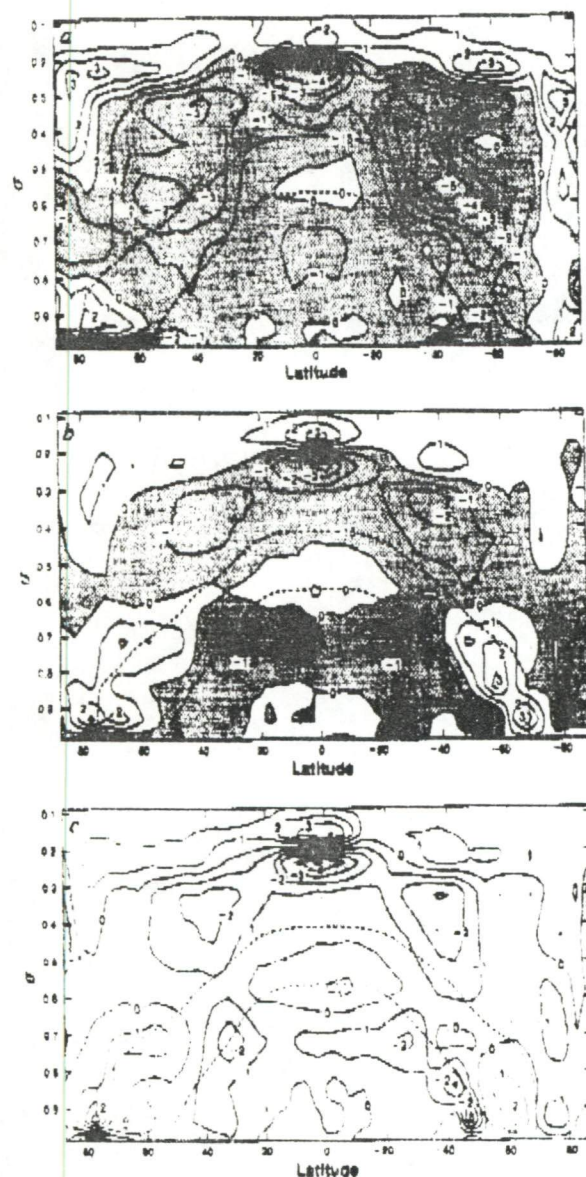


FIG. 2 Height-latitude cross-section of equilibrium changes in cloud amount on doubling CO_2 . The height coordinate is σ (pressure/surface pressure). Areas of reduction are stippled and the contours are every 1%. The dashed lines are the 0 and -15 °C contours from the control simulation. a, Simulation with RH. b, Simulation with CW. c, Simulation with CWH.

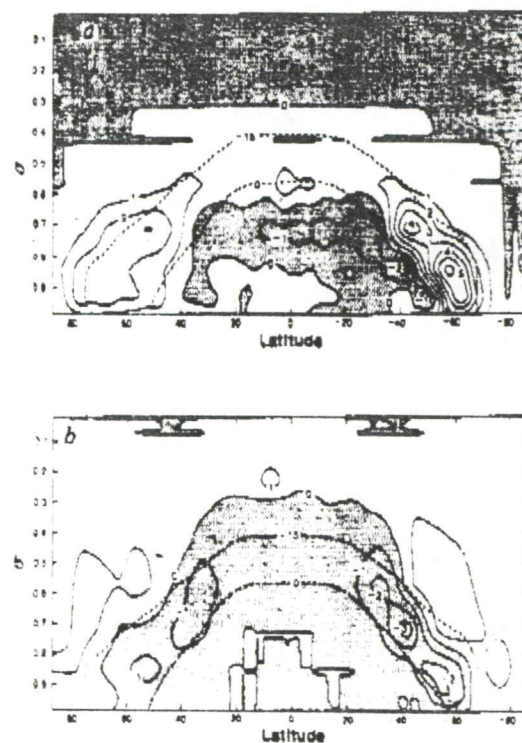


FIG. 3 Height-latitude cross-section of equilibrium changes in cloud water in CW on doubling CO_2 . The height coordinate is σ . Areas of reduction are stippled. The dashed lines are the 0 and -15 °C contours from the control simulation. a, Liquid-water content only. Contours every $4 \times 10^{-6} \text{ kg kg}^{-1}$. b, Ice-water content only. Contours every $4 \times 10^{-7} \text{ kg kg}^{-1}$.

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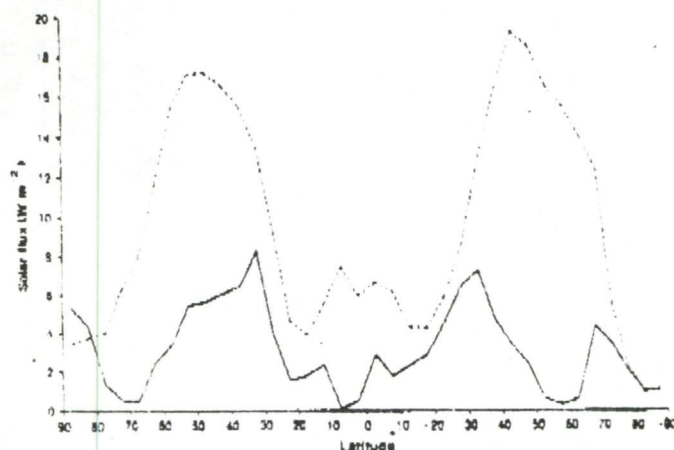


FIG. 4 Zone-averaged equilibrium change in net solar flux at the top of the atmosphere on doubling CO_2 (five-year mean). Solid line, simulation with CW. Dashed line, simulation with RH.

allow the cloud radiative properties to depend on the cloud water content (scheme CWRP). (Given the similarity between CW and CWH, this experiment was carried out with the CW formulation only.) Analytical fits of the short-wave albedo and transmittance as functions of cloud-water path and solar zenith angle were made to a published scheme¹⁷ based on observations and theoretical considerations. The long-wave flux emittance was given by $(1 - \exp(-\kappa q))$ where q is the condensed-water path and $\kappa = 0.13 \text{ m}^2 \text{ g}^{-1}$ for water clouds and $0.065 \text{ m}^2 \text{ g}^{-1}$ for ice clouds¹⁸.

On doubling the CO_2 concentrations the global annual average equilibrium surface temperature increased by 1.9 K with CWRP compared to 2.7 K with prescribed cloud radiative properties (CW), indicating a further increase in λ to $2.1 \text{ W m}^{-2} \text{ K}^{-1}$. This negative feedback from changes in cloud radiative properties lies between the very strong negative feedback suggested by one-dimensional calculations^{16,19} and the positive feedback found in a previous study with a low-resolution general-circulation model (GCM)⁴⁻⁶. We note that all existing numerical studies assume that the number of CCN remains constant under climate change. Changes in CCN are a further possible source of feedback^{7,20}.

The sensitivity of the climate to doubling the CO_2 concentrations that we have found is substantially smaller than the 4–5 K found in other recent studies^{10,21}. A significant part of this reduction in sensitivity is due to the different cloud scheme. If correct this will have two important consequences. First, the equilibrium warming expected from the estimated 2 W m^{-2} increase in radiative heating at the tropopause since 1860 (ref. 9) will be smaller. Second, the proportion of the equilibrium reached will be greater, because the thermal response time of the climate system is reduced if climate sensitivity is reduced²². Based on calculations using a simple one-dimensional model of the ocean, the expected warming to date, using the climate sensitivity found when employing CW, is 0.6 K. This is close to the observed warming since the beginning of the century (0.5 K; ref. 23). The record of observations shows considerable variability on interannual and interdecadal timescales, however, including a period of cooling during the 1950s and 1960s, so that it is not possible to attribute the 0.5 K rise unambiguously to the effect of increases in trace gases. □

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Disequilibrium silicate mineral textures: fractal and non-fractal features

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IGNEOUS rocks formed from lava flows of the Archaean era (>2,700 million years ago) are often found to contain disequilibrium-textured crystals characterized by spherulitic, branching or dendritic morphologies that occur in layers near the flow surface. Well-known examples are the plagioclase spherulites of basalts and the platy and branching spinifex-textured olivines and pyroxenes of komatiites^{1,2}. Here we present evidence that, over a finite range of length scales, some disequilibrium textures are scale invariant. This observation implies that over this range of length scales their random patterns can be quantitatively characterized by a unique number, the fractal dimension³. We also demonstrate that some textures have a crossover from fractal to non-fractal behaviour. It is known that most disequilibrium crystals arise in part from rapid cooling and represent the case where the growth rates of the crystals are large compared to the diffusion rates in the silicate melt^{1,2,4}. We therefore formulate a quantitative model for the growth that is based on a variant of diffusion-limited aggregation (DLA)⁵.

Figure 1 shows a section of small disequilibrium crystals, at different magnifications. These form close to the quench/glassy margin of some lava flows⁶, and their outline remains the same as the microscope objective power is increased. Similar remarks can be made about textures on other length scales, such as the much larger branching pyroxene crystal of Fig. 2a.

The concepts and techniques of fractal geometry⁷ have proven useful in understanding other random morphologies, in part because a fractal object is characterized quantitatively by a number, the fractal dimension d_f , that relates the increase in mass M of the object to its characteristic length scale L , $M \propto L^{d_f}$ (ref. 7).

To determine d_f we digitized photographs of the textures using a video camera with a grid of 65,536 pixels. First we randomly chose any pixel belonging to the digitized texture. About this 'local origin' we constructed a sequence of concentric shells of

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THIS DOCUMENT CONSISTS OF 5 PAGES
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Dialog

Fielding Perceptions About the Disabilities Act

I am writing to voice my displeasure with "Disabling Businesses" [Cover Story, April 13]. The cover, indicating that the Americans with Disabilities Act will handicap the economy, is very insensitive to the handicapped. An attitude such as yours is the reason there has to be a law.

Ann McRae
Director, Special Education
Anderson County Schools
Clinton, Tenn.

Your readers deserve more than innuendo and loaded terms about the Americans with Disabilities Act. In part this is a response to your incredibly biased article and in part an explanation of the act and its implications. The ADA did not "breeze through." Thousands of people worked on its passage, despite lukewarm support from the White House. The issue is not to "give a break to the disabled," but to treat human beings as human beings.

Charlotte Allen cites Marc Fiedler's suits, filed after he contacted violators and got no response — and then suggests that we "depend on . . . goodwill." For shame. As Fiedler says, he has no plans to collect damages. He wants to get in the door. Jerry Mashaw suggests hordes of people want to sue because they are "disappointed and frustrated with the way they've been treated." Try being treated as most people with disabilities are; disappointment and frustration have nothing on that.

As an eager supporter of the ADA, I did not once hear of plans to picket large businesses that opposed it. We knew our cause was just. Some business associations continue, as you do, to spread inflammatory misinformation about the act. I know of no one who supports it who is not working very hard to correct misinformation, to educate employers, to direct people to resources, to make integration a reality.

We have explained carefully some issues. The margin for most businesses is close. Why would anyone in business willfully bar the door, eliminate a substantial market? In addition, until changes are made in medical coverage, most people who are disabled and who receive assistance cannot afford to work because they would lose medical coverage. The myth that hordes of people who use wheelchairs are lining up attorneys to sue is just plain

idiotic. A job, a place to live, the possibility of a life like any other life. Reasonable. Perhaps more than Charlotte Allen, terrified that people with disabilities might join into community life, perhaps more than her lack of reason would find reasonable.

Jacqueline T. Alfonso
Executive Director
United Handicapped Federation
St. Paul, Minn.

Certainly, people with disabilities have been treated unfairly, and I am certain that many of them are justly quite angry. But in today's society, where hardworking, motivated employees are at a premium, employers would be foolish not to hire and make accommodations for qualified disabled people. In fact, long before the Americans with Disabilities Act became law, employers were reaching out to the disabled: Witness the proliferation of curb cuts, parking spaces for the handicapped and braille elevator signs that have been part of the landscape for more than a decade. All the employers I interviewed, from giants like Marriott down to tiny family businesses, told of positive experiences in hiring the disabled; if accommodating a disabled work force and customer base will make the economy more productive, there is no need for a law forcing accommodations.

But the Americans with Disabilities Act is not about this sort of thing. It is about using litigation — an extremely expensive mechanism that adds nothing to a society's productivity — to force businesses and state and local governments to comply with standards that may or may not have anything to do with the kind of people who actually need accommodations and that certainly have nothing to do with whether there is any payoff of benefits for the cost. Congress refused to define what a "reasonable" accommodation is, leaving the task to judges on a case-by-case basis. What better guarantee of years of lawsuits?

Congress did not even bother to make an accurate count of the disabled. Only about 5 million Americans actually need the kind of massive architectural changes the act decrees.

The disabilities act not only requires litigation to define its parameters but enthusiastically invites litigation now that disability advocates have managed to secure their constituents certified victim status under the 1991 Civil Rights Act, which gives them access to compensatory and punitive damages and attorney's fees in cases of employment and public-sector discrimination.

If the history of suits under the 1973 Rehabilitation Act (outlawing disability discrimination among federal contractors) is any guide, future lawsuits are not likely to be over wheelchair use or learning disabilities. They will be over stress, smoke sensitivity, mandatory overtime and so forth — CA.

A Dispute over Factors in the Ozone Equation

Your article titled "The Ozone Scare" [Cover Story, April 6] was misleading and factually incorrect in several instances. It was seriously wrong: (1) in its assessment of the motives and scientific basis for the president's action on advancing the phaseout schedule of chlorofluorocarbons; (2) on the motives of NASA, NOAA and the scientists in issuing their press release; (3) on questioning the integrity of the scientists involved in environmental research; and (4) on the exclusive role of chemists in shaping our understanding of ozone depletion.

The information presented in the NASA/NOAA press release was timely, precisely scientific and presented in a factual manner. Neither the information nor the process was alarmist, as suggested by your article. The press release had the complete support of the scientists involved in the campaign and the program managers at NASA and NOAA, and was not a case of "grandstanding" by the project scientist.

The article suggests that President Bush was rushed into making a policy statement concerning chlorofluorocarbons and their accelerated phaseout based on the NASA/NOAA press release. This is totally incorrect. The United Nations ozone assessments, which were finalized in October — not the press release — were used by the administration as the basis for its recent policy statement concerning the chlorofluorocarbons and their accelerated phaseout.

The scientific data presented in the press release significantly strengthened the key conclusions of the peer-reviewed U.N.-sponsored international scientific ozone assessment. These conclusions are: (1) The weight of scientific evidence suggests that ozone depletion observed over the last two decades at temperate and high latitudes throughout the year is in large part caused by chlorine- and bromine-containing chemicals; and (2) As atmospheric levels of chlorine and bromine increase in the future, significant additional ozone losses are expected at temperate latitudes and in the Arctic.

President Bush provided the required leadership to protect human health and ecological systems from the adverse consequences of anticipated increased ultraviolet radiation. Economics and technology issues were carefully addressed in the international assessments and given due consideration by the president. Bush's decision is strongly supported by industry; will not cost consumers "hundreds of billions of dollars"; will not require them to purchase new refrigerators, because there is an exemption for chlorofluorocarbons recycling and production to service existing equipment; and will not expose them to risks of a "refrigerator blowing up" since these chlorofluorocarbon substitutes are not flammable.

The allegations that the prevailing view of ozone depletion has been shaped largely by chemists with little appreciation of meteorology is again incorrect and insulting to the numerous meteorologists and dynamicists who have been involved in the arctic and Antarctic aircraft campaigns and the international scientific ozone assessments. The impact of meteorological processes on daily changes in chemical composition and on the long-term depletion of ozone is an integral component of all analyses.

Your article implied that the press release was based on limited scientific data with a new tool, which had not yet undergone the scrutiny of peer review. The facts do not support this implication. The press statement was not based on data from a single flight, but rather on data obtained from more than 20 NASA ER-2 aircraft flights over a six-month period, in conjunction with a number of DC-8 flights and more than several months of "near-global" satellite observations. All critical data reported at the press conference had been obtained by instruments that have been thoroughly tested in the field, and their prior results were stringently peer-reviewed in the scientific literature. There have been over 130 flights of the ER-2 since 1987 studying the chemical, meteorological and radiative processes controlling atmospheric ozone, including the Antarctic aircraft campaign in 1987 and arctic campaign in 1989.

The press release correctly stated that highly elevated concentrations of the chlorine monoxide radical, the key agent responsible for stratospheric ozone depletion, were observed in the arctic by both the in situ sensor on the ER-2 aircraft and the remote sounding sensor on the Upper Atmosphere Research Satellite at high latitudes in the Northern Hemisphere over populated areas. Concentrations of chlorine monoxide as high as 1.5 parts per billion by volume

(ppbv) were observed over Canada and northern New England using the aircraft sensor. Even higher values than 1.5 ppbv were observed by the satellite sensor over Europe and Asia. These are the highest atmospheric concentrations ever observed. The release also said the highly elevated concentrations of chlorine monoxide, and companion measurements of bromine monoxide, implied that ozone levels within the arctic vortex could decrease at a rate of 1 to 2 percent per day at ER-2 flight altitudes, depending on how long those chemical conditions persisted under sunlit conditions.

The NASA, NOAA and academic scientists involved in the data collection and analysis concluded that they had an obligation to release these findings because of their importance. The press release correctly, and rightly, warned that under "unfavorable" meteorological conditions, significant ozone depletion could occur either this year or some year in the future while the concentrations of chlorine and bromine are comparable to, or higher than, those of today. The press release did not, however, state that an "ozone hole" would occur this year. The atmospheric concentrations of ozone at northern high latitudes in winter and spring are highly variable; to ascertain whether significant ozone depletion has occurred this winter requires careful analysis of all available aircraft and satellite data. NASA and NOAA will be in a position to appraise the extent of this year's seasonal ozone depletion during April. An ozone decrease is likely to be widely distributed; hence the term "ozone hole" is a misnomer.

Allegations that the scientists involved in research in environmental issues, such as ozone depletion and global warming, are driven by funding considerations are an insult to the integrity of not only the scientists but also the funding agencies and my office, which plays a critical role in the establishment of research priorities. Government funding is not driven by alarmism. The U.S. Global Change Research Program was established as a presidential initiative to provide the scientific basis for national and international policy decisions by investigating the influence of all natural phenomena and human activities that might affect Earth's environment.

The president recognized the danger of a continued erosion of the ozone layer at middle and high latitudes and provided critical leadership to the international community by announcing that the U.S. would eliminate the production and consumption

of these chemicals by Dec. 31, 1995, faster than currently required. Bush's action is not a crash project at major expense to the American people. In fact, the costs of protecting society will be much less than paying the costs associated with the adverse consequences of ozone depletion. In addition, it bears emphasis that the president's action has been strongly endorsed by both U.S. industry and European governments.

These new data on ozone have potentially serious consequences for all humanity, and it is important that they be made available both quickly and correctly. So also is it important that appropriate action based on them be taken. This the president has done.

D. Allan Bromley
Assistant to the President
for Science and Technology
Washington

Mr. Bromley is a skilled defender of the prevailing ideology of ozone and of the president he serves. But his letter distorts my article and, worse, is part of a campaign of intimidation directed at those in the scientific community who dare dissent from current wisdom.

Bromley's assertion that scientists involved in research in environmental issues are not driven by funding considerations is unfounded. All science is driven by funding considerations. Furthermore, it is widely known in the scientific community that the atmospheric chemists have been the driving force in shaping our understanding of ozone depletion. Many do fine work, and the article did not "insult" their contribution. It pointed out that there are many other factors at work in ozone depletion, factors the public does not hear about due to an unfortunate conjunction of scientific, political and media interests.

That conjunction was a central issue in my article. I am grateful that Bromley is now backing away from the misleading term "ozone hole" — a term the ideologists of ozone, who know better, have done little to discourage. As I demonstrated, it was the conjunction of scientific, political and media forces that pushed the Bush administration to accelerate the CFC phaseout, and not merely the NASA press release and the studies that preceded it, as Mr. Bromley states. These same interests give little thought to the true costs of a hasty CFC phaseout, which, contrary to Bromley's claims, would be high — M.M.

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DECISIONMAKING IN THE FACE OF UNCERTAINTY **

John H. Gibbons*

The art of decision making under uncertainty has a long history; the science of that activity is still in a rudimentary stage and deserves imaginative thought. We must not be driven to poor choices by emotional convictions. But we must not be deferred from action by rigid ideological beliefs. Thomas Malone, Sigma Xi.

I. INTRODUCTION

Policymakers thrive on uncertainty. The challenge of making educated guesses, balancing costs and benefits, weighing the consequences of action versus inaction lures intelligent, creative people into decisionmaking roles. Scientific uncertainty often serves equally well as sword or shield in the battles over values that actually result in international and national policy. In this paper, I hope to bring a bit of the policymaker's perspective to this meeting. The facts about climate change play a critical role in policymaking—especially to the extent that they narrow the debatable issues. But disagreements over current values (traditional economic values vs. new environmental values) and over issues of equity (global, regional, and inter-generational) inevitably drive the debate.

The issue that brings us together at this conference presents a larger challenge, in a way, than any previously experienced. Human activities are altering the concentration of atmospheric gases that affect the earth's stratospheric ozone shield against solar ultraviolet radiation. These gases are also intimately linked to the earth's long term heat balance. In terms of geological time, these alterations—global warming—are occurring at lightning speed, but in terms of human institutional foresight and concern, the "greenhouse" rate of change is barely visible. We know surprisingly little about Earth's HVAC (heating, ventilating, and air conditioning) system, but know for certain that failure to govern exponentially expanding human activity—particularly energy consumption and population expansion—will ultimately mean an irreversible commitment to climate change on catastrophic levels for major regions of the world.

The challenges to governance are enormous. Governments are simultaneously propelled by centripetal and centrifugal forces. The necessity of

Director

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**Keynote paper, Conference on Energy & Environment: Intersecting Global Issues," Jan. 17-18, 1992, Tucson, AZ. Co-sponsored by the U. of Arizona College of Law, Udall Center for Public Policy, and the College of Engineering,

affecting energy consumption decisions that normally take place at very disaggregate levels forces governments to focus on internal business with an unusually fine level of detail. Conversely, the worldwide cooperation required to understand and cope with global warming forces governments to focus outward on affairs well beyond national boundaries. The question before us at this conference is whether there are technical and policy opportunities to diminish the threat of greenhouse gases and still ensure opportunities for sustained, worldwide economic progress. In the remarks that follow, I will put the greenhouse debate in context to help us better understand the fundamental problems we must address.

II. THE NATURE OF THE CRISIS

SCALE makes the global warming problem unique. Those who govern typically deal with issues that are rife with uncertainties—scientific and otherwise—and they must usually make decisions before receiving all of the facts. But they are rarely called upon to set policies or make decisions that affect as many people, over such a long period of time, as the decisions that lie at the heart of this issue. *Thus, it is essential for our governors to have the technical certainties and uncertainties surrounding climate change spelled out as clearly as possible.*

A. Certainties

Through activities such as producing and burning fossil fuels, deforestation, raising animals and crops, heating, air conditioning, and insulating, mankind releases "greenhouse gases" into the air. These gases are transparent to incoming solar radiation, but opaque to outgoing infrared radiation. This process traps heat and slowly warms the atmosphere, earth, and oceans.

Global atmospheric concentrations of several "greenhouse gases" have risen rapidly over the last 100 years.¹ Some of these gases (carbon dioxide, methane, and nitrous oxide) also occur naturally, but their rapid increase is attributable to human activity. Globally, fossil fuel use—the primary source of CO₂—has nearly quadrupled since 1950.² The atmospheric concentration of carbon dioxide is currently increasing about 30 to 100 times faster than

1. Intergovernmental Panel on Climate Change, WMO/U.N. Environment Program, *Climate Change: The IPCC Scientific Assessment*, fig. 3, at xvi (John T. Houghton, G.J. Jenkins, J.J. Ephraums eds., 1990) [hereinafter "IPCC Scientific Assessment"].

2. T.A. Boden, P. Kanciruk, and M.P. Farrell, Carbon Dioxide Information Analysis Center, U.S. Dep't of Energy, *Trends '90: A Compendium of Data on Global Change* ORNL/CDIAC-36, 89 (1990).

the rate of "natural" fluctuations indicated in the paleoclimatic record.³ Likewise, the atmospheric concentration of methane is increasing more than 400 times faster than the natural rates of variability.⁴ Other greenhouse gases—chlorofluorocarbons ("CFCs") and halons—that did not even exist half a century ago are causing global impacts (e.g., stratospheric ozone destruction).

We know that if greenhouse gas emissions continue to increase under "Business As Usual" scenarios, the earth's average temperature is expected to increase 0.3 °C per decade, or by about 3 °C by the end of the next century.⁵ At some uncertain net cost, policy measures could conceivably halve that rate of change, and allow more time for human and natural systems to adapt.⁶ We also know that the delay between the time the gases are produced and the time when the climatic and ecological impacts are fully felt is considerable. At any given time we are emitting gases whose warming effects on the atmosphere will not be felt fully for another 20 to 60 years, i.e. we are committing ourselves to future warming. History also tells us that considerable delays are involved between the time policy options are identified and implemented, and when selected policies actually make a significant difference. In other words, to effect major, lasting change in greenhouse emissions realistically requires several decades or more of sustained action.

Currently, industrialized countries (including Russia and Eastern Europe) contribute about two-thirds of all greenhouse gas emissions, mostly from fossil fuels that are used to power their highly energy-intensive societies (Figure 1). Projections for the United States⁷ and several other industrialized countries⁸ suggest that over the next two to three decades a combination of conservation, energy efficiency, and alternative energy schemes will allow developed countries to grow economically while keeping their energy growth minimal or even negative at little or no net economic penalty. Positive environmental impacts independent of CO₂ changes will also follow.

Because of their technological sophistication and low population growth, there may be, given time, ample opportunity for industrialized countries to stabilize or even decrease their annual emissions of greenhouse gases.

3. J.M. Barnola, et al., *Vostok Ice Core Provides 160,000-year Record of Atmospheric CO₂*, 329 *Nature* 408 (1987). See also C. Lorius, et al., *The Ice-Core Record: Climate Sensitivity and Future Greenhouse Warming*, 347 *Nature* 139 (1990).

4. J. Chappellez, et al., *Ice-Core Record of Atmospheric Methane Over the Past 160,000 Years*, 345 *Nature* 127 (1990), and IPCC Scientific Assessment, *supra* note 1, at 18-23.

5. Chappellez et al., *supra* note 4.

6. *Id.*

7. See Office of Technology Assessment, U.S. Congress, *Changing by Degrees: Steps to Reduce Greenhouse Gases* OTA-O-482 (1991) [hereinafter "*Changing by Degrees*"]; Comm. on Sci., Eng'g and Public Pol'y, Nat'l Academy of Sci., *Policy Implications of Greenhouse Warming—Synthesis Panel* (1991).

8. Carbon Emissions Control Strategies: Case Studies in International Cooperation (W.U. Chandler ed., 1990).

However, greenhouse gas emissions will surely rise for developing nations still rapidly growing in population and building industrial bases. Developing countries are just beginning to supply electricity to their people, and only starting to use modern methods for cooking, heating, and transportation. Developing countries currently contribute one-third of the global greenhouse gas increase, but each year they are increasing their share.⁹ Presently, their emissions come mostly from land use changes and practices (e.g., carbon dioxide from tropical deforestation, and methane from rice cultivation and livestock). Energy projections made for developing countries must recognize that efficiency investments, while crucial to growth, will only decrease the amount of new power needed, but cannot eliminate it.

Figure 2 shows the great disparity in per-capita energy use in different parts of the world. Although a person in a developing country uses about one-fifteenth the amount of energy as the average U.S. citizen, even modest gains in per-capita and total economic growth in these countries translates into emissions that will collectively exceed those from the developed world within a few decades. Developing countries have been increasing their total energy use by approximately 6% per year, in contrast to a 1% increase in OECD countries. They also increased their *electrical* power consumption by an average of 8 percent per year between 1971 and 1987. Most of the added electrical capacity was provided by conventional power plants (which are high CO₂ emitters) for manufacturing and use in buildings. Further increases in electricity generation will be needed since many countries are continuing to electrify as refrigeration and air-conditioning are becoming more widely available, due partly to falling relative price. Without question, rapid population growth, in combination with economic growth, will continue to fuel increased demands for energy and land resources over the next few decades and cause major emissions increases (see Figure 3).

Some global warming seems inevitable, according to a strong consensus that has developed among those researchers closest to the issue. For example, the recent report from the Inter-Governmental Panel on Climate Change, produced by scientists of various disciplines from 25 countries, suggests that a 50%-80% reduction in *current* CO₂ emissions, as well as significant reductions in the other greenhouse gases, are required simply to keep the atmosphere at its already perturbed levels. That extraordinary level of reduction would require the world to rapidly wean itself from fossil fuels. The bulk of the reductions would fall on the *developed* world if the *developing* world is to increase greenhouse emissions, as it must, to feed population growth and raise standards of living. Ultimately, new technologies using solar and/or nuclear energy must replace fossil fuels if the world hopes to keep emissions from growing steeply response to the population doubling

9. Office of Pol'y, Planning and Evaluation, EPA, Policy Options for Stabilizing Global Climate, Draft Report to Congress ch. 9, 5-7 (Daniel A. Lashof and Dennis A. Tirpak eds., 1989).

again, coupled with the corresponding economic growth. In the interim, shifts from carbon-rich fuels (coal) to hydrogen-rich fuels (natural gas) will help.

The fact that most of the actions that can be taken to reduce greenhouse gases are helpful and desirable in other ways as well, should greatly facilitate policy making. Strategies that reduce greenhouse gases generally have ancillary environmental benefits including reducing acid rain, urban smog, groundwater contamination, and waste disposal. Developing and producing renewable energy technologies can strengthen trade markets and international competitiveness. In the United States, the time is especially ripe for a sustained increase in our currently modest efforts to mine the considerable resource of energy efficiency still possible in virtually all sectors of the economy. We must also enhance our ability to develop renewable energy resources. Worries over the negative impacts (on the Nation's trade balance) of increasing the level of oil imports, our national security interests connected with oil production in the Middle East, and the need for industrial innovation to restore U.S. competitiveness in world markets, are all addressed by accelerating the commercial development of nonfossil energy supplies and conservation technologies.

We can learn many lessons from the experience of past energy crises although policies implemented then were focussed primarily on cutting U.S. dependence on oil rather than on all fossil fuels. The energy intensity (energy consumed per unit of GNP produced) of the United States dropped significantly (by about one-third; see Figure 4) between 1973 and 1985. This widely touted flattening of energy consumption, while the GNP grew 35 percent, was mostly due to increases in energy efficiency (the rest came from changes in the make-up of the GNP). But for the most part, investments in energy efficiency occurred when fuel was expensive, when public policies supported such actions, and when the payback for such an investment could be realized quickly. The energy crises of the 1970s taught us that price is a powerful signal, and that there are also surrogates to price (e.g., regulations, taxes, standards, threat of shortages). Signals to affect the energy system of production and use, however, need to be consistent and reinforcing; it is destabilizing to let policy goals get very far away from price-equivalence (e.g., expensive synfuels production failed when fuel prices failed to rise). The pace of permanent change in energy use corresponds to turnover of capital equipment and therefore is measured in decades. Thus government policies need to track such a time schedule; *policies to mitigate global warming must be long-lived and sustained.*

B. Uncertainties

The major uncertainties that remain in the science of climate change are: 1) regional effects; 2) timing of effects; and 3) severity of effects. The

available General Circulation Models are not equipped to handle spatial detail and currently give conflicting pictures of climate change for less than continent-sized areas of the globe. Therefore, we cannot expect science to provide guidance for regional "adaptation" strategies (the domain of most public policies) in the near future.

Timing of decision-making and action regarding global warming is more of a policy issue than a scientific one because by the time any effects are discernible (another decade or two for a clear temperature signal), we will have committed ourselves to very substantial effects farther down the road. It could, therefore, be exceedingly helpful to policy makers if science could provide ways of detecting evidence of climate change that are sufficiently convincing to sustain political support. Finally, the potential severity of the greenhouse effect still weighs heavily upon the minds of thoughtful people. Whether the perturbations from human activities might lead to major unanticipated responses in regional or global climate remains an important question. There is ample evidence that the planet's climate has, in times past, shifted suddenly and rapidly. How certain are we that our actions might not trigger unexpected and unhappy consequences from seemingly minor instabilities? Despite our propensity to expect nature to inherently provide negative feedback to man's foibles, we should not count on it. For example, recent observations in the northern hemisphere of stratospheric ozone depletion show that the actual effect of CFCs and other gases is much worse than was predicted by our "best" models.

III. DEFINING AND ATTACKING THE PROBLEM

While a much more detailed understanding of the greenhouse effect provides interesting and critical questions for science, it is not the stuff of which most policy is made. The most interesting and critical question for policy is how governments can react, individually and collectively, to the fact that ultimately the amount of greenhouse gas ("GG") is related to a product of three terms:

$$\begin{aligned} \text{GG} &= (\text{GG}/\text{GNP}) \times (\text{GNP}/\text{P}) \times (\text{P}), \text{ where:} \\ \text{GG} &= \text{greenhouse gas} \\ \text{GNP} &= \text{gross national product (or, preferably, some better} \\ &\quad \text{measure of delivered goods, services, and amenities)} \\ \text{P} &= \text{number of people} \end{aligned}$$

Clearly, from one family, region, or nation to another the different GG factors vary a great deal. For example, in some countries P is large but GNP/P is small. Thus, in working out global strategies one clearly needs to take into account the local situations. If technology were perfect, one could follow a collection of strategies to reduce the first term (GG/GNP) close to zero,

theoretically enabling continued expansion of standard of living and/or population without serious GG consequences.

"GG/GNP" is the *technology/marketbasket* term. It has attracted most of our attention in thinking about how to cut the risk of climate change. It lies close to the realm of certainties, for we know that it can be reduced (over decades) by: 1) switching to greater dependence on methane and non-fossil fuels; 2) increasing efficiency of both energy and materials use; 3) halting deforestation by reforestation, and by changing agriculture; and 4) shifting our consumer marketbasket to one that is less energy intensive. Whether we can muster the political will to make these changes is an uncertainty that is highly dependent on strong leadership and technology development.

"GNP/P" is the *goods and services* term. It represents the per-capita standard of living. Governors and the governed balk, rightly, at any suggestion that this term be reduced. International efforts are aimed, again rightly, at increasing this term for as much of the global population as possible. The *population* growth term, "P", is fundamental and its future size is subject to great uncertainty. Over the past several decades, many Lesser Developed Countries ("LDCs") have made important progress in slowing birth rates. This has significantly improved maternal health as well as per-capita economic growth. But even in the face of this progress, the *world population now grows at an all-time record net rate of 10,000 people per hour*, or the population of Mexico every year, with more than 90 percent of that increase occurring in the LDCs (see Figure 5).

The reason for continuing high rates of population growth despite declining birth rates is population "momentum" or the continued growth of a population in absolute numbers for many decades even when couples have only as many children as are needed to replace themselves, or about 2-2.5 children per couple.¹⁰ Population momentum occurs when populations contain a large proportion of young people so that most people are in or entering the reproductive years. Then, the population will continue to grow even with replacement levels of fertility until the population becomes evenly distributed among all age groups. Africa illustrates this point (see figure 6). If birthrates in Africa fell until it attained replacement level fertility by 2030, its population would continue to increase until a stable population of about 1.4 billion is reached. If, however, replacement level is not attained until 2065, just 35 years later, Africa's population would rise to more than three times that number and level off at 4.4 billion. Thus, even a short delay in the date at which replacement rates are reached causes a dramatically different outcome in terms of total population.

On the other hand, sudden, very large decreases in fertility can also have undesirable consequences. China realized this after it instituted its one child

10. Population Reference Bureau, 1990 World Population Data Sheet (1990).

family policy. Strict adherence to the policy would reduce China's population from its current 1.1 billion to about 700 million people by 2050. However, at that time, about 40 percent of the population would be at least 65 years old, a proportion considerably larger than the working population would likely be willing to support.¹¹ This realization has led to some easing of the one child family policy in China.

Different standards of living and technological sophistication alter the impact of population increases in different countries on GG additions by as much as a factor of 10. A small population growth rate in a very affluent society like the United States can increase GG by as much or more than a large population growth rate in a very poor society—*unless* the affluent society's technological sophistication enables it to, for example, sustain its growth while avoiding fossil fuels.

One hopes and trusts that people in the LDCs will grow more wealthy and that GG additions per person will ultimately stabilize around the planet. Under those conditions, the imperfections of technology and population size are the sole drivers of changes in GG and associated risks. Thus, population stabilization—at home and abroad—is an absolutely essential ingredient in any comprehensive pursuit of protecting global climate.

IV. SHOULD THE UNITED STATES TAKE THE LEAD?

Before I make suggestions for what government could do in response to global warming, let me review some arguments as to why the United States should take the lead. Even though climate change is a "global" problem of sustainable development, leadership by the United States carries several benefits, including:

- Many of the policies to avert global warming *are of merit in themselves for economic, energy security, or environmental reasons*—the so called "no regrets" policies.
- Unilateral action, at least to the extent of "no regrets" initiatives, would indicate the seriousness with which the United States, the largest single contributor to greenhouse emissions, views the problem and would *help to generate a political environment conducive to full international participation*.

And reasons abound for the United States to foster reduced emissions abroad, including:

11. Thomas W. Merrick with PRB Staff, World Population in Transition, 42(2) Population Bulletin 42 (1988).

- Climate change is a global challenge. While the industrialization that has occurred over the past century is the main culprit for changes in greenhouse gas concentrations to date, industrialization over the next 25 years may have an even greater effect. The effects of climate change will be felt globally, and every country has an interest in the problems associated with the issue. Solutions must come from long-term participation and cooperation by all emitters, as the reductions by any one country—even the United States—will only make a small dent in total greenhouse gas emissions.
- Greenhouse gas emissions will certainly increase in the less developed countries and may rise in the Eastern Bloc and Russia. The less developed countries have higher growth rates for energy use, population, and GNP than industrialized countries. All of these indicators suggest that emissions of greenhouse gases will continue to rise significantly in these countries, just as they have been rising faster than anywhere else in the world. While the industrialized world is talking of stabilizing or even reducing greenhouse gas emissions, general consensus says that a similar goal for developing countries would be next to impossible to achieve.
- Improvements in GG/P may be cheaper and more effective in less developed countries, Eastern Europe, and Russia. Energy use in all of their economic sectors (industry, transportation, agriculture, and residential/commercial) is relatively inefficient when compared to industrialized countries. Therefore, efficiency gains may be greater and less expensive than in an OECD country. Also, much of the energy production and consumption infrastructure is yet to be built in developing countries; they can take advantage of new technologies that may be cost-effective for new construction, but expensive to retrofit.
- Many non-OECD countries lack sufficient internal capital to meet development needs. Large foreign debts coupled with the fact that state-of-the-art, efficient equipment generally has higher first costs have led many poorer countries to adopt policies that favor short-term over long-term benefits. Tropical deforestation is but one result of such policies. Lack of capital is often the motivating force behind unsustainable policies; the United States and other aid-giving countries and institutions could make capital conditionally available and help countries adopt longer term sustainable development policies.
- Infrastructure investment that is undertaken now will have a long-term effect on global warming. Many developing countries will dramatically increase their energy and other infrastructure systems

over the next twenty-five years. Decisions they make now will likely have important long-term effects. China, for example, has expressed great interest in exploiting its vast coal deposits. Decisions made within the next five to ten years about how coal will be used will impact China's share of greenhouse gas emissions for decades to come.

V. WHAT CAN WE DO?

The major options available or likely to be available for reducing CO₂ emissions in the near-term fall into three categories:

1. Increasing energy conversion efficiency in end-use technologies;
2. Changing patterns of energy consumption; and
3. Shifting energy supply away from high CO₂ emitting fuels.

Decisionmakers may choose from policies which comprise two interdependent components: the universe of possible technical (or in some cases, behavioral) changes and the policy instruments available (e.g., taxes, regulations, financial incentives) to require or encourage the technical change. There are a large number of technical options to pick from and many targets of opportunity within each economic sector (see Figure 7). For effective reduction in CO₂ emissions, these options must be pursued simultaneously through a variety of policy instruments implemented at various levels of government.

For decades, most people have assumed that a single technical option—fossil fuels—would supply human energy needs for another two or more centuries.¹² The rising specter of air pollution and climate change casts an ominous shadow over the already troubled fossil option. In other words, the fossil era may need to end in less than a century. This means that solar and nuclear power (fission and fusion) may be the energy sources for mankind that will be globally dominant, perhaps within fifty years. Unfortunately, for different reasons, neither nuclear nor solar power are attractive options in their present state.

Our only serious technological "bet-hedging" to fossil fuels has taken the form of work on harness nuclear power—fission and fusion. While the latter goal remains frustrating and elusive, the former now accounts for 20% of U.S. electricity, or about 8% of the U.S. total primary energy budget.¹³ Other non-fossil fuel (mostly hydroelectric and biomass) adds another 8%. Our present non-fossil energy budget is thus about 16%. But the nuclear fission

12. U.S. Dep't of Energy, *Annual Energy Outlook* (1990).

13. John H. Gibbons & Peter D. Blair, *U.S. Energy Transition: On Getting from Here to There*, *Physics Today*, July 1991, at 22, 28.

enterprise, for several reasons, is in deep trouble — so deep that the requirement to rescue it could well be more difficult than the original task of creating it. Additionally, our commitments to more effectively and broadly harnessing renewable energy sources have been comparatively minimal.

Developing and preserving attractive nuclear and renewable options is certainly possible. For example, photovoltaic conversion efficiency gains have resulted in half an order of magnitude reduction in installed costs.¹⁴ Additional gains are promising; wind turbines are now directly competitive in large areas; and aeroderivative turbines (driven with biomass fuels) and solar thermal technology are nearing direct economic competitiveness.¹⁵ Despite the gains to date, such options require—and merit—long-term commitments of research, development, and investment which, in turn, means we must move ahead on that odyssey now. One candidate goal for U.S. energy policy would be to reduce the carbon intensity of energy use (i.e., net carbon released to the atmosphere per unit of energy delivered) on average by perhaps 5 to 10 percent per decade for at least the next two decades.¹⁶ This goal could be achieved in part by energy conversion efficiency improvements and changing the fuel mix by replacing (and mixing) coal use with natural gas, as well as increasing the use of renewables and nuclear power. The number chosen for this goal is perhaps less important than the will to define a goal and vigorously pursue it. Increased use of natural gas and greater system efficiency would dominate the first decade or two, securing time to allow non-fossil alternative transportation fuels and sources for electric power generation to develop systematically and efficiently. Technologies that would flow from such a commitment could position the U.S. advantageously in terms of future economic competitiveness.

The continuing turmoil and instability in the Middle East has focussed attention once again on energy security concerns and, in particular, on strategies for reducing U.S. dependence on imported oil. Figure 8 sketches the possible impacts—in size and timing—of several aggressive import reduction strategies in supply, efficiency, and fuel shifting. The options include improving automotive fuel economy, increasing domestic produc-

14. Office of Technology Assessment, U.S. Congress, *Energy Technology Choices: Shaping Our Future* OTA-E-493, at 98 (1991).

15. *Id.* at 92-101.

16. OTA's analysis shows that a decrease of 5-10 percent per decade would be technically feasible but "tough." For *Changing by Degrees*, OTA developed a "moderate" emissions reduction scenario (which could be achieved at a net savings but would require substantial shifts in the economy) that could freeze carbon emissions until 2005 and also developed a "tough" scenario (technically possible but entailing costs in excess of projected fuel savings) that would reduce carbon emissions by 20 percent below expected levels by 2005. An emissions reduction of 5-10 percent per decade brackets the "tough" scenario. See *Changing by Degrees*, *supra* note 7.

strategies, we could consider the concept of "global bubbles" for least-cost greenhouse gas reduction. If it is less costly to trap CO₂ in the tropics than in the temperate zone, what could be done to take advantage of that fact?

- The government could set some measurable, sensible goals beyond CFC regulation, e.g., on energy consumption levels, or efficiency improvement levels, or gains in nonfossil supplies, for the near term (next 10 years) and the long term (next 50 years). This would define the path we will follow as a nation and could help us get past the doldrums of drifting along energy paths that lead to more dependence on imports from insecure sources, increased greenhouse emissions, and loss of global leadership in making a major energy transition in the coming decades.
- For more than a decade, U.S. policy on population growth and family planning assistance has been counter-productive to the goal of rapid achievement of population equilibrium. U.S. refusal to support the U.N. Population Office, policies that block research on contraception and discourage U.S. production of contraceptives, and policies to cut teen pregnancies need to be reexamined in light of the crucial role that population stabilization will play in reducing greenhouse gas emissions. Where appropriate, these policies should be reversed or revised. The unmet need for family planning services is tremendous in much of the world and represents a policy arena in which the United States could make an important contribution. In addition, research and education in contraception and demographics could be boosted substantially.
- Many traditional public policies that bias actions toward higher resource consumption need to be fixed. We still measure economic progress in terms of how fast raw materials flow through our economic system. We generally remain hooked on the notion that exponential expansion is a favored route to salvation, even though that paradigm is woefully out of date. We must develop a better appreciation of the need to think in terms of S-curves rather than exponentials (see Figure 9).

The United States is ideally positioned to lead a global effort to both minimize and adapt to climate change and help change exponentials into S-curves so that sustainable development can become a reality. We are technically sophisticated; we are open and innovative; and we presently use a major portion of the world's resources. Confronted by the harsh reality of resource finiteness, we should recognize and respond to the good news of

our enormous potential to provide the means for progress through thoughtful use of technology.

VI. SUMMARY

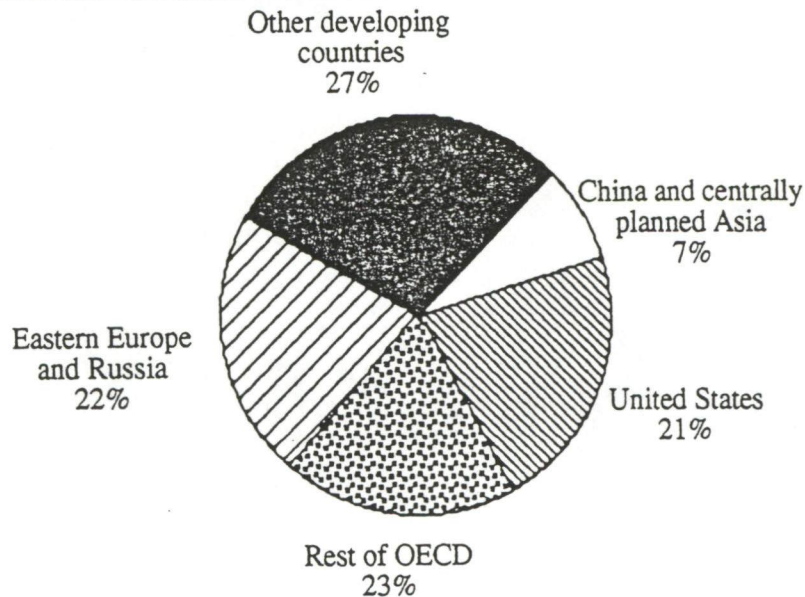
Public policy-making is frequently done in an environment of technical uncertainty. Other factors, such as public opinion, special interest pressures, and fear of alternatives generally dominate. The defense budget is full of enormous commitments to counter threats that are arguably much less certain—or damaging—than global climate change.

Public policy is a *process*, not an event. It is usually iterative and adaptive, making "uncertainty" less important than it might be otherwise.

Policy decision-making with respect to global climate must compete with other priorities. The fact that effective climate policies must include market interventions, lifestyle changes, long time commitments, and widespread participation from local and international bodies doesn't make the challenge any easier. Fortunately, the vast bulk of actions that can be taken to thwart global climate change are also helpful in achieving other goals such as sustainable development, environmental quality, the *inevitable* transition beyond fossil fuels for energy supply, and international economic and military security.



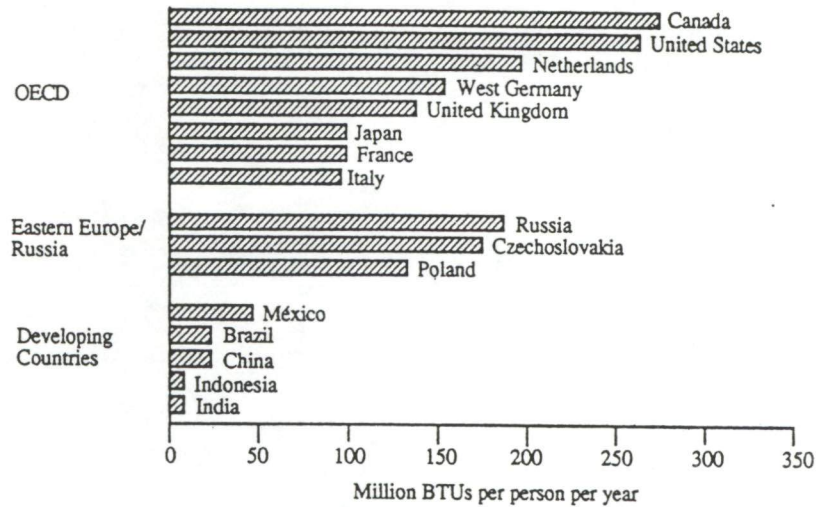
Figure 1. Greenhouse Gas Emissions in 1985 by Region



NOTE: Figure shows the share of greenhouse gas emissions by region, weighted by their contribution to radiative forcing between 1980 and 1990. It includes all greenhouse gases and CO₂ from deforestation and fossil fuel use. Estimates for CO₂ emissions from deforestation range from less than 10 to about 30 percent to total CO₂. If the upper range proves to be correct, developing countries' shares would be larger.

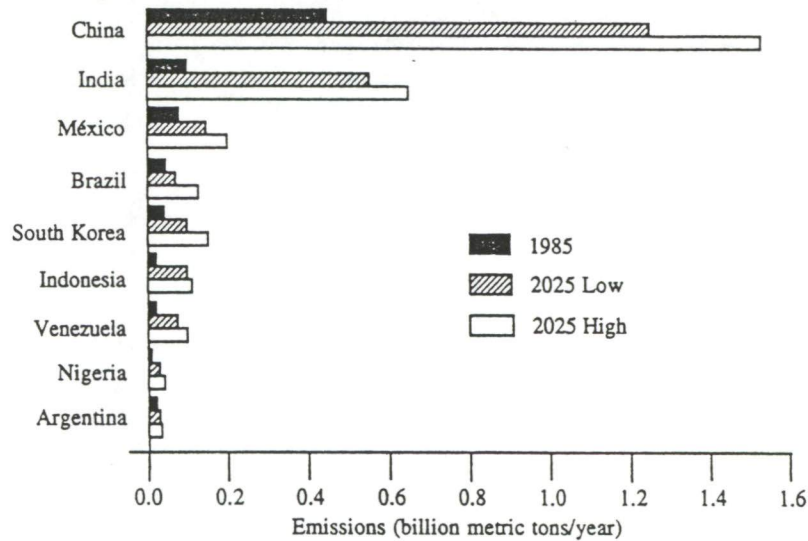
SOURCE: Adapted from U.S. Environmental Protection Agency, 1990.

Figure 2. Per Capita Energy Consumption



SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

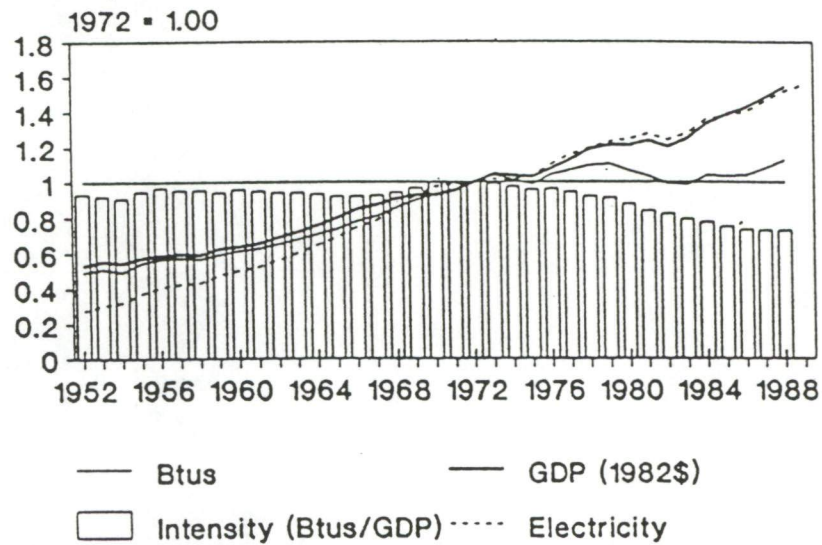
Figure 3. Projected CO₂ Emissions in Selected Developing Countries (including use of biomass).



CO₂ emissions in developing countries are projected to rise significantly by 2025, as shown here for four countries in Asia, four in Latin America, and one in Africa. The "High" scenario assumed no constraints on economic and energy growth. The "Low" scenario assumed that policies are enacted to improve energy efficiency and change the fuel mix.

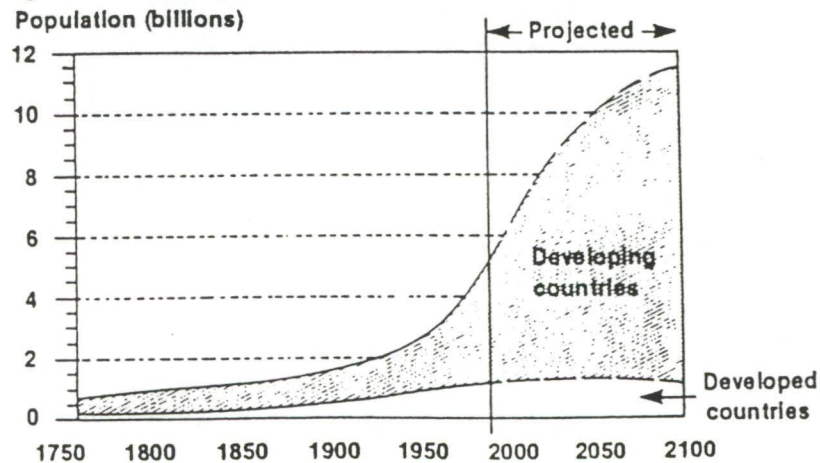
SOURCE: J. Sathaye and A. Ketoff, *CO₂ Emissions From Major Developing Countries: Better Understanding the Role of Energy in the Long Term*, Interim Report, LBL-29507 (Berkeley, CA: Lawrence Livermore Laboratory, August 1990).

Figure 4. Index of U.S. GDP, Energy Intensity, Energy Use, and Electricity Use

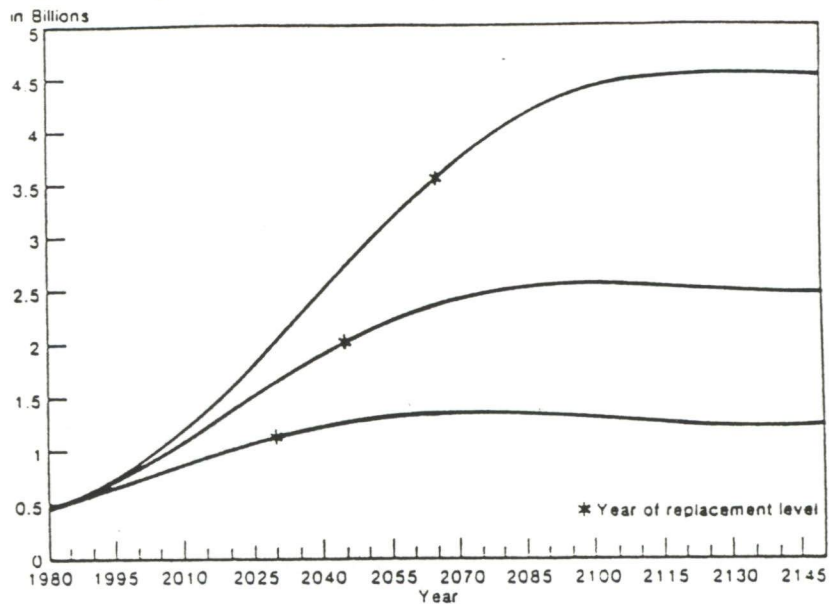


SOURCE: U.S. Energy Information Administration, Monthly Energy Review, March 1991, DOE/EIA-0035(91-03) (Washington DC: U.S. Government Printing Office, Mar. 28, 1991).

Figure 5. World Population Growth, 1750-2100



SOURCE: Thomas W. Merrick with PRB Staff "World Population in Transition," *Population Bulletin*, Volume 41, No. 2, Pg. 4, January 1988 Reprint, update by Carl Haub, Population Reference Bureau, 1991.

Figure 6. Population Momentum in Africa

When a country reaches replacement-level fertility, it might be expected that the population growth rate would immediately reach zero. However, if the decrease to replacement is comparatively rapid, the large proportion of younger persons in the population will cause growth to continue for some time. In the above UN projections for Africa, note that in all three variants the population continues to grow after replacement is reached.

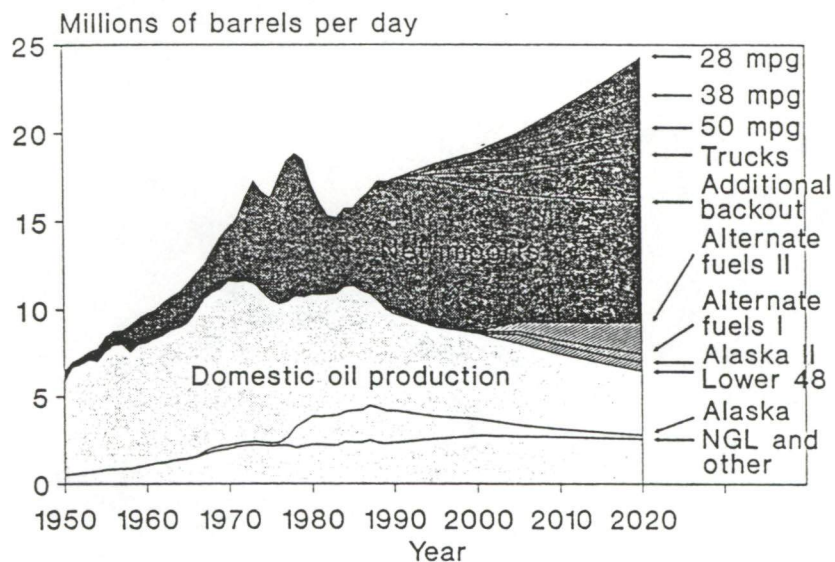
SOURCE: Carl Haub, "Understanding Population Projections," *Population Bulletin*, Vol. 42, No. 4, p. 28, December 1987.

Figure 7. Policy Instruments To Reduce CO₂

	Taxes		Financial incentives			Marketable permits		Regulations		RD & D		Information	
	Energy tax	Carbon tax	Purchase tax	Tax incentive	Low cost loans	Direct payments	Permits	Performance standards	Building codes	R&D	Demonstration	Labels/rating	Audits
Commercial buildings													
Thermal integrity	✓	✓	—	✓	✓	✓	—	—	✓	✓	✓	✓	✓
Appliance/lighting	✓	✓	✓	—	—	—	—	—	—	—	—	—	✓
Usage patterns	✓	✓	—	✓	—	—	—	—	—	—	—	—	✓
Residential buildings													
Thermal integrity	✓	✓	—	✓	✓	✓	—	—	✓	✓	✓	✓	✓
Appliance/lighting	✓	✓	✓	✓	✓	—	—	—	—	—	—	—	✓
Usage patterns	✓	✓	—	—	—	—	—	—	—	—	—	—	✓
Transportation													
Small car/truck efficiency ..	✓	✓	✓	✓	✓	✓	—	✓	—	✓	✓	✓	—
Alternate fuels	—	✓	—	✓	✓	—	—	✓	✓	✓	✓	—	—
Off highway ^a	✓	✓	—	—	—	—	—	—	—	—	—	—	—
Vehicle miles traveled	✓	✓	—	—	—	—	—	—	—	—	—	—	—
Manufacturing													
Efficiency	✓	✓	—	—	—	—	✓	—	✓	✓	—	—	✓
Recycling	✓	✓	—	—	—	—	—	—	—	—	—	—	—
Energy supply													
High to low carbon fuels ..	—	✓	—	—	—	—	✓	—	—	✓	✓	—	—
Renewable	✓	✓	—	✓	—	—	✓	—	✓	✓	—	—	—
Cogeneration	✓	✓	—	✓	—	—	✓	—	—	—	—	—	✓
Efficiency, existing plants ..	✓	✓	—	—	—	—	✓	—	—	—	—	—	—
Forests													
Recycling	—	✓	—	✓	—	✓	—	✓	—	—	—	✓	—
Increased productivity	—	✓	—	✓	—	✓	—	—	—	—	—	—	—
Afforestation	—	✓	—	✓	—	✓	—	—	—	✓	—	—	—
Biomass	✓	✓	—	✓	—	—	—	—	✓	—	—	—	—
Food													
Farm inputs	—	✓	—	—	—	✓	—	✓	—	—	✓	✓	✓
Farm operation & efficiency	—	✓	—	✓	—	—	—	✓	—	✓	—	—	—
Food processing	—	✓	—	—	—	—	—	—	—	—	—	—	✓
Heavy equipment, aircraft.													

SOURCE: Office of Technology Assessment, 1991.
Report on Changing by Degrees: Steps to Reduce Greenhouse Gases.

Figure 8(1). U.S. Oil Supply and Demand Futures
Baseline Porjection: Current Trends in Domestic Oil Production,
Net Imports, and 1989 New Car Fuel Economy



SOURCE: Office of Technology Assessment 1991.

Figure 8(2). U.S. Oil Supply and Demand Futures
Improved Supply, Mileage, and Backout

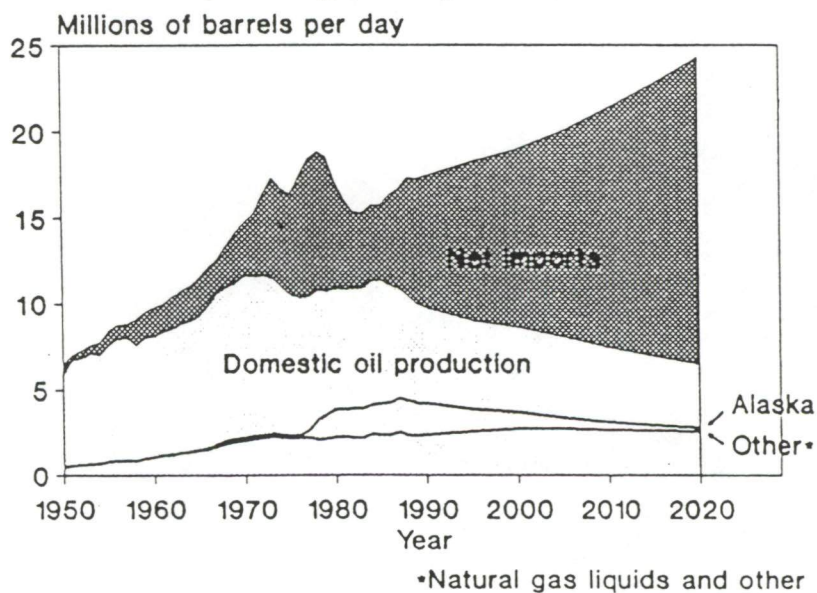
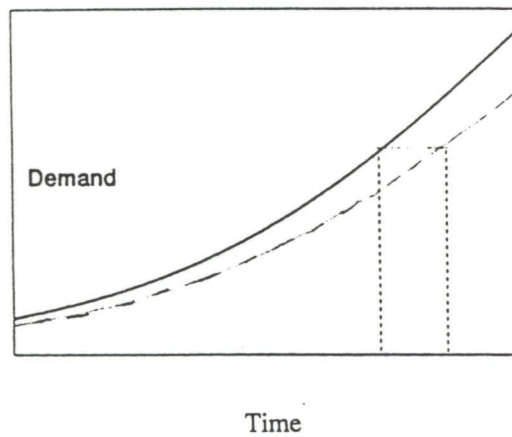


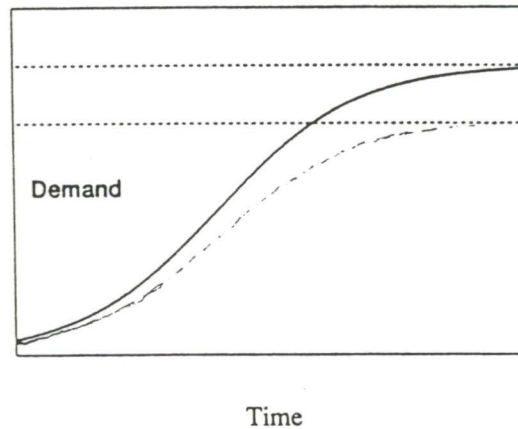
Figure 9
Alternative Growth Models

Exponential Model



The change in efficiency of energy use translates to only delaying for a few years the inevitable growth of demand.

Sustainable Model



The change in efficiency of energy use translates to a permanent lowering of demand and, therefore, pollution for a given level of economic activity.

Severe Ozone Depletion Likely Again This Year

Large, Deep Hole Opens Over Antarctica

By William Booth
Washington Post Staff Writer

The seasonal ozone hole over Antarctica is back and looks as if it may be as big and bad as the deep hole that formed in 1987, when record amounts of radiation-shielding ozone were destroyed over the frozen continent, according to scientists monitoring the depletion by satellite.

Last year, scientists were surprised to find, the hole was shallow and ozone depletion was relatively slight. But this year, ozone depletion over Antarctica is closely following the events of 1987, when ozone plunged on Oct. 5 to the lowest levels ever recorded, with about 50 percent of the Antarctic ozone layer destroyed by the chemical interaction of sunlight, ice clouds and chlorine-containing chlorofluorocarbons, the so-called CFCs used in plastic foams, air conditioners and solvents.

"It looks as if 1989 could be as bad as 1987," said Robert Watson, chief of NASA's atmospheric chemistry program.

This year's hole covers some 10 million square miles. And ozone is decreasing about 1.5 percent per day, according to Arlin Krueger at the National Aeronautics and Space Administration's Goddard Space Flight Center in Greenbelt, who is monitoring the ozone hole with instruments mounted onboard a NASA NIMBUS-7 satellite. "It's a horse race between 1987 and 1989," Krueger said.

Ozone is a natural form of oxygen that in the upper atmosphere shields the Earth from the sun's cancer-causing ultraviolet radiation. A one percent decrease in ozone results in 2 percent more harmful radiation reaching Earth's surface, an increase that raises skin cancer rates in white people from 3 to 5 percent.

The discovery in 1985 that a large hole in the ozone layer formed over Antarctica surprised scientists and confirmed fears that man-made pollutants are disrupting the delicate chemistry of the atmosphere. In each succeeding year the hole returned, generally growing wider and more severe.

In 1988, however, it failed to appear. But scientists predicted that it would return with a vengeance when weather over Antarctica resembled that of 1987.

The ozone hole is created in the months of the austral spring, which is occurring now, when sunlight returns to the South Pole. The stage is set during the dark, cold Antarctic winter when atmospheric temperatures plummet to 112 below zero Fahrenheit, forming ice clouds in the lower stratosphere at an altitude of 6 to 12 miles. When the sunlight returns, the light acts with chlorine from the CFCs to attack ozone.

Scientists think that the ozone hole will probably not get much worse in coming years. Most of the ozone that could be destroyed by chlorine and ice clouds—90 percent of the ozone in the 6- to 12-mile-high layer—is destroyed during the worst years. The width of the hole will also probably not get much bigger, since the ozone is destroyed within the polar vortex, a mass of rapidly rotating air that is constrained by surrounding weather systems.

Scientists have learned that the worst ozone losses are to be expected when the polar vortex is unusu-

ally tight and when temperatures are especially cold, which allow more ice clouds to form. These conditions vary from year to year, based on the planetary waves of air that affect not only weather in Antarctica but the jet stream and storm fronts around the world, according to Rolando Garcia, an atmospheric scientist at the National Center for Atmospheric Research in Boulder, Colo.

It is not known what effect this annual ozone destruction is having on global ozone levels. Atmospheric scientists have watched ozone levels dropping a few percent over North America during the winter, but ozone levels appear to rebound in the summer. Finding a clear pattern of global ozone depletion has been difficult, given the variability from year to year and season to season.

The United States and some 30 other countries agreed that starting in 1990 they would freeze CFC production at 1986 levels. In 1992, there would be 20 percent reduc-

*contact.
system of
complex systems which
regulate the temperature of
the earth. One element is*

the amount of GHG (CO₂, methane, nitrous oxide, etc). Increases in GHG in atmosphere will cause increases in warming. But this is unknown

Washington Post, October 6, 1989, p. A18

however, the amount, timing, ... and natural mitigating

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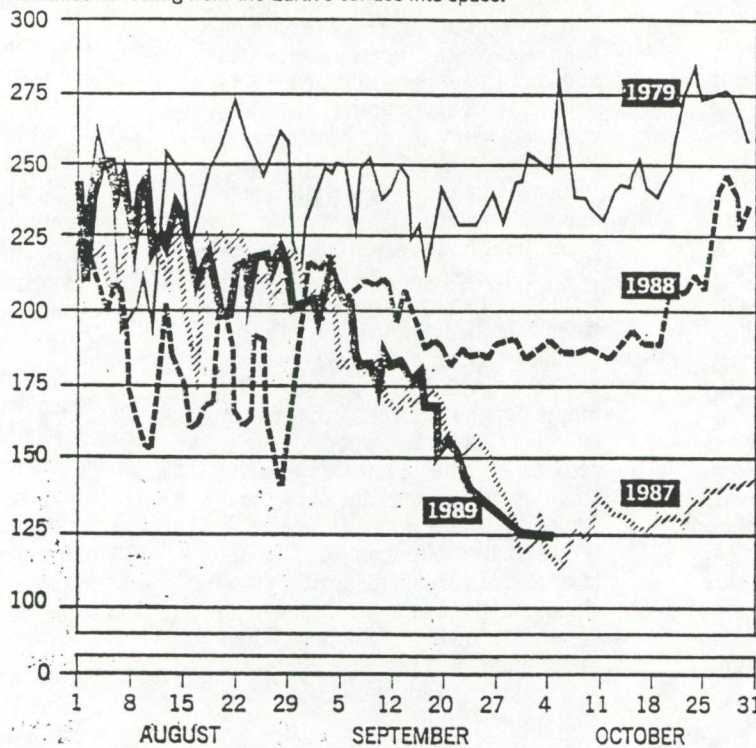
factors of any climate change due to increases in GHG are unknown.

*return to low level
large!*

*equator
to the tropics
to the equator*

THE OZONE HOLE: HOW DEEP?

Concentration of ozone, as measured in Dobson units, a gauge of ultraviolet radiation reflecting from the Earth's surface into space.



SOURCE: NASA, Goddard Space Flight Center

THE WASHINGTON POST

tion and by 1998, they would reduce CFCs by half. In the past year, there have been serious discussions of a complete phaseout of CFCs by the year 2000.

"If you want to repair damage in

Antarctica, it will require the complete cutoff of all these long-lived chlorine compounds. . . . And even if you do, the Antarctic will not completely recover until the year 2075," said NASA's Watson.

Greenhouse Policy and Climate Uncertainty¹

Robert M. White
National Academy of Engineering
Washington, D.C.

1. Introduction

The global climate warming issue has now become an international scientific and political happening. It is difficult today to pick up a newspaper or view television without encountering a story or an interview on the subject of global climate warming, now familiarly embraced in the vernacular under the rubric of the "greenhouse effect."

No ideological or political boundary separates the calls to action. From General Secretary Gorbachev of the USSR and Prime Minister Thatcher of the United Kingdom, to prime ministers Mulroney of Canada and Brundtland of Norway, calls for international action resound.

In March 1989, representatives of 23 nations, including many heads of state, gathered in the Hague at the urging of President Mitterand of France and other European leaders and recommended that the United Nations be given supranational authority to regulate global activities regarded as the causes of the greenhouse problem.

Not to be outdone, in the bidding for international leadership on the issue, the United States through the pronouncements and actions of President Bush and Secretary of State Baker, is urging action on many international environmental fronts. The Congress is no less active. A half-dozen new pieces of climate legislation are being considered.

Nor have the academies of sciences and engineering been silent. Quite the contrary, we have been vocal and forward on the issue. For over a decade these academies have conducted studies on global climate change, making assessments that have buttressed the legitimacy of the concerns expressed by our political representatives. Most recently, as a result of legislation in the last Congress, the academies have embarked on new studies of climate and the underlying energy issues. In a move to place its views before the new Bush administration, the academies have issued a "white paper" on global change with broad policy recommendations.

The scientific community has identified an issue

that lends itself to support by leaders everywhere—the mission of saving the inhabitability of the planet. It is a mission that now ranks in importance and political panache with saving the planet from nuclear destruction. Like the mission to save the planet from nuclear destruction, it raises politically divisive concerns such as those between the technologically advanced and developing nations.

How robust is the scientific basis for this grand outpouring of world concern? What are the policy directions that make sense in the light of the certainties and uncertainties in our knowledge? What are the policy problems that need resolution given the likely social and economic costs of action or the consequences of inaction?

My colleagues Bert Bolin and Steve Schneider have ably described the state of our knowledge of the forcing functions (those activities that cause the changes in the composition of the atmosphere) and the atmosphere's response to these changes, or the ways in which the earth's climate is projected to be altered as a result of such compositional changes.

As scientists and engineers we often eschew responsibility for policy decisions because they are laden with judgments balancing known facts, uncertain interpretation, and social and economic costs more properly made in the political arena. Unfortunately, we cannot totally escape that responsibility because those political judgments are shaped by the way we present our conclusions to those who have to formulate policy. We have it in our power to trigger political action unwarranted by data or scientific findings. Conversely, we can so allay real concerns that inaction results when action is desirable.

Whether we in the scientific community like it or not, we have awakened the political beast and those communities of scholars who revel in the challenge of public policy formulation and debate. The ability of the scientific community to influence actions recedes as groups are increasingly locked into policy positions.

The fact is that we grapple with an issue that is noisy in many dimensions. The climate record is noisy, as are the results of mathematical computations. Knowledge of likely effects is speculative and the policy debate is informed with contradictory data and interpretations. Can we isolate the signals from

¹ Speech given at the Annual Meeting of the National Academy of Science, April 1989, Washington, D.C.
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the noise in all significant dimensions? That is our task. That is our obligation.

2. The knowledge base

Any soundly based policy actions must emerge from our knowledge of causes and effects and the uncertainties in that knowledge weighed against the risks, consequences, and costs of action. We know much about the former and little about the latter. Our knowledge of the likely causes is well documented. Our knowledge of the climate system response to these causes is extensive but fraught with uncertainty. Our knowledge of the social and economic consequences is weak and speculative.

The concentrations of greenhouse gases have been accurately measured for over a quarter of a century in many parts of the world and they reveal inexorable increases. The CO₂ record of observations taken at the National Oceanic and Atmospheric Administration (NOAA) Mauna Loa Observatory in Hawaii is arguably the most important geophysical record of this century. We know much about causes of changing atmosphere composition—the burning of fossil fuels, the industrial production of CFCs, and the agricultural production of nitrous oxides. We know less about others, the sources of the increases in methane, for example.

We can assess the climate system response in two ways. We can simulate the system with mathematical models and examine the range of responses to the known and projected forcing functions. We can also examine the actual climatic record. Mathematical models developed by many groups in the United States and abroad yield the basic projections on which our concerns are principally based. As Steve Schneider has described, they yield projections of global average surface temperature increases ranging from 2°–5°C since the turn of the century with greater increases in polar regions for a doubling of greenhouse gas concentrations sometime after the middle of the next century. The models do not portray regional and local effects well.

The models are approximations to the real world and their simulation of natural physical processes is well known to generate considerable uncertainties in the results, especially as they reproduce critical feedback processes.

Our confidence in the mathematical models is based on their ability to reproduce the seasonal variations of climate, the general reasonableness of the manner in which climatic factors are portrayed, and the consistency of results. Some question whether our confidence in the output of these models is well

placed given the uncertainties. Yet there is a preponderance of views among those who have worked the problem, that a large measure of confidence is warranted but that the uncertainties are troubling and need much attention.

What about the system response as deduced from the observational record? Does the observational system response support the theoretical response calculations and does the response evidence any systematic changes in climate.

It is well documented that climate is observed to fluctuate on all time and space scales. Drought and wet climates have been the perennial scourge of mankind. For the past century, during which humanity's introduction of greenhouse gases into the atmosphere has increased greatly, the instrumental record is equivocal. It is a noisy record affected by the sampling of the global atmosphere through a network of observations established for other reasons—principally weather forecasting. It is affected by the accuracy and representativeness of the observations. It is also affected by external factors such as urban growth, which produces real, but climatically artificial, local and regional temperature readings. Such data reveal that global average surface temperatures have had a roller coaster history. During the period 1900–40, temperatures increased, cooled during the 1940–65 period, and have increased again from 1965–88.

In over-land areas of the United States where we have the richest and probably most reliable data, there has been no detectable increase in temperature since the turn of the century. This could be a sampling problem. The United States may be unrepresentative of the global average temperature. The data pool also presents sampling difficulties for the globe. Over many parts of the less-developed world, the tropics, and the oceans, data are of poor quality, sparse, and may be unrepresentative. The best analyses of such data reveal a net increase of about 0.5°C over the past century. This net temperature change is consistent with the lower end of the projections from the mathematical models but could also be a natural phenomenon. Recent findings of the effects of urban growth suggest that this increase may be an overestimate.

But, there are puzzling features of the observed global climate record. For example, temperature increases, largely attributable to the records from tropical and ocean areas, are not consistent with model projections that the largest temperature increases should occur in polar regions.

Is it too early to extract the signal from the noise of the record? Many would argue yes. Others would argue that a century during which the CO₂ content

of the atmosphere has increased some 25% should have revealed a clear signal by now. Those who argue that the global temperatures of the past five years, the warmest in the instrumental record, signal the onset of the greenhouse climate could have come to an analogous conclusion during the drought of the thirties. However, they would have encountered the systematic cooling during the midcentury years, which incidentally gave rise at that time to predictions by some of a new ice age. In my view, the jury is out.

We are confronted with an inverted pyramid of knowledge; a huge and growing mass of proposals for policy action is balanced upon a handful of real facts. Data on likely causes are robust, though future emission projections vary widely. Projections based upon mathematical approximations of atmospheric and oceanic conditions are credible but uncertain. Evidence from the climatic data is equivocal.

Policy actions must reflect the risk of serious social and economic consequences of climatic change. They could be severe but are in the realm of informed speculation. Most of our information is analogue or scenario based. We know a great deal about the effect of weather and climate on agriculture, water resources, forestry, and other economic functions from extensive study of the effects of droughts or heat waves or severe winters. We know the devastating ramifications for economic and social conditions—witness the effects of the droughts of the Sahel in Africa in recent years, and the drought of last summer on the Midwest. Such analogue information is sound and can be extrapolated. It is the scenario based information that is speculative. By "scenario" I refer to the "what if" studies. These studies are useful if they are considered for what they do: provide a range of possibilities. But frequently they are interpreted as forecasts. It is here that the apocalyptic nature of outcomes emerges and penetrates the political consciousness through news stories about imminent global catastrophe.

If our model projections are correct we can say some interesting things. For example, we can expect an increase in sea level. Recent observations seem consistent with this projection. If sea level rises we can be reasonably certain that coastal areas will be affected with saline intrusions and increased coastal erosion. On the other hand, we cannot say much about local and regional effects of temperature and precipitation changes and their specific local effects on agriculture, water resource, and ecological and economic systems. There would be effects on agriculture, but we are not quite sure what they would be and whether they might be acceptable or even beneficial. Increased carbon dioxide content of the

atmosphere favors increased photosynthesis and crop growth. There would be effects on storm tracks, probably moving them toward the poles, a result of the reduced pole-to-equator temperature gradients. Precipitation belts would likely migrate to more polar latitudes with consequences for agriculture and water resources in the Southwest. There would be effects on natural ecosystems and their resiliency would depend upon the rate of change of climatic temperatures and precipitation. But it is impossible to be specific beyond such generalization.

3. Policy principles

And so we find ourselves in a classic dilemma of policy formulation—possibly severe but unknown levels of risk of undesirable consequences of climatic change in the face of great uncertainty about causes, costs and consequences. The dilemma is compounded because the consequences will be visited on future generations unevenly through the redistribution of global climatic resources. Policy principles in such a situation would suggest (1) investment in improving the information base to reduce uncertainties so that policy actions could be based on improved understanding; and (2) adoption of policies—insurance policies, if you wish—that address causes and predicted consequences in such a way that future options are not foreclosed if projections turn out to be incorrect, and which may be desirable for other environmental and economic reasons.

The policy framework would have to recognize the inherent international nature of the issue, its potential divisiveness as between developed and developing nations, the considerable social and economic costs attendant on significant actions, and the absence of institutions on the international scene in a position to formulate and implement necessary policies. Let us examine the policy issues and see to what conclusions they lead.

Improving the information base to reduce uncertainties in our data, in our projections, and in the understanding of consequences would seem to be a sine qua non. These actions are not costly, do not preclude future policy options, and can sharpen policy decisions. This means investment in improved understanding of physical processes so that they can be modeled more accurately, intensified examination of climate data bases, improved assessments of projected emission rates of greenhouse gases, and improved space and ground based monitoring systems. Programs to achieve some of these objectives have been formulated in President Bush's proposed Global Change Initiative and it is expected that strong sup-

port will be forthcoming from Congress. The World Climate Research Program of the World Meteorological Organization and the International Geosphere-Biosphere Program of the International Council of Scientific Unions are underway and receiving widespread international support. The first international intergovernmental forum has been established to examine the full range of climate problems, including the possibilities for national and international responses under the aegis of the World Meteorological Organization and the United Nations Environmental Program.

The really controversial policy issues surround the possibilities for intervention in the climate change process. Can we arrest or slow the processes that increase the concentrations of greenhouse gases? The answer is yes. But we have no grasp on the social and economic ramifications of intervention. We have a reasonable grip on the sources and amounts of emissions and we have a reasonable grasp on the reductions in emissions that would be necessary to constrain the global temperature increase.

The possible courses of policy action are in a sense obvious, and they relate largely to the production, distribution, and end use of energy. If fossil fuels use is the principal culprit in the CO₂ buildup, policies should be directed to the use of the least polluting fossil fuels, the reduction in use of all fossil fuels, and development and use of nonfossil energy sources. In practical terms, we must shift from coal to oil to natural gas, undertake major efforts to increase energy efficiency, and develop and deploy passively safe and publicly acceptable nuclear power as well as other nonfossil energy sources.

Energy policy actions have great leverage because they also address a broad set of environmental issues. Most environmental problems are interrelated through their physics, chemistry, and biology and have common causes. Thus certain policies will have multiple environmental leverage. For example, the problems of acid rain, global warming, and local air pollution are largely energy-based environmental problems generated by the use of fossil fuels.

Energy policies that move the national energy system toward energy efficiency also serve many other national objectives: the lessening of dependence on foreign sources of oil, thus achieving a greater measure of energy independence; reduction of the energy component of the trade deficit; and increasing industrial competitiveness to the extent that energy efficiency can lower costs of production.

It is in the implementation of policies that the issues are joined. It is here that we finally address the economic and social consequences and the hard questions of who pays, who is affected, at what costs, and

with what societal disruptions. In the case of the greenhouse problem, we are forced to address the fundamental activities of society that relate to economic growth, the production of food, and the sources of energy. We are talking about changing the global energy and agricultural systems, to say nothing of the implications for global population growth.

Recently the Environmental Protection Agency (EPA) issued a most useful report in response to a congressional request for options for stabilizing the greenhouse gas concentrations in the atmosphere. A sampling of some of their proposals indicates the pervasiveness of the measures that need to be considered (the social and economic costs were not assessed): raise average gasoline mileage of new cars to 50 mpg—a doubling of present fleet mileage; impose fuel emission fees to reflect full social costs of about \$30/ton of coal and \$3.00/barrel of oil; launch major reforestation programs; and phase out CFCs.

Ultimately if the climate warming is to be prevented other forms of intervention in the world energy structure will be required. The logical direction for policy is to encourage the development and use of nonfossil energy sources. Science, engineering, and technology offer the promise of alternative energy sources, such as nuclear energy. Today the problems of public acceptability of nuclear power are severe. Concerns about nuclear power plant safety and the disposal of radioactive wastes dominate any concerns about the greenhouse problem. But research on passively safe reactors has been underway for years and it appears that commercially useful passively safe reactors are on the horizon.

The world must face up to the fact that within the bounds of current technological knowledge there may be no way out of the greenhouse problem without some recourse to the nuclear option. Other forms of nonfossil energy have become more promising as the years have passed. There is new promise in photovoltaics, with efficiency increases up to 30% in recent experiments. Biomass as a source of energy can be further emphasized. Policy options aimed at other causes of increasing greenhouse gas concentrations, such as the release of CFCs and deforestation, present their own politically divisive features. The tropical deforestation issue confronts us with the conflict between economic development and environmental protection in a direct way. Mankind has traditionally used the environment for economic growth and mankind's track record is poor. We in the United States have polluted our rivers, destroyed our wildlife, and replaced our forests with farms. We continue to overuse the last of our natural rain forests in the northwest for economic gain.

Now, recognizing the global consequences of the destruction of forests, we call upon other nations emerging from economic penury to arrest their development to protect the global environment. Is it any wonder that countries like Brazil or India or China perceive our proposals as hypocritical? Nobody has yet advanced a workable proposal, but many have been suggested. The swap of foreign debt for the preservation of tropical forests is an interesting proposal, but who will pay?

The issue of economic development and environmental protection arose in March 1989 in London at a conference called by Prime Minister Thatcher to phase out the production of CFCs. China, India, and other nations refused to submerge their need for CFCs and associated economic development in the global interest in environmental protection. If we are to be serious about international action, a global bargain will be necessary. But what kind of global bargain makes sense?

The divisive nature of the issue is also evident in the suggestion that we shift from fossil fuels such as coal to other kinds of fossil fuels such as oil and gas. But what of countries like China whose energy future is dependent on their large supplies of coal? The recent United Nations report, *Our Common Future* (1987), on economic development and the environment carried the message on the necessary global bargain clearly. Global environmental protection will only be resolved in the context of the economic development of less prosperous nations.

If we cannot arrest the processes of climate change then we will need to adapt to them. Adaptation policies need to be those that will foreclose least on future options. It seems wise that we introduce into our long range planning for our coastal areas the possibility of a sea level rise of the order of one-half meter over the next fifty years. Water resource planning must take into account the possibility that the climatic regimes of the future will be different and water resource infrastructures and management techniques will have to incorporate a flexibility not inherent in present planning. Planning for agricultural adjustment will need to take advantage of genetic engineering of plants and animals so that they can be more tolerant of environmental extremes.

Perhaps, however, the policy approaches to the climate warming issue which we seem to be taking are inappropriate to the problem. We are dealing with intergenerational matters where the conse-

quences of action taken by one generation are visited on another. Nor do we have guidelines for developing policies in the face of uncertainties of the scope involved in the climate problem. We address a problem in which knowledge and information are being continually refreshed by new findings and interpretations, and our assessment of risk and uncertainties are continually changing.

Robert Lind of Cornell University has suggested that we should not think in terms of choosing a static "best policy," but think in terms of strategies and sets of options. We should think in terms of a continuous policy process where we periodically reassess our responses in light of new findings and information. In such a policy approach, the design of research and information gathering projections must become an integral part of the policy process.

This view suggests that what we might do is establish continuing mechanisms and processes that periodically, say every three or five years, would be charged with performing an evaluation of the state of our knowledge about the science and implications of various policy options. Through this process, recommendations for changes in policies and in areas of scientific investigation would emerge. In this way, by a series of incremental policy steps, policy would be kept in lockstep with knowledge.

In the end, scientists and engineers must accept the responsibility for having triggered a worldwide movement that may result in policies of a pervasive nature affecting all humanity. Each of us is responsible for representing the extent of our knowledge and accompanying uncertainties so that there is a balance between optimism and catastrophism. Each of us can make headlines any day by projecting or intimating that mankind faces a global catastrophe.

We have sufficient experience to know that controversy makes headlines and those not as familiar with the scientific uncertainties take us at our word. Our pronouncements will be excerpted to suit the needs of an exciting story. We need to make sure that the uncertainties in our knowledge are well understood and that there are risks in action as well as in inaction. We need to be true to ourselves and our work as well as to the humanity we serve.

Let us not confuse selected observations with representative samples. Let us not confuse scenarios with predictions. Let us not confuse short-term fluctuations with long-term implications. Above all, let us not confuse our friends and colleagues who must make the political decisions that will ensure the inhabitability of this planet.

ENVIRONMENT

CFC DISPLACEMENT REVISITED

Large-scale chlorofluorocarbon users and producers find that developing substitutes is just the beginning

When the Montreal Protocol was ratified last year, government and industry recognized the decision to stop using chlorofluorocarbons as a solid step toward saving the Earth's protective ozone layer. But now, large-scale users and producers of CFCs are realizing that the cost of phasing out the compounds for more-benign substitutes will be astronomical. Their estimations include not only research and development expenses but also the cost of redesigning and converting production systems. And while all CFC

and that's the key" to understanding the economic impact of CFC substitution, says Bernard Sukornick, director of fluorocarbon research at Allied-Signal's engineered materials sector. Automakers will have to develop new systems compatible with hydrofluorocarbon (HFC-134a), the substitute coolant they will likely phase in between 1993 and 1994. That will "probably cost in the hundreds of millions of dollars," says Sukornick. And HFC-134a is a less-efficient heat exchanger, so more of the compound will be needed than

the three pounds of CFC-12 per car used now, along with a larger compressor and a new lubricant, say spokespersons with General Motors, Chrysler, and Ford Motor. Once the new system and lubricant are developed, already-crowded engine compartments will have to be rearranged.

In Detroit, such rearranging is never minor nor inexpensive. Finding space to fit larger systems will be "quite a

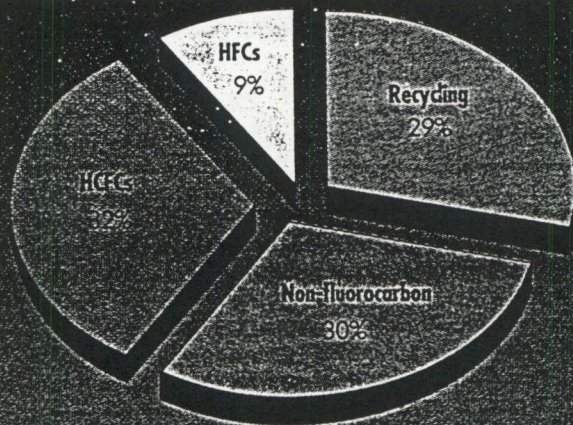
output to 50% of 1986 levels. Demand for a shrinking amount of CFC-12 is already starting to increase (CW, April 26, p. 14).

To help conserve the precious compound, GM announced earlier this month that its 10,000 dealers will be required to use a new machine to recover, purify, and recycle used refrigerant beginning with the 1991 model year. And General Electric's Appliance Division plans to furnish its repair personnel with equipment capable of recovering CFC-11 from its home refrigerators, says spokeswoman Bonnie Otto.

Producers are proceeding with caution in their plans to expand capacity for CFC alternatives. For example, Vogelsberg says Du Pont and ICI plan to produce about one million pounds of HFC-134a by the end of 1990—far less than the automobile industry will need. Such limited production plans reflect the uncertainty over what are perceived to be imminent congressional actions. Says Allied-Signal's Sukornick, "We are in a serious quandary, because we have little if no direction from the government" over how CFC substitutes will be assessed in fees. President Bush pledged during his campaign not to impose new taxes on anything, which should include the substitutes, industry sources point out. But such semantic maneuverings mean little to producers forced to reconsider priorities, says Sukornick. Such reconsideration, he adds, delays development of CFC alternatives. "The job of allocating capital is more difficult in a climate of uncertainty."

Allied is "proceeding full speed ahead at an accelerated pace" to build commercial production of alternative compounds, says Sukornick. R&D costs for its group of substitutes will run to the tens of millions, he says, excluding commercialization costs. Vogelsberg says Du Pont could produce commercial quantities of CFC alternatives "if the business climate is attractive." Du Pont has two plants planned for 1990 start-up; one in Corpus Christi, TX, to supply HFC-134a; and one in Maitland, Ontario, to make HCFC-123, a substitute for CFC-11, which is used in mak-

HOW CFC DEMAND WILL BE SATISFIED IN 2000



users will be affected, the automobile and electronics industries could be hit hardest.

Worldwide, automakers use about 30,000 tons of CFC-12 annually for on-board air conditioners, while IBM alone uses nearly 6,000 tons of CFC-113 each year in its global operations. Plastics manufacturers also will be forced to make costly changeovers, but with relatively less disruption to their operations.

Final decisions on the types and costs of CFC substitutes can't be made until toxicity tests by a consortium of producers are finished in another two to four years. Users and producers also cite pending legislation in Congress that could impose fees on alternatives, making commercial production of some compounds financially impractical.

"These are not drop-in replacements,

challenge" and will "more than likely" raise sticker prices, notes Toni Simonetti of GM. Plus, because of the greater technical complexity needed to make HFC-134a, per-unit costs will be two to five times those for CFC-12, says Tony Vogelsberg, environmental manager for Du Pont's Freon Products Division, which will make HFC-134a.

Gasoline mileage also will fall, since HFC-134a-based systems are less efficient, says Mike Schwarz, a Ford spokesman. The switchover presents "a major packaging issue," he adds. And the costs of these changes don't account for the CFC-12 that will still be needed to service older cars, says Simonetti. Even now, the price of CFC-12 is rising, as Du Pont and other producers of the compound reduce production for phaseout by 1998. That's when the Montreal Protocol requires CFC producers to cut

ing insulation and as a refrigerant.

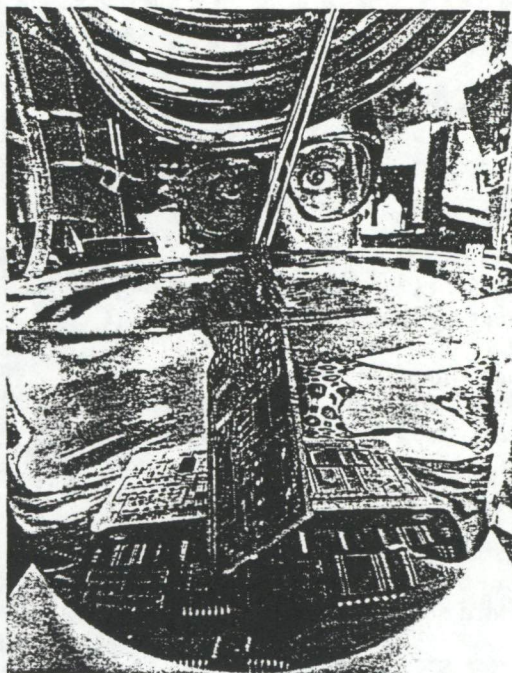
Yet the challenges automakers face pale compared with those of electronics manufacturers. The Delco-Remy Division of GM, for example, is "heavily dependent" on CFC-113 to clean components used in its electronic assemblies, says John Borneman, who heads the unit's corporate cleaning action group. And although Delco is working with Du Pont to develop replacement agents, "there's no good one," Borneman says. Two criteria must be met, he notes: The replacements can't be more hazardous to the employees using them; and reliability of the components cannot be compromised. Those being considered include terpine hydrocarbons and water, he adds.

Because elimination of CFCs in electronic assemblies is not included in GM's 1993 phaseout, Delco has a bit more time to find a solution. But since remaining CFC compounds will cost more, GM wants to eliminate all CFC use before 2000—the official cutoff date for CFC use in electronic manufacture.

IBM uses 5,650 tons of CFCs (mainly CFC-113) each year in its worldwide operations—actually closer to "two to three times [that] amount due to recycling of CFCs at our sites," according to spokeswoman Diana Lee. The company has had "some success in eliminating the need for CFCs," she says, largely in the parts-cleaning processes. At IBM's San Jose, CA facility, 1988 CFC emissions (500,000 tons) were reduced 50% from 1987 levels by using a water-soap cleaning solution, she notes.

All IBM sites are working toward meeting the firm's goal of eliminating CFC use completely by the end of 1993, she says. Further research is needed, she adds, because "substitute chemicals that have been proposed often present serious problems." Many, she continues, "are combustible and often more toxic than CFCs." Lee notes that eliminating CFCs company-wide will require major technology developments, but she does not reveal IBM's cost projections.

Electronics. Cheryl Russell of the American Electronics Association suggests a far gloomier scenario for electronics manufacturers, who she says account for 11% of the U.S. CFC market. While "cost is not an issue," because all 3,500 member companies are committed to substituting CFCs, the major problem will be to develop substitutes that do not damage delicate



Research on CFC substitutes: a costly effort.

electronic components and still clean as well, Russell says. Some alternatives leave more dirt than CFC-113, the prevalent compound, she adds. Military contracts, in particular, will be troublesome, she says, because each contract calls for exacting specifications that cannot easily be changed. But, adds Russell, "I don't know of anyone" who doesn't assume the contracts will be revised to include CFC substitutes.

AT&T plans to replace by 1994 the three million pounds of CFCs it uses annually. Like IBM, AT&T will substitute CFCs with terpine hydrocarbons and water systems, in addition to modified flux materials that produce

cleaner results, according to Leslie Guth of AT&T Bell Laboratories. And like other companies, AT&T predicts eliminating CFCs will cost many millions of dollars. Guth also explains that AT&T won't accept shipments from vendors who use packaging produced with CFCs. The company believes such packing materials will inevitably be banned by law and wants to be prepared, she says.

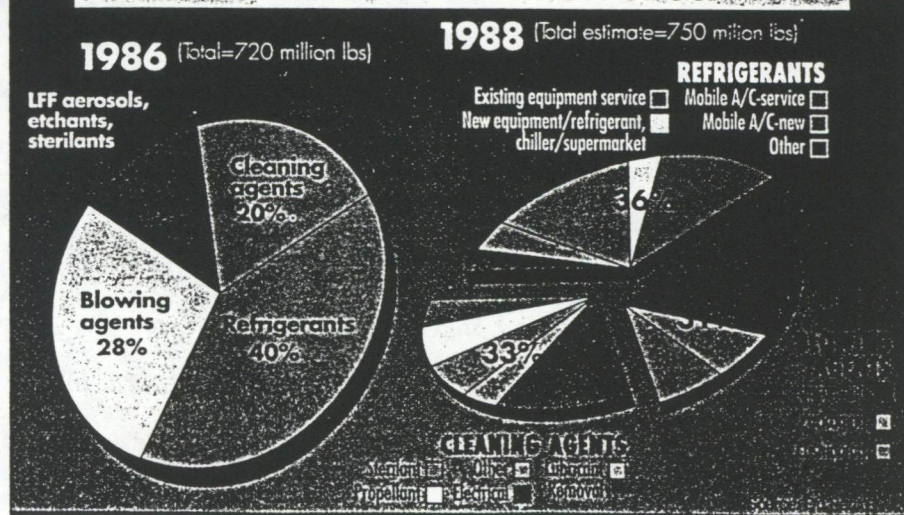
Plastic packing and foam is one industry that should weather the CFC phasedown with relative technical ease, according to preliminary data collected by the United Nations Environmental Program (UNEP). The foam industry can likely reduce CFC consumption "by 50% to 70% by 1993," says Jean Lupinacci of the EPA's Global Change Division. Adequate substitutes are available and can be dropped in without unduly disrupting production, says Lupinacci, though she adds that in the case of

foam, operating costs will likely rise by 10%-20%.

Dow Chemical has already converted much of its polystyrene and polyethylene fabricated foam operations from use of CFC-12 and CFC-114 to HCFC-142b, says spokesman Douglas Draper. "We don't foresee any major problems" switching, he adds, although it will ultimately cost "several million dollars." Draper says the plastic utensil and plate industry converted "quite quickly" because "90% [of such products] never had CFCs" in the first place.

KEN STERNBERG

THE U.S. MARKET FOR CFCs



Nations Urged To Unite in Efforts To Stem Global Climate Change

Science, industry, and government leaders discuss actions, policies, leadership needed to avert environmental disasters, face climate issues

The next decade will be critical in facing the challenge of global environmental change, according to scientists, industry representatives, and government officials who met in Washington, D.C., earlier this month to discuss the problem. By the turn of the century, they warned, the nations of the world must have mustered the will to take steps to ward off environmental disaster.

"The threats to the global climate prove beyond a doubt that, if everyone does as they please in the short run, we will all be losers in the long run," said Norway's prime minister, Gro Harlem Brundtland, in her keynote address to the "Forum on Global Change and Our Common Future." "We need to develop a more global mentality in charting the course towards the future, and we need sound scientific advice and firm political and institutional leadership."

Scientists at the symposium—sponsored by the National Academy of Sciences, Smithsonian Institution, the American Association for the Advancement of Science, and Sigma Xi—reviewed the data that link the accumulation of trace gases such as chlorofluorocarbons (CFCs), carbon dioxide, and other greenhouse gases to ozone depletion and global warming. They also bemoaned their lack of knowledge about the complex interactions among Earth's atmosphere, oceans, and biosphere.

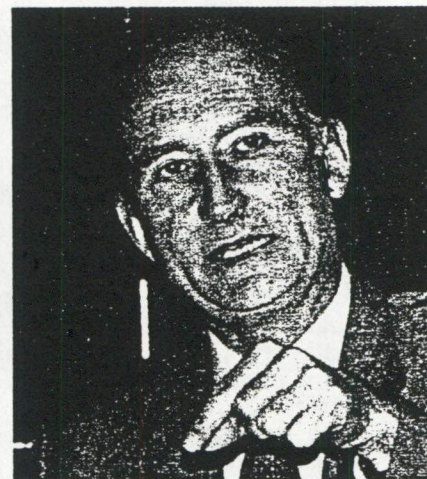
"What really concerns me as a

scientist," says Francis Bretherton, director of the space science and engineering center at the University of Wisconsin, Madison, "is how totally inadequate is our understanding to answer any but the very broadest of questions, like 'Will the Earth warm up?' All the specifics are missing. Under these circumstances, a real organized program of global change research is an investment that we as a country and a society simply cannot afford not to make."



Among speakers at forum on climate change were (clockwise from above): U.S.'s Corell, Norway's Brundtland, and Switzerland's Holdgate

But much of the meeting focused on the necessity of developing policies to limit global change despite the inability to predict rigorously what changes the future holds in store. "The options for action must be considered now, in parallel with the development of further science that will reduce the uncertainties," says Martin Holdgate, director general of the International Union for the Conservation of Nature & Natural Resources in Switzerland.



The mood at the meeting alternated between optimism and despair. The optimism arose from knowledge that some actions that slow global change—such as energy conservation—could be put in place right away. The conferees also took hope from the fact that political leaders are growing more concerned about global environmental concerns.

The despair stemmed from recognition of the difficulty of designing and implementing other strate-

gies to limit the buildup of trace gases in the atmosphere. And even if drastic measures were taken immediately, the world would not escape some measure of ozone depletion and global warming caused by the CFCs and greenhouse gases that have already accumulated.

Noting that slowing the buildup of carbon dioxide is the biggest challenge, Holdgate proposed that the industrialized nations set a goal of halving their carbon dioxide emissions by the year 2020. "That will make room for Third World growth without environmental disaster," he said, pointing out that the one quarter of the world's population that lives in industrialized countries contributes three fourths of the greenhouse gas emissions.

Holdgate suggested a series of strategies for reducing carbon dioxide emissions including improved efficiency in production and use of energy from fossil fuels; reforestation; energy generation from organic wastes; substitution of fuels like natural gas for coal; removal of carbon dioxide from power station flue gases; more efficient use of fuel in transportation; the development of renewable energy sources, like hydro, wind, wave, geothermal, and solar; and increased use of nuclear power.

Brundtland, Holdgate, and other speakers called repeatedly for international cooperation in working toward solutions for global change issues. Negotiations leading to an international treaty that could protect climate were proposed. And the United Nations Security Council, Holdgate suggested, could periodically review major environmental issues of global concern that might threaten peace and security.

The consensus, it seems, is that environmental problems are now a focus of international concern as worthy of attention by world leaders as, say, arms control. "Foreign affairs have been dominated by security issues and economic issues," says Robert Corell, assistant director for geosciences at the National Science Foundation. "The environment is going to join as a third partner. This truly is a significant development of political thought."

Pamela Zurer

In Protecting the Atmosphere, Choices Are Costly and Complex

Substitutes for ozone-destroying chemicals all have disadvantages.

By MALCOLM W. BROWNE

AS the world moves toward a ban on ozone-destroying chemicals to head off an epidemic of skin cancer, experts searching for substitute chemicals predict that the technical and economic cost of the change will be high.

Potential replacements for the chlorofluorocarbon (CFC) chemicals now extensively used as refrigerants, propellants, bubbles in plastic and cleaning fluids have already been identified. But engineers say the replacements are generally more expensive and less effective than the original chemicals. Equipment using some of the replacements, moreover, is expected to consume more power and wear out sooner.

Environmentalists, chemical manufacturers and many governments are in broad agreement on the need to phase out certain CFC's. Released into the air from the bubbles in plastic foam, from leaks in defective or abandoned refrigerators and air-conditioning systems, from solvents used to clean computer circuits and other sources, these compounds rise over a period of years into the stratosphere, where intense sunlight breaks them down. The chemical products of these reactions go on to destroy ozone, a minor but important component of the upper atmosphere, which shields the earth from much of the sun's harmful ultraviolet radiation.

But spokesmen for major chemical companies say that \$135 billion of equipment in the United States operates using the soon-to-be-prohibited chemicals, and much of this equipment will eventually have to be replaced to accommodate

substitute chemicals.

The likely substitutes for the three main ozone-destroying CFC's may, in many cases, be less effective.

The main ozone-destroying refrigerant, CFC-12, could be replaced by a fluorocarbon called HFC-134a. CFC-12 consists of a single atom of carbon with two atoms each of fluorine and chlorine, and is easy to manufacture from two common chemicals. But HFC-134a contains two carbon atoms, four fluorine atoms and two hydrogen atoms, and is much more difficult to manufacture. Chemical engineers say that the replacement chemical is likely to cost three times as much as CFC-12, and it may not last as long. The substance cannot be used in refrigeration equipment previously operated on CFC-12, partly because major corrosion problems would result.

The proposed replacement for CFC-11, a chlorofluorocarbon used to make plastic foam and in central air-conditioning systems, is a compound called HCFC-22. This is a chlorofluorocarbon already in use in home air-conditioners, but it is more expensive than CFC-11 and its potential applications are limited by its inferior characteristics. HCFC-22 is not as good a heat insulator as CFC-11, and it is therefore unsuitable as a foaming agent for insulating plastic foams. Moreover, its boiling point is too low for it to be useful as a refrigerant in automobile air-conditioners, unless the latter undergo major modifications.

Yesterday E.I. du Pont de Nemours & Company announced that it had developed two potential substitutes for CFC-113, the third important member of the ozone-destroying group. This chemical is used in foaming plastics and in other applications, but DuPont's substitutes are suitable only for cleaning electronic components. The most promising of the two products, KCD-9438, a proprietary blend of organic solvents containing no CFC's, will be available for testing later

this year, the company said, and "may be acceptable" for some customers. A second product, which contains some chlorofluorocarbons but in only small amounts, would not be available commercially until the mid-1990s. Both products are expected to cost about three times as much as the present cost of CFC-113.



A technician at a Du Pont pilot plant in Deepwater, N.J., for chlorofluorocarbon alternatives. They are generally more complicated to make.

The 12 nations of the European Community vowed last week to eliminate production of the most harmful CFC's by the end of the century, and President Bush has proposed an international agreement to do the same.

Du Pont, which manufactures about one quarter of the world's annual production of two billion pounds of chlorofluorocarbons, announced last March that it would phase out production of these compounds. Representatives of 124 governments are now meeting in London to discuss ways to hasten the phasing-out of the chemical throughout the world.

But the cost of eliminating chlorofluorocarbons will be high. According to Charles A. McCain, Du Pont's manager for the development of alternative products, the more rapidly the chemicals are removed from industrial applications, the higher will be the cost.

"America and the world need time to replace the equipment that now uses CFC's, and time to develop adequate substitutes for the chemicals," he said in an interview. In this country alone, he said, 100 million home refrigerators, the air-conditioners in 90 million cars and the central air-conditioning plants in 100,000 large buildings use the chemicals.

Home refrigerators may operate for many years without replenishment of their supplies of the chemicals and are often junked before they need replenishment. The ban would therefore have little effect on the average household refrigerator. But central air-conditioning plants in large buildings periodically need fresh supplies of chlorofluorocarbons, and in these cases, replacement of equipment would be needed sooner. Home air-conditioners do not use the ozone-destroying chemicals.

Although the family of chlorofluorocarbons includes many hundreds of compounds, only the five considered most damaging to the ozone layer are being banned: CFC-11 and CFC-12, which are used as refrigerants; CFC-113, used mainly as a cleaning agent, and CFC-114 and CFC-115, which have a variety of uses. The first three of these compounds constitute more than 90 percent of chlorofluorocarbons manufactured in this country.

The chemicals have special properties that make them extraordinarily useful. Very little energy is required to convert them from gases to liquids or vice versa, owing to their low boiling points and high vapor pressures. This makes them ideal for refrigeration applications and as propellants in canned aerosol products. (Although they have been banned as propellants in this country, except for dispensing drugs, they are still used

in aerosols in other parts of the world.)

CFC's are so chemically unreactive that they do not cause corrosion and are completely non-toxic. When converted under pressure into liquids, they have an extraordinary ability to wet any solid material they touch; they are much wetter than water. This perfectly suits them for

cleaning the microscopic pores, scratches and irregularities in computer circuit boards, especially since they evaporate rapidly, leaving no residue.

The substitutes in all these applications, manufacturers say, are a step backward in product quality, except for the fact that they will be less damaging to the ozone layer. They are expected to be less durable, to require redesign of much equipment, and to pose potential questions about their toxicity. Many of the substitutes are actually other CFC's whose chemical structure has been designed to break down quickly in the lower atmosphere.

Leo Manzer, manager of research at Du Pont, said the search for acceptable substitutes has already cost his company \$100 million. The quest has focused on compounds that have one, two or three carbon atoms, along with varying combinations of hydrogen, chlorine and fluorine atoms. "Mathematically," he said, "that gives us 601 chemical possibilities, and testing them all for flammability, toxicity, stability and engineering qualities is no simple matter."

A contrasting view was offered by Dr. Mario J. Molina, a chemist at the Jet Propulsion Laboratory in Pasadena, Calif., who is a leading authority

on atmospheric chemistry. "There's no doubt that eliminating CFC's will be expensive," he said, "but I doubt that it will be as expensive as many industry spokesmen contend."

Dr. Molina disputes claims that the ban might have dangerous economic consequences. "In 1978, when the United States prohibited the use of CFC's as propellants in spray cans, lots of experts said the ban would put a lot of people out of work," he said. "It didn't. In any case, the world cannot afford the consequences of continuing to release CFC's into the atmosphere."

The special merits of the chlorofluorocarbons stem from the exceptionally strong chemical bonds that hold their molecules together. The strength of the molecular bonds in CFC-11 and CFC-12 makes them extremely resistant to chemical attack; their chemical cousins include Teflon, the non-reactive polymer used as a non-stick lining in kitchen pots.

When released into the atmosphere they resist breaking down almost indefinitely, until they reach the stratosphere where they are exposed to fierce solar ultraviolet radiation. This radiation is so strong that even the

strong bonds holding CFC molecules together finally break apart, and the resulting fragments start the chain of chemical events that leads to ozone destruction. Ozone depletion has already been observed in both Antarctica and the Arctic.

When CFC refrigerants were invented in 1930, they were seen by engineers as an answer to a prayer. In the late 19th century and early 20th century, the gases used in refrigerators had included ether vapor, ammonia and sulfur dioxide, all of which are chemically reactive, poisonous

and dangerous to handle. By contrast, CFC's were completely inert and non-toxic, caused no damage to the machines in which they were used, and saved electrical power.

Most refrigerators, air-conditioners and heat pumps are based on gases that can be easily liquefied under pressure. In a typical refrigeration cycle, an electric motor drives a piston to compress the working gas. The pressure heats the gas, which is then pumped into a radiator cooled by moving air or flowing water.

The cooled, compressed gas liquefies in the radiator, and the liquid is pumped into the cooling section of a freezer, refrigerator or air-conditioner, where the pressure is suddenly released. This allows the liquid to rapidly evaporate and cool, chilling the metal coils with which it is in contact. The resulting vapor is returned to the compressor to begin a new cycle.

Lasting for 30 Years

If a refrigeration system contains CFC-12, the compressor can usually operate for up to 30 years without a need to replenish or replace the gas, experts say. But it remains to be seen whether a substitute gas not based on chlorofluorocarbons will hold up for nearly as long.

A likely substitute for many applications of CFC-11, which consists of one carbon atom, three chlorine atoms and one fluorine atom, will be a compound called HCFC-22, consisting of one carbon, one chlorine, two fluorines and one hydrogen.

Technically speaking, HCFC-22 is a chlorofluorocarbon, but since it contains a hydrogen atom and only a partial complement of chlorine and fluorine atoms, it is regarded as environmentally safer than CFC-11. The hydrogen makes it more vulnerable to attack, and scientists believe that most of the HCFC-22 released into the air will be destroyed by sunlight before ever reaching the stratospheric ozone layer. The compound would still destroy some ozone, but only a negligible amount, it is believed.

The fact that HCFC-22 is already the refrigerant used in virtually all home air-conditioners means that these machines will not be made obsolete by the phasing-out of chlorofluorocarbons. The compound is not among the five CFC's singled out for elimination by the signers of the 1987 Montreal agreement to curb destruction of the ozone layer.

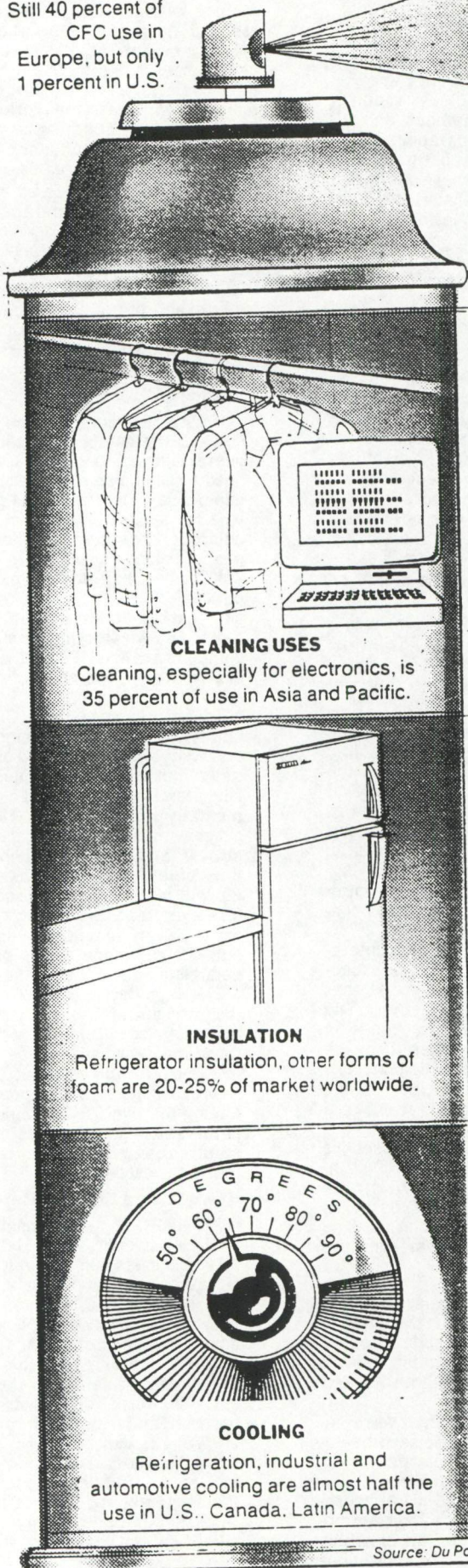
'It Would Be a Catastrophe'

"If HCFC-22 were banned it would be a catastrophe," Mr. McCain said. "Everyone is counting on it as a substitute." In response to a Du Pont initiative, he said, the entire American foam-polystyrene packaging industry switched this year from CFC-12 as a foaming gas to HCFC-22. Questions remain about the stability and long-term safety of HCFC-22, however, and testing will continue.

"We all want to save the ozone layer," a Federal environmental official said. "But let's hope we don't inadvertently end up creating substitutes that damage the environment in some new and unforeseen way."

AEROSOL CANS

Still 40 percent of CFC use in Europe, but only 1 percent in U.S.



The Many Uses of CFC's

The threat that some chlorofluorocarbons pose to the Earth's ozone shield against cancer-causing ultraviolet rays has prompted plans to abandon them. They are used in about \$135 billion worth of equipment in the United States. Many substitutes have their own disadvantages.

CLEANING USES

Cleaning, especially for electronics, is 35 percent of use in Asia and Pacific.

INSULATION

Refrigerator insulation, other forms of foam are 20-25% of market worldwide.

COOLING

Refrigeration, industrial and automotive cooling are almost half the use in U.S., Canada, Latin America.

Source: Du Pont

Arctic Ozone Loss: Fact-Finding Mission Concludes Outlook Is Bleak

Comprehensive probe finds Arctic's winter atmosphere loaded with same chlorine compounds that cause the Antarctic ozone hole

Pamela S. Zurer, C&EN Washington

Scientists have returned from the first comprehensive probe of the Arctic stratosphere with unexpectedly dire results: The winter atmosphere in the north polar region is loaded with the same destructive chlorine compounds that cause the Antarctic ozone hole. Atmospheric researchers who only a few weeks ago were comforted by the thought that the warmer Northern Hemisphere is strongly protected from the processes that lead to massive losses of ozone during spring in Antarctica now see very little standing in the way of an Arctic ozone hole.

The inescapable conclusion is that only a complete phaseout of fully halogenated chlorofluorocarbons—CFCs, the ultimate source of man-made chlorine in the stratosphere—can prevent further deterioration of the ozone layer. Even with an immediate ban on CFCs, their long atmospheric lifetimes mean it would take decades to centuries for the atmosphere to recover.

This new bleak outlook stems from data gathered during the first six weeks of the year by the Airborne Arctic Stratospheric Expedition (C&EN, Jan. 2, page 30). During that international mission, two National Aeronautics & Space Administration research aircraft each flew 14 flights north from Stavanger, Norway.

The goal of the \$10 million project

Arctic stratosphere, like Antarctic, holds dangerous active chlorine

- Winter temperatures sometimes drop to -80°C
- Variable polar vortex usually breaks up before sun returns to North Pole
- Polar stratospheric clouds are mostly Type I ($\text{HNO}_3 \cdot 3\text{H}_2\text{O}$)
- Lots of active chlorine (ClO)
- Ozone loss?



- Winter temperatures always drop to -90°C
- Polar vortex lasts well into spring after sun returns to South Pole
- Polar stratospheric clouds are both Type I and Type II (water ice)
- Lots of active chlorine (ClO)
- Massive ozone loss

was to determine to what extent the heterogeneous chlorine chemistry that is responsible for the Antarctic ozone hole also takes place in the Arctic. The answer—that heterogeneous chemistry has primed the Arctic air for ozone destruction—was a surprise to virtually all of the 150 or so scientists who participated.

Specifically, a key experiment by Harvard chemistry professor James G. Anderson's group found chlorine monoxide (ClO) concentrations as high as 800 ppt within the polar

vortex—almost as high as the researchers had found within the Antarctic ozone hole (C&EN, May 30, 1988, page 16). Chlorine monoxide has been dubbed the "smoking gun" of ozone depletion, because the chain reactions believed to destroy ozone depend on chlorine monoxide to carry the chain. ("Normal" amounts of chlorine monoxide would be about 10 to 20 ppt.)

Now the atmospheric science community is anxiously waiting to see what happens next. The only factor that is preventing substantial ozone destruction in the Arctic region is that the air containing active chlorine is still mostly in the darkness of the polar night. Once the air is hit by sunlight, chlorine-catalyzed chain reactions that chew up ozone will take off—unless competing processes can first reconvert the active chlorine compounds to nondestructive inert forms.

"All our observations have shown that the Arctic stratosphere looks a heck of a lot like the Antarctic stratosphere," says chemist Susan Solomon of the National Oceanic & Atmospheric Administration's aeronomy lab in Boulder. "The dangerous chemicals are there. What we don't know is how close to the edge we are."

So far, there is no large ozone hole in the Arctic, says Robert T. Watson, NASA's program manager for upper atmospheric research. No phenomenon comparable to the massive loss of ozone—up to 50%—that has been occurring over Antarctica every spring for the past decade has been observed in the Arctic, he says. Rather, a small, long-term loss of ozone—on the order of 5 to 6% since 1970—has occurred in the high northern latitudes in winter.

However, with the new insight



Watson: new insight provided

provided by the just-completed Arctic campaign, "We can't rule out the potential for a very rapid onset of a decrease in ozone in the Arctic regions," Watson says.

Before the scientists left for Norway, there was a consensus that the Antarctic ozone hole was a result of Antarctica's unique frigid meteorology. "Antarctica is a very special place in terms of temperatures, and because of those special physical characteristics, man-made chlorine compounds enter the picture there in a way that they do not elsewhere on the globe," said NOAA's Daniel L. Albritton shortly before the mission began.

Now, that conventional wisdom has to be revised. The Arctic results show that the stratosphere does not have to get so cold as it does in Antarctica to set up the conditions that change inert chlorine compounds to destructive ones.

In both the Antarctic and Arctic regions, stable wind patterns in the stratosphere known as polar vortices circle the dark poles in winter-time. Air within the vortices, isolated from the sun and from warmer air from the temperate regions, gets extremely cold.

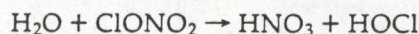
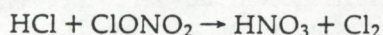
The Antarctic polar vortex, however, gets much colder than does the Arctic. In winter in Antarctica, stratospheric temperatures drop to -90°C and the vortex persists for

about five months, well into spring. In the Arctic, minimum temperatures tend to be about 10 degrees warmer, and the vortex itself only holds together for a few months, usually breaking up by late February or early March. The climatic differences between the two hemispheres reflect the difference in land distribution. Much more dynamical activity from land masses in the lower latitudes reaches the Arctic polar region than reaches Antarctica, which is surrounded by ocean.

The winter temperatures at both poles are cold enough for two types of clouds to form even within the extremely dry stratosphere. It is these polar stratospheric clouds that are the key to the Antarctic ozone hole—and as it turns out, whatever is happening in the Arctic. One kind of cloud (Type I) is composed mostly of nitric acid trihydrate and forms at about -77°C . Type II clouds are mostly water ice and require still lower temperatures to grow—about -85°C .

On the 1987 aircraft expedition to Antarctica to study the ozone hole, wherever researchers found high levels of active chlorine, they also found low levels of nitric acid and water vapor. "From our experience in Antarctica, we had come to correlate high chlorine monoxide with denitrification and dehydration," Watson says.

The scientists reasoned that that correlation could be explained by the occurrence of Type II polar stratospheric clouds. The clouds provide surfaces on which inactive forms of chlorine are converted to destructive forms. The heterogeneous reactions convert chlorine nitrate (ClONO_2) and hydrogen chloride—molecules that are relatively inert—to more active molecular chlorine and hypochlorous acid (HOCl):



The molecular chlorine and the hypochlorous acid fly off into the gas phase, where both can be easily photolyzed by even small levels of light to radicals that can catalyze ozone destruction. In contrast, the nitric acid (HNO_3) that is produced

sticks to the cloud particles, tying up nitrogen species that, if free, could react with the reactive chlorine to reform inert chlorine nitrate.

As the ice crystals of the Type II clouds grow large enough, they precipitate out of the stratosphere, removing both water and nitric acid. When the sun comes up in the Antarctic spring, the active chlorine compounds begin to destroy ozone photochemically. The process stops only when the Antarctic polar vortex breaks down after it has been in the sun for a month or more, allowing air full of nitrogen oxides to rush in.

In the Arctic, however, it is rare for the temperature to get down to -85°C , the temperature at which Type II clouds form, Watson says. And, indeed, on this year's Arctic expedition, the scientists observed very little of the dehydration that would be expected to accompany Type II clouds. Although they did occasionally observe Type II clouds, the Type I nitric acid trihydrate clouds were much more frequent. Nevertheless, they saw very high levels of chlorine monoxide.

"This means that Type I [clouds] are enough to perturb the chemistry," Watson says. "The surprise is you only have to get down to -77°C to allow reservoir chlorine to be converted to active chlorine. That



Tuck: much depends on the vortex

happens much more frequently in the Arctic than -85°C ."

That the north polar vortex usually breaks up before the sun comes up is probably what has prevented a full-blown Arctic ozone hole so far. However, in some unusual years the vortex has held together until April or May, notes NOAA's Adrian F. Tuck.

"If the vortex holds together for a few more weeks, we should see an ozone loss," Tuck says. "The degree of Arctic ozone depletion [that will actually appear] depends on the rate at which normal partitioning of chlorine species is re-established. We don't know how much exposure to sunlight the primed air is going to get; we don't know how much the vortex is going to wobble about."

Ozone losses in the Arctic region if the vortex continues to hold together could range from 5 to 20% this year, the scientists estimate. However, even if the vortex does break down soon, there will likely be smaller, harder to measure, changes in ozone.

"One way or another there will be some ozone lost," Watson says. "There is now a very large volume of air, roughly reaching from the North Pole to about 70°N , with very high chlorine monoxide levels. When the vortex breaks down and that air gets sent out to lower latitudes, it will indeed destroy ozone. The amount of ozone destruction will be limited by how quickly the chlorine will be converted back into its reservoir forms."

"It's a race between how fast molecular diffusion can bring in nitrogen oxides to react with the active chlorine and how fast the chlorine chain can destroy ozone," says Michael J. Kurylo III, a chemist on assignment to NASA from the National Institute of Standards & Technology.

Unfortunately, the Arctic expedition scientists left Norway with the their instruments in mid-February and so will not be able to track any upcoming changes in ozone with the sophisticated array of equipment that was assembled on the NASA research aircraft. The expedition, planned well in advance, was scheduled for early in the winter to make



Rod Jones (left) of the U.K. Meteorological Office and NOAA's Solomon review computer-modeled predictions of atmospheric chemistry effects

sure the researchers would be in the Arctic at the right time to observe the formation and distribution of the polar stratospheric clouds. By the time the team realized how greatly the chemistry of the winter Arctic stratosphere is perturbed, it was too late to extend the program long enough to follow the breakup of the vortex.

The official statement of preliminary findings from the Arctic expedition asserts that it is too soon to say whether the perturbed chemistry the researchers found in the Arctic can quantitatively explain the decreases in ozone reported last March by the International Ozone Trends Panel (C&EN, March 21, 1988, page 6). That study found that since 1970, ozone between about 40° and 60°N had decreased 5 to 6% in the winter months.

Despite the scientists' reluctance to say so definitely, it is clear that blobs or streamers of air rich in active chlorine from the Arctic vortex drifting into sunlight at lower latitudes could account for that wintertime decrease in ozone in the Northern Hemisphere. Although not nearly so striking as the Antarctic ozone hole, such small changes in ozone over a populated area are still significant. The Environmental Protection Agency has estimated that each 1% depletion of ozone leads to a 2% increase in skin cancer among fair-skinned people.

The latest findings in the Arctic

are leading both scientists and policymakers to step up their calls to strengthen the terms of the Montreal Protocol on Substances That Deplete the Ozone Layer. That international treaty, which went into effect Jan. 1, calls for a 50% reduction in output of CFCs by mid-1998. However, the photochemical models that were used as a basis for negotiating the treaty did not include any heterogeneous processes, now known to be so devastating to ozone.

"We're much more concerned than before we went to Norway about protecting atmospheric ozone, especially in the polar regions," Watson says. "It's now absolutely clear that the terms of the Montreal protocol will not lead to adequate protection of ozone in Antarctica and probably not in the Arctic."

"There's about 3 ppb of chlorine in the atmosphere today," he says. "Under the Montreal protocol, chlorine will continue to increase to about 6 ppb. Even if we were to stop producing the fully halogenated CFCs today, the Antarctic ozone hole would be here for centuries to come. Time is of the essence. Every year we continue to put chlorine in adds 10 years to the time it will take to remove it."

Meanwhile, the Arctic polar vortex is still holding together. Atmospheric scientists are monitoring ozone in the Arctic through satellite-based instruments and balloon flights. □

A Character Sketch of Greenhouse

by Dr. David Rind

The Greenhouse Effect has caught the imagination of the general populace in the last decade. What's more, the respected, generally conservative scientific establishment has become associated with relatively dire predictions of future climate changes the Greenhouse Effect may cause.

But how much do we actually know about the Greenhouse Effect? Can we really establish how much the climate will change, and when? Perhaps by separating the "hard" science—that which can be verified and is considered well-understood—from scientific theory or estimates, we can investigate the likelihood of near-term climate changes that have been projected. The series of questions which follow will help us explore what we currently know, or think we know, about the Greenhouse Effect.

Question: Do we really understand the "Greenhouse Effect"?

The "Greenhouse Effect" is the name for the physical process whereby energy from the sun passes through the atmosphere relatively freely, while heat radiating from the earth is partially blocked or absorbed by particular gases in the atmosphere. Because the sun is warmer than the earth, its energy is radiated at a higher frequency which is not absorbed well by gases such as carbon dioxide (CO₂) or water vapor. In contrast, these triatomic gases (gases with three atoms per molecule) are effective absorbers of the lower-frequency energy radiated by the earth. Since the gases responsible for this selective absorption make up only about one percent of the atmosphere, they are known as "trace" gases. In general, we can calculate very accurately the energy absorbed by different gases, although there are some uncertainties, and when the

concentration of a gas changes, we know how much more energy is being absorbed. This additional absorption by itself warms the planet: for example, doubling the concentration of CO₂ in the atmosphere would eventually lead to a global air temperature increase of 1.2° Centigrade (C)—about 2.2° Fahrenheit (F)—if there were no other changes in the climate system.

However, what we do not know is exactly how the rest of the system will react. The current numerical computer models of the earth's climate predict that the warming due to the increase in CO₂ will lead to more evaporation of water vapor from the ocean. Water vapor itself is a "greenhouse" gas, so as its concentration increases in the atmosphere, the planet will warm even further. With rising temperatures there will be less snow and ice to reflect energy from the sun back to space (snow and ice are very good reflectors). This promotes further warming because more of the sun's heat is retained in the earth.

These are examples of "positive feedbacks" in which the system responds to a warming climate with changes which amplify the warming even further. Both of these system responses are very likely to occur, although we cannot be sure of the magnitude of the changes. The models also predict cloud cover changes that will provide even more warming, but clouds are not modeled in a very sophisticated way because they are not well understood. Thus, the likely impact of cloud cover changes is quite uncertain.

The net result of these different processes in the various models is the tripling of the warming caused by the doubled CO₂ levels alone, producing a total warming of about 4° C (or 7° F) for the global, annual average. Yet it is only the initial Greenhouse Effect due to increased CO₂ or increases in other trace gases, which we know with great confidence.

Question: Can we use the temperatures on other planets to determine what the climate system feedback will be on earth?

The atmospheres of nearby planets validate the general concept of the greenhouse theory, especially in a qualitative sense, but they cannot tell us what the magnitude of the changes on earth will be. Venus, with its massive atmosphere composed essentially of CO₂, has a surface air temperature close to 500° warmer than would be expected without a Greenhouse Effect. Mars, with a very thin atmosphere and thus little atmospheric capacity to absorb radiation, has an observed temperature close to the expected. The earth, with intermediate amounts of greenhouse gases in its atmosphere, is about 30° C (54° F) warmer than it would be otherwise. The differences among the planets are very large, and cannot really be used to estimate sensitivity to relatively small changes in greenhouse gas levels. Furthermore, as noted above, the big uncertainty lies in the magnitude of the climate system response (or feedbacks). The most important feedbacks involve the reaction or processes related to water, and the other planets have no free-standing water.

Are greenhouse gases increasing?

Since the establishment of an atmospheric monitoring system in 1958, we have observed the concentration of CO₂ growing systematically. During the past 28 years, CO₂ values in our atmosphere have increased from 315 parts per million (ppm) to 350 ppm. These values are especially significant since air bubbles trapped within the ice in Greenland and Antarctica have been used to measure what CO₂

SUNLIGHT

STRATOSPHERE

TROPOSPHERE

Carbon dioxide and other gases absorb infrared radiation in the troposphere and warm the earth.

EARTH'S SURFACE

INFRARED RADIATION

concentrations were like over the past several hundred thousand years. During that time, up to just prior to the industrial revolution, CO₂ levels had not exceeded 280 ppm (and thus were well below current values). The rising CO₂ concentrations are believed to be associated with the widespread use of fossil fuels such as gas and oil and by the denuding of the world's tropical and other forests, a process which lowers the earth's ability to use trees as a CO₂ absorbent.

Chlorofluorocarbons (CFCs), better known for their impact on atmospheric ozone levels, are artificially generated gases that also have the capacity to contribute to the Greenhouse Effect, and which are known to be increasing. They have no natural sources and probably did not exist in the atmosphere prior to the last few decades. Recent measurements indicate that other contributing greenhouse gases, such as methane and nitrous oxide, are also increasing; however, since we are not sure of the reason for their increase, we have less confidence in their long-term trends.

Question: Is the temperature record of the past century consistent with the increase of gases which contribute to the Greenhouse Effect?

It is estimated that the average surface air temperature has increased globally by about 0.6° C (or 1° F) in the past century, but there is some uncertainty as to how accurately the change can be estimated because there were far fewer temperature recording stations 100 years ago. Large portions of the globe were poorly sampled, especially in the Southern Hemisphere. Even today, full global coverage is not available.

The record, such as it is, does not indicate a continuous worldwide

warming. There was apparently a cooling period in the Northern Hemisphere from the 1940s into the early 1970s. This is inconsistent with the concept of greenhouse warming, but it may be due to other climate disturbances, such as variations in the solar energy constant, or a change in the amount of volcanic discharge into the atmosphere, or it may simply represent internal variability within the system.

The overall warming for the past century is the right order of magnitude for the expected Greenhouse Effect. However, given the uncertainties about the actual temperature change, the climate feedback factor, the actual amount of CO₂ in the atmosphere in 1880, and the rate at which oceans absorb heat (which slows down the atmospheric warming), we cannot be more precise in determining what the expected warming would have been. Similarly, we cannot use the record to establish what the climate-feedback factor really is.

Despite these qualifications, one aspect of the temperature record clearly stands out: during the past century, the four warmest years, globally, were all during the 1980s; this does not include 1988, which appears as if it will be the warmest year of all. This has occurred despite the eruption of the El Chicon volcano, putting additional dust into the air, and a decrease in the sun's energy output, both of which should have had a cooling effect. While modern temperature records may be contaminated to some extent by heat island effects which create warm areas in cities, the rapid rise of temperature during the 1980s is consistent with computer model projections. This suggests that the anticipated Greenhouse Effect changes may actually be appearing at this time.

Question: Are current computer models adequate to allow us to forecast climate change?

Numerical models (called general circulation models) which simulate the known workings of the earth's climate system are used to calculate its response to increases in trace gases. The four models in current use all estimate that the doubled CO₂ climate will have a global average temperature some 4° C (7° F) warmer than today. They are thus all calculating similar climate feedback factors. However, even though many climate processes are handled similarly in the different models, their unanimity does not guarantee accuracy. For example, the treatment of cloud cover in all the models represents a major uncertainty. The models also differ to some extent as to the seasonal and latitudinal distributions of the calculated warming. It is thought unlikely that the models could be wrong by more than a factor of two, but this cannot be proven.

In addition, a climate change forecast should indicate when the warming would be expected to be evident, but only one model, the Goddard Institute of Space Studies (GISS) model, has been used to calculate the temperature increase over the next 50 years in response to a gradual change in greenhouse gas concentrations. Its results indicate substantial warming in the next decade. This calculation is affected to some extent by uncertainties in how much heat the oceans will absorb and the true climate feedback factor. Nonetheless, by providing an estimate of how much warming should be observed in the relatively near future, the model does give us a chance to test the accuracy of its projections.

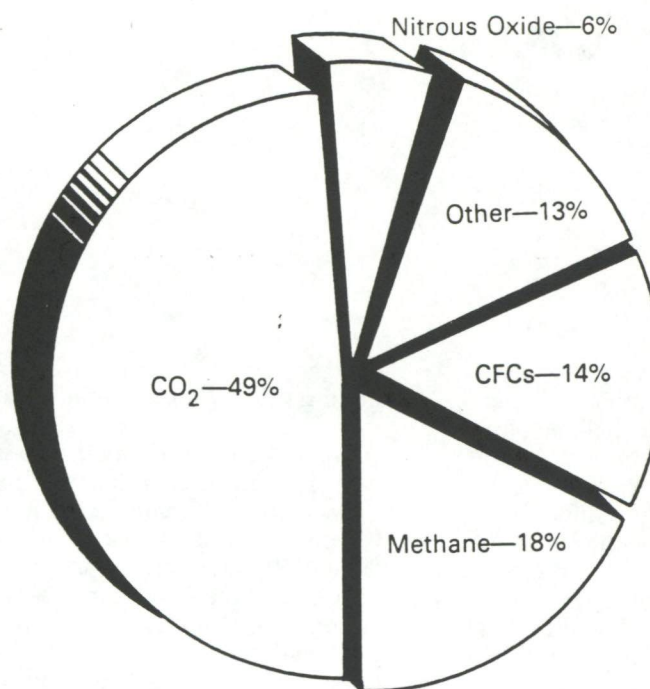
Question: How "dire" is the forecast of coming climate change?

It is estimated that the ice age climate was some 4° C colder than today's. At that time (some 18,000 years ago), ice covered the area now occupied by New York City. Considering that the doubled CO₂ climate is estimated to be warmer to the same degree that the ice ages were cooler, large changes in the climate system may well be expected if this comes to pass. The GISS model's forecast for the next 50 years gives changes of 2° C (3.6° F) by the year 2020, which would make the earth warmer than it is thought to have been at any point in historical time. Estimates for summer temperatures in the doubled CO₂ climate indicate that Washington, DC, which currently experiences 36 days of temperature above 90° F would routinely have 87 such days; Dallas would go from 19 days with temperatures above 100° F to 78 days.

Sea-level rise due to thermal expansion of the oceans would cause severe problems in many coastal cities, and this effect would be exacerbated if additional glacial melting occurred. Rainfall patterns would likely be substantially altered, posing the threat of large-scale disruptions of agricultural and economic productivity, and water shortages in some areas.

We may start experiencing the effects of a changing climate fairly soon. If we define a "hot" summer as the warmest one-third of the summers during the period 1950-1980, then, if the models are correct, during the 1990s we will experience "hot" summers twice as often, or two-thirds of the time. The summer of 1988 may be an all-too-tangible indication of how dire such changes in summertime climate can be.

Manmade Contributions to the Greenhouse Effect



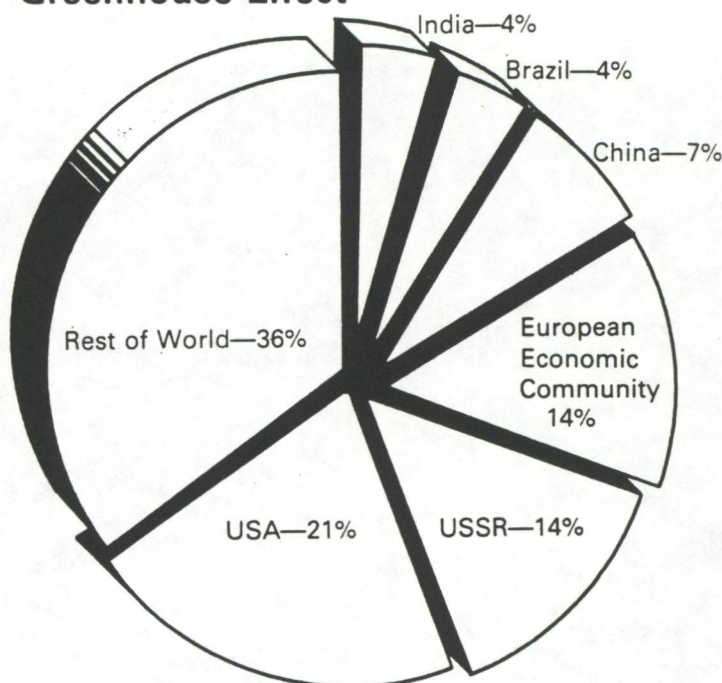
Question: Is there any way to prevent these changes from occurring?

The climate is being altered by the release of greenhouse gases due to fossil fuel consumption and industrial processes, and by deforestation. These factors are inherent in our current civilization. It may be possible to limit specific trace gas increases (such as the CFCs) and slow down rates of increase of CO₂ through increased energy conservation. Our ability to manipulate the climate system deliberately, so as to offset the warming by some other process, is nonexistent. It is likely that the additional greenhouse gases which have been added to the atmosphere during the past 50 years have already built considerable warming into the system, which we have not yet experienced because of the slow warming response of the ocean.

The climate of the next century will very likely be substantially different from that to which we have become accustomed. Uncertainties in our knowledge of the true climate sensitivity prevent us from knowing exactly how different it will be. The consequences of the climate change that is currently being estimated would be enormous. With that in mind, it is worthwhile for us to factor climatic change into decision-making processes related to our future, even though there are many uncertainties that still exist in our understanding of what may actually happen. □

(Dr. Rind is an atmospheric scientist at the Institute for Space Studies, Goddard Space Flight Center, National Aeronautics and Space Administration, and an adjunct associate professor at Columbia University. He is a leading researcher on aspects of the greenhouse theory of atmospheric warming from certain gases.)

Regional Contributions to the Greenhouse Effect



(The top chart represents the estimated increase in the Greenhouse Effect due to manmade emissions of Greenhouse gases in the 1980s. The chart is adapted from work by Dr. James Hansen and his associates at the Goddard Institute for Space Studies. The bottom chart is based on EPA estimates of each region's contribution to manmade emissions of Greenhouse gases.)

From an Industry View

by Stephen C. Peck and
Richard G. Richels

The possibility of climate change presents a unique challenge to American electric utilities. If there is indeed a significant warming of the earth's climate due to rising concentrations of greenhouse gases, utilities may be affected at three distinct levels. First, they will inevitably play an important role in any broad societal response to climate change and have an opportunity to forge a new relationship with their customers to achieve common goals. Second, utilities recognize that their industry will be

among those whose operations are most deeply affected by a changing climate, perhaps within the time-frame of current planning for construction of new facilities. Finally, electric utilities are concerned that costly and potentially counterproductive regulations may be promulgated before a rational basis for policy-making is achieved.

An overriding consideration in each of these three areas is the number of uncertainties that remain in the scientific understanding of the

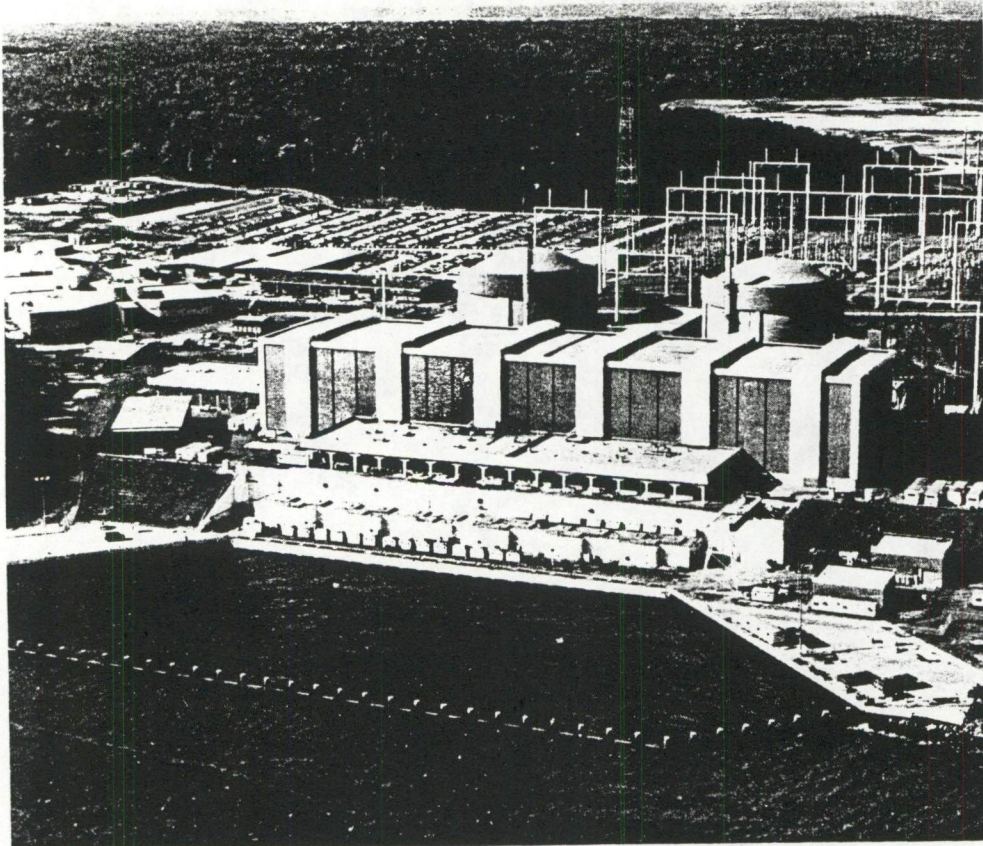
Greenhouse Effect and in the likely effectiveness of various countermeasures. In particular, the apparent 0.6°C (1°F) rise in average global temperature over the last century lies within the long-term range of natural variability, although the recent rate of increases seems rapid. Current models suggest that a warming trend of this magnitude could result solely from the increases in atmospheric CO_2 and other greenhouse gases (e.g., nitrous oxide, methane, chlorofluorocarbons, and ozone). However, the observed rise in temperature over the last century has not been steady and has been marked by unexplained periods of cooling. More research is needed before the time-scale of present climate change and the contribution of human activity to this change are well understood.

Even more uncertain are future trends. The earth has numerous, complex feedback mechanisms that could enhance or counteract the Greenhouse Effect in still unpredictable ways. Rising temperatures, for example, could increase evaporation of surface moisture, leading to a greater cloud cover that could influence the warming by both reflecting more sunlight away from the earth and trapping more outgoing radiation. No one knows which of the opposing feedbacks would dominate.

Perspective on Regulation

In spite of these uncertainties, legislation has been proposed that would reduce U.S. CO_2 emissions 20 percent from current levels by the year 2000 and 50 percent by 2015. Achieving these goals—which many knowledgeable observers doubt is possible—would involve tremendous costs for electric utility customers and for the economy as a whole. Unfortunately, it is impossible to say, given the current state of knowledge,

Baltimore Gas and Electric Company photo.



One of the issues in the debate about how to deal with the Greenhouse Effect is the role nuclear power should play as an alternative to fossil fuel. Shown is the Baltimore Gas and Electric Company's Calvert Cliffs Nuclear Power Plant on the Chesapeake Bay in Maryland.

whether such measures would significantly affect any global warming that might occur.

At issue is whether we can afford to wait for greater scientific certainty about the Greenhouse Effect and its likely impacts. The answer requires weighing the possible costs of delay against those of premature action, such as the imposition of tremendous costs on the U.S. economy unnecessarily if the warming trend turns out to be more modest than some current projections.

Calculations by Irving Mintzer at the World Resources Institute indicate that if no action is taken for 30 years to alter current trends, we would probably have to deal with an additional average warming of between .25° to .8° C.

Clearly, a significantly higher degree of certainty on a wide range of critical scientific issues could be gained in a far shorter period of time. The first order of business for the research community, therefore, is to develop a better understanding of both the consequences and likelihood of an additional commitment to global warming within the range calculated by Mintzer. Such an understanding would tell us what is at stake by waiting.

Research is not only needed to tell us when to act but also how to act. Although the focus of recent debates has been primarily on strategies to reduce emissions, it is not at all clear that the point of emissions is the best place for intervention. There is, in fact, a wide variety of options potentially available for countering the Greenhouse Effect. The four main options:

● Reducing greenhouse gas production:

Examples are reducing energy use, fuel switching from coal to natural gas, increasing the use of nonfossil sources, and reducing the rate of deforestation.

● Removing greenhouse gases from effluents or the atmosphere: Examples are removing CO₂ from power plant emissions as well as starting forestation programs.

● Making countervailing modifications in climate and weather: One example is cloud seeding; another more speculative example is changing the atmosphere's reflectivity by releasing particles in the stratosphere.

● Adapting to changing climate:

Examples are heating and cooling of buildings, compensation of disadvantaged regions, and changing of agricultural practices.

Thus, another important research direction is to conduct analyses of the feasibility and cost-effectiveness of such options so that an informed judgment can be made on the appropriate combination of options, when action is required.

Regardless of when action may be taken, however, it is clear that unilateral emissions reductions by the United States or its utilities would do very little

There is, in fact, a wide variety of options potentially available for countering the Greenhouse Effect.

to slow global trends. While worldwide emissions of manmade CO₂ more than tripled between 1950 and 1980, the U.S. share of the total steadily decreased, from about 42 percent to a current level of about 22 percent. By contrast, the portion attributable to developing countries grew during the same period 7 percent to more than 20 percent, and these countries may produce two-thirds of CO₂ emissions by the middle of the next century.

American utilities, on the other hand, now produce about 35 percent of U.S. and 8 percent of global emissions—an amount which, even if it were reduced significantly, would delay the date of a doubling of atmospheric CO₂ from pre-industrial levels by a fraction of a decade at most. Paradoxically, premature restrictions on American utilities could actually increase CO₂ emissions by driving up the domestic price of electricity and forcing more industries to move offshore, where the efficiency of energy use is frequently lower. Clearly, any regulatory attempts to counteract global warming must be international in character.

Effects on Utility Operations

Because of the large amounts of capital and time required to build generation and transmission facilities, electric utilities must plan for decades ahead.

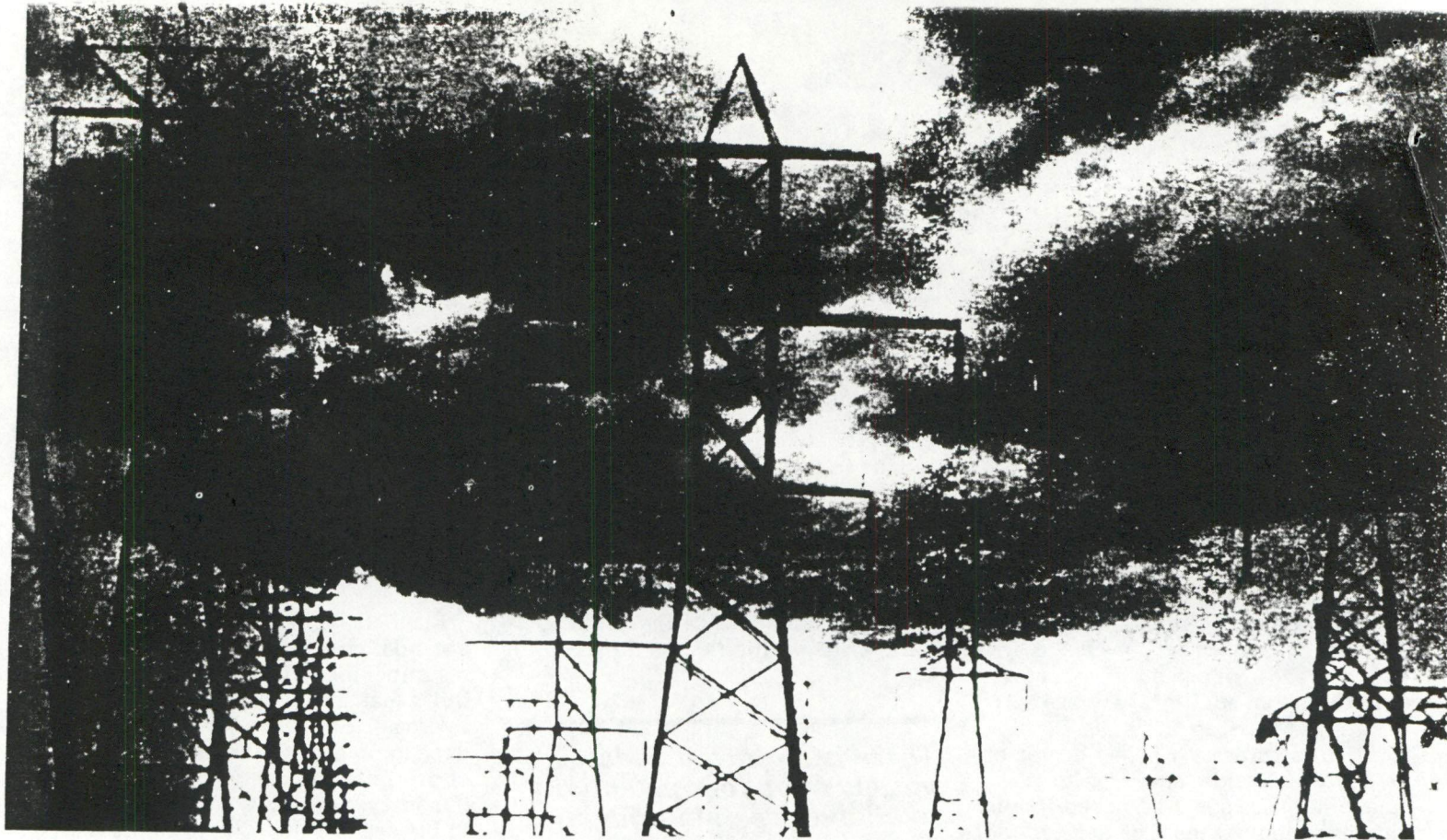
Recent studies indicate that if significant climate change occurs, some effects may be felt within the current planning horizon for utilities. The need for more air conditioning during longer, hotter summers, for example, would not only raise the annual demand for electric energy but increase demand peaks as well. Utility planners must therefore consider both the likelihood of having to build new power plants to meet higher peak demand and the probable need to purchase more fuel for increased generation.

Planners will also need to consider potential changes in energy supply resulting from climate change. Stream flows that affect the availability of hydroelectric energy, for example, depend on both the amount and timing of precipitation, which could be altered in some regions by even small changes in the average global temperature. In addition, the reliability of electricity delivery systems could be affected by shifts in the frequency and intensity of weather extremes, such as tornadoes, hurricanes, and severe storms. Power plant operations in some coastal regions could also be hampered by even a moderate rise in the sea level resulting from thermal expansion of the oceans and possibly increased melting of glaciers and Antarctic ice.

To meet these challenges, utilities will need to adopt more sophisticated strategies of risk management. Although many of the effects of climate change remain unpredictable, the cost of adapting will be much less if some prudent contingency plans are made well in advance. Recognizing this need, the utility industry is sponsoring a program of research to provide a better understanding of the linkages between climate change and electric power operations, and to develop strategies for considering climate-related uncertainties in capacity planning, long-term fuel commitments, and transmission investment.

Helping Society Respond to Climate Change

Beyond facing immediate regulatory and operational challenges, electric utilities will play an important role in the broad societal response to any climate change that does occur. Several of these initiatives, which are quite diverse, represent extensions of ongoing



Richard G. Richels photo

cooperative efforts between utilities and their customers and are being taken to use our natural resources more effectively:

- **Energy conservation:** Many utilities have longstanding, customer-focused conservation programs in place, involving such actions as helping finance home insulation or the purchase of efficient electrical appliances. Such efforts, on a global scale, probably represent the most cost-effective means of slowing the accumulation of greenhouse gases.

- **End-use efficiency:** The utility industry, largely through the activities of the Electric Power Research Institute (EPRI), is co-sponsoring research on increasing the efficiency of electricity use in the residential, commercial, and industrial sectors. Such efficiency improvements are contributing to a longstanding trend of electrification of the world economy, which will also aid adaptation to climate change.

- **Electric vehicles:** Electric vehicles, charged overnight using off-peak power from the most efficient baseload power plants, could significantly reduce urban pollution and—depending on the use of nonfossil power plants—could potentially reduce overall emissions of greenhouse gases as well.

- **Generation technology:** The efficiency of existing plants is being improved, one of the many benefits of the clean coal program. In addition, new technologies are being developed that, over the long term, can help reduce emissions of greenhouse gases from

More research is needed before the time-scale of present climate change and the contribution of human activity to this change are well understood.

power plant operations. These include more efficient ways of burning coal, development of renewable sources such as wind and solar energy, and design of smaller, advanced nuclear plants with improved safety features.

- **Technology transfer:** Since the major contribution of greenhouse gases may eventually come from developing countries, utilities in industrialized nations can play an important role in making advanced technology more widely available for both the generation and use of electric power. Such technologies could help raise the currently low efficiency of power generation and hence reduce CO₂ emissions in the Third World.

- **Planning for adaptability:** As the effects of climate change become more apparent, utilities will need to work closely with government agencies and the public to make plans for adapting. These plans should include multifaceted responses to population shifts, economic dislocation, increased irrigation needs in major agricultural areas, and possibly the pumping of sea water in extensive coastal dike systems.

U.S. electric utilities represent a relatively minor part of the problem of global warming, but potentially a major part of the solution. They remain an easy target for regulation, but national resources would now be better spent on contributing to the scientific basis for policy-making and providing future options to help the world manage climate change if it occurs. Since both utilities themselves and the communities they serve will inevitably be effected by climate change, now is the time to forge a new partnership for creatively addressing the challenges that lie ahead. □

(Peck is Director of the Environmental Risk and Health Science Department at the Electric Power Research Institute. Richels is Manager of the Environmental Risk Analysis Program at EPRI.)

eco



Eco has been published by Non-Governmental Environmental Groups at major international conferences since the Stockholm Environment Conference in 1972. This issue is produced cooperatively by groups attending the Intergovernmental Negotiating Committee on a Framework Convention on Climate Change, Westfields Center, Chantilly, Virginia

NEGOTIATIONS FACE FAILURE?

By Eco Reporter

Climate convention negotiations at Chantilly near Washington, DC start their second week with delegates gloomy at the prospect of achieving a meaningful draft treaty by the meeting's scheduled close on Thursday. The US Administration faces the possible embarrassment of seeing the US\$2m gathering it has hosted, ending amidst disagreement over procedures as well as policy.

Failure will mean that the process is not living up to the Ministerial Declaration of the Second World Climate Conference held in Geneva in November 1990 and which was cited by the United Nations General Assembly Resolution of December 1990, which established the climate convention International Negotiating Committee on a Framework Convention on Climate Change — the climate convention negotiations. The UN Resolution refers to preparing 'an effective framework convention on climate change, containing appropriate commitments.'

Working Groups Confusion, No Draft

Countries have been so far unable to even agree on which draft text to start discussing, although several are in existence. Moreover, nations have yet to put in place the key Working Groups which will hammer out the practicalities of a climate treaty. Some favour one group to debate sources and sinks of greenhouse gases (such as forests to absorb carbon dioxide) as well as financing

mechanisms for this, with another to develop an institution to run the negotiations. The US in particular opposes the specific and binding mandates for Working Groups which the developing countries want to see. Nevertheless, despite frequent side-meetings, the Lesser Developed Countries and others in the Group of 77 have yet to agree on a clear common position.

Europeans Divided

Observers say the Europeans, frequently profiled as the most progressive countries on climate change issues because of a commitment to stabilize net emissions of carbon dioxide from the European Community in 2000, are failing to put much pressure on more recalcitrant major polluters such as the US, because of internal political divisions. The United Kingdom opposes the granting of any real authority to the European Commission in order to work out a fiscal instrument (such as an energy tax) in order to equitably achieve the necessary carbon cuts, a position which if unchanged, could render the joint target largely meaningless. Germany, which has detailed domestic policies to cut its own carbon dioxide by much more than countries such as the UK, has so far remained silent in discussions among the EC delegations. France has departed from the common European position by talking of carbon cuts based on per capita calculations, a similar formula to the ambiguous position adopted by Japan. The French delegation includes no representation from the Environment Ministry.

Continued on back page, column 2

Almost \$1m Shortfall in Climate Fund

By Eco Reporter

A key fund established to enable developing countries to take part in negotiations for a world climate treaty has barely half the money needed to make it work effectively. Observers and delegates at the first session of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change have pointed to the inadequate representation of developing countries at meetings as one

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• *This is an eight page Eco.*

Interview With Robert F. Van Lierop and Colleagues

Last week, ECO spoke to the recently elected Chairman of the Alliance of Small Island States (AOSIS), Vanautu's Ambassador to the United Nations, Robert F. Van Lierop. Renagi Lohia Ambassador to the UN from Papua New Guinea and Naresh Singh, delegate of St Lucia, also contributed to the discussion.

On a day to day basis, Robert Van Lierop spends time on Manhattan Island, representing the interests of his diminutive island state on the world stage down at United Nations Plaza. But increasingly often, he and his colleagues in AOSIS are to be found dealing with climatology, ecology and the international economics of energy, taking news of the problems faced by nations in the front-line states of global warming, and their ideas for solutions, to publics and decision-makers the world over. AOSIS countries made quite an impact at the Second World Climate Conference in Geneva, and the eyes of many developing countries are now upon them as they constitute the first readily identifiable bloc of potential 'victim' countries in climate negotiations.

ECO: What does global warming mean to the people of the Alliance of Small Island States?

Ambassador Van Lierop: Really it's a question of survival — it's that simple. A number of the small island states are actually low-lying and sea level rise of a foot or less could have disastrous consequences. At the very least it could destroy the ecosystems — at worse whole countries could disappear underwater. Others are already experiencing increased tropical storms: we take that as an indication of what may be to come. And even countries as large and wealthy as the United States already have serious climate-related problems, for example with soil erosion.

ECO: In Geneva your group likened the drowning of a nation and the extinction of a culture, to the loss of a species like the blue whale. Do you feel you have to resort to comparing yourselves with wildlife to get the attention of people in the 'north'?

Ambassador Van Lierop: It is a sad commentary but a truth that there are some people who care more about endangered animals than endangered humans. Already whole indigenous cultures have disappeared through economic and cultural expansion from other regions — now environmental and ecological destruction caused by economic expansion threatens to wipe out our cultures.

ECO: Are you getting your message across?

Ambassador Van Lierop: The test will be the result of the negotiations: the real proof will lie in what gets included in the convention and what types of action are required to be taken.

ECO: It seems bizarre to many people outside this process that shortage of even the modest finance to support participation by developing countries may be preventing the active participation of many of them in negotiations over the world's most important environmental issue, in which they are the principal victims. We understand that the UN has only been able to provide money for one air ticket and that some countries didn't receive notice of that until the week before it started. Would you comment on that?

Ambassador Van Lierop: We have been encouraged by the US statement this week, which mentioned a US intention to provide assistance in the form of per diems as well as travel costs. To the developed countries it is not much money but to developing countries the cost of attending such a meeting is enormous. You'll notice there are plenty of empty seats which ought to have been filled by developing country delegates. Ten days here with no extravagances costs about \$US1500, which could pay a graduate teacher for two months in our country. It is important to be here: we need to ensure our survival and the future well being of our countries but it is really important to have two people present to cover a negotiation. AOSIS helps with that: it's not just a joint representation of interests but a way to cooperate and help keep each other up to date.

Naresh Singh: Countries need to know what is going on in the negotiations and the presence of the Alliance at these negotiations is a chance to see our views taken into

account but it is also a way for nations to start planning their own strategies. In the past we have been presented with conventions and asked to sign them. That naturally makes developing countries suspicious of such processes themselves. As for finance, it is now generally accepted that the ability to obtain justice shouldn't be dependent on wealth. In practice there are many countries who have been unable to afford to attend this meeting.

Ambassador Renagi Lohia: Yes, and to be effective, countries need to know ahead of time what is happening — everyone in small developing countries has more than one job to do.

ECO: AOSIS has spoken of the need for 'compensation': what do you have in mind, how would it work?

Ambassador Van Lierop: We mean economic assistance for adaptation as well as compensation for damage. As to how it would work, that's too early to tell. Generally AOSIS states prefer a multilateral approach as it is more objective and less prone to improprieties.

ECO: Have you personally experienced impacts you attribute to climate change?

Ambassador Van Lierop: Yes, we have experienced intense tropical storms in recent years. One did damage to the capital city of Vanautu amounting to ten times the national budget. The storm came from a different direction to many which had come before, the people were unprepared for its direction, intensity and timing. That was in 1987. Its impact was very similar to that of Hurricane Hugo in the Caribbean. Similarly, equally unusual storms had occurred a few years before in Samoa, the Solomon Islands and Fiji. The Vanautu storm caused flooding and wind damage to buildings, houses and crops. It cost \$US28m.

ECO: Is there a problem with insurance?

Ambassador Van Lierop: Yes, there is! And if the government eventually has to become the insurer of private concerns, that will only increase the foreign debt.

ECO: We have heard a lot about coral bleaching: what is the status of that problem?

Ambassador Renagi Lohia: The bleaching is now more evident than ever before. It's due to a warming of the sea.

Naresh Singh: The most recent information has come from Dr. Hays of Howard University at the Discovery Bay Marine Laboratory in Jamaica. He has reported this to the US Congress. He studies one area in some detail. It's important to realize that when the corals die, it affects the whole marine life cycle, and that is the basis of food not only for fish but for human communities. And fisheries here include industrial fishing significant for government economies and subsistence fishing on which many local communities depend.

ECO: What do you and AOSIS hope to get from this meeting at Westfields?

Ambassador Van Lierop: Realistically, a draft text. But we also need to bring the need for urgent action to the attention of the world community. There are only 16 months between now and the target date of June 1992. We need a very good draft text to take forward.



Robert F. Van Lierop

Millions Could Become Climate Refugees

By Nicola Pain

In 1987, President Gayoom of the Maldives, warned the United Nations that, as a result of sea level rise induced by global warming, his country could literally disappear beneath the waves. Like many small island states in the Indian Ocean, South Pacific, the Caribbean and Mediterranean, the Maldives lie only a few meters above sea level. Thus, the rise of 30 to 110 cm predicted by the IPCC to occur by 2100, would have a devastating effect. Exacerbating the problem is the fact that

many of these islands are densely populated, giving rise to the specter of sea level rise creating thousands, perhaps millions of landless "environmental refugees."

To address the acute problems which global warming and its effects pose to these vulnerable countries, the Alliance of Small Island States (AOSIS) was formed during the Second World Climate Conference in Geneva in 1990. In order to prepare for the INC meeting this week, AOSIS held a scientific and political briefing for its members on February 2 and 3 in Washington, DC.

Coral

The serious problems of coral reef bleaching was discussed at length by Dr. Raymond Hays, of Howard University. He described coral bleaching as "one of the earliest signals of climate warming by a biological ecosystem." Bleaching occurs when coral reefs undergo severe stress, which Dr. Hays believes is occurring as a result of changes in water temperature. The AOSIS participants saw dramatic evidence of the link between bleaching and temperature when Dr. Hays displayed a chart showing that bleaching has occurred simultaneously with peaks in water temperature.

Plea For Action

The 20 countries of AOSIS last week called on industrial nations and others at the Climate Convention Negotiations in Washington, to take immediate action to curb greenhouse gases and avert the growing threats of sea-level rise, storm surge, cyclones, tropical storms, and salt-water intrusion. The AOSIS countries called for the Convention to be 'comprehensive, equitable, and meaningful.'

The island states want to see an agreement based on six principles. They are seeking 'immediate and significant cuts in the emissions from industrialized countries of carbon dioxide and other greenhouse gases into the atmosphere.' The island nations also call for 'a preventive approach based on the precautionary principle,' new funding mechanisms including compensation, the 'transfer on an equitable basis of appropriate and environmentally sound technologies,' 'application of the Polluter-Pays Principle to the consequences of climate change' and a 'commitment to binding energy conservation and efficiency requirements and the development of alternative energy sources.'

One Caribbean delegate stated, "there is clear evidence of hurricane increases and coral bleaching as would be expected with

global warming." The delegate added, "we need to go much further than fuel efficiency - steps which we will all take anyway."

Alliance of Small Island States

'Member' countries of the Alliance of Small Island States (AOSIS) (underlined) and other states with an interest in the alliance. (The number of states involved is actively increasing).

Caribbean

1. Antigua and Barbuda
2. Barbados
3. Bahamas
4. Dominica
5. Grenada
6. Montserrat and Anguilla
7. Jamaica
8. St. Christopher and Nevis
9. Saint Lucia
10. Saint Vincent and the Grenadines
11. Trinidad and Tobago
12. Guyana
13. Belize
14. British Virgin Islands
15. Turks and Caicos Islands
16. Cayman Islands

Pacific

17. Fiji
18. Kiribati
19. Tuvalu
20. Samoa
21. Marshall Islands
22. Vanuatu
23. Soloman Islands
24. Paria New Guinea
25. Federated States of Micronesia
26. Nauru
27. Cook Islands
28. Tonga
29. Nive
- Pacific Non-Self Governing Territories
30. New Caledonia
31. Palau (TTPI)
32. American Samoa
33. Guam
34. Tokelau
35. Tahiti
36. Wallis and Fatuna
37. East Timor

Indian Ocean

38. Mauritius
39. Maldives
40. Comoros

Mediterranean

41. Malta

Atlantic Ocean

42. St. Helena

eco Policy, Science, and People

Policy makers and scientists dominate the negotiating sessions on climate. Their credentials are experience in making international and national laws and understanding why 400-560 ppm of CO₂ will create a rise in temperature 1-2 degrees centigrade. The beneficiaries of their work will be the people of the world, most of whom are unaware of what has begun in Chantilly, Virginia on their behalf. What if they were here?

Imagine adding to the negotiating sessions at Westfields the indigenous peoples of the Amazon, farmers from the US midwest, Norwegian fishermen, Indian villagers, ecologists from the Central America, women from rural Africa, youth from the islands of the Pacific, industrialists from Singapore and Japan, and students from Eastern Europe. Would the pace of the negotiations increase? Would the decisions reached be more equitable?

An experiment along these lines was tried by the Economic Commission of Europe in Bergen last May. The ECE, in part of the regional preparations for the 1992 United Nations Conference on Environment and Development, brought together representatives of governments, youth, industry, labor, science and voluntary organizations to build an agenda for action that could be pursued at least in part by each sector.

What difference did the new players make in the negotiations? The words of the agenda were hammered out in all night negotiating sessions, not unlike ones we can expect in the months to come. Partisanship was evident. Youth argued for expenditures that would benefit future generations; scientists saw the benefits of monitoring and research. Yet it was different. These major constituencies understood much better the tradeoffs needed to reach agreement on energy, economics, technology transfer and public participation. They were better prepared to implement the agenda immediately. Governments began to think in a different time frame, too. When youth insisted on an economic goal of reducing military expenditure, it was hard to argue it was not their business.

The 1992 UN Conference on Environment and Development is seeking to involve even more sectors of society in negotiations and events leading to Brazil. The experiment of Bergen is expanded to include most countries of the world and many more issues than the four addressed by the ECE. As in Bergen, only Ministers can ultimately sign an agreement that will bind countries to actions to slow global warming or save biological diversity. People, however, will be the ones to allow these agreements to be implemented and will set the pace for change. If they are involved from the beginning, the odds improve that efforts here and over the next eighteen months will make a difference.

The Road to Brazil

By Fran Spivy-Weber

June 1992 will see the United Nations Conference on Environment and Development (UNCED) in Brazil. The Climate Convention will be a centerpiece of this event. The UNCED comes twenty years after the 1972 Stockholm Conference on the Environment which led to the creation of the United Nations Environment Programme. The UNCED will be the largest conference ever to address the dual needs of people and the environment, today and in the future.

However, climate is not the only issue of the summit, nor is the climate treaty the only convention winding its way down the road to Brazil.

The products of the UN Conference on Environment and Development are expected to include:

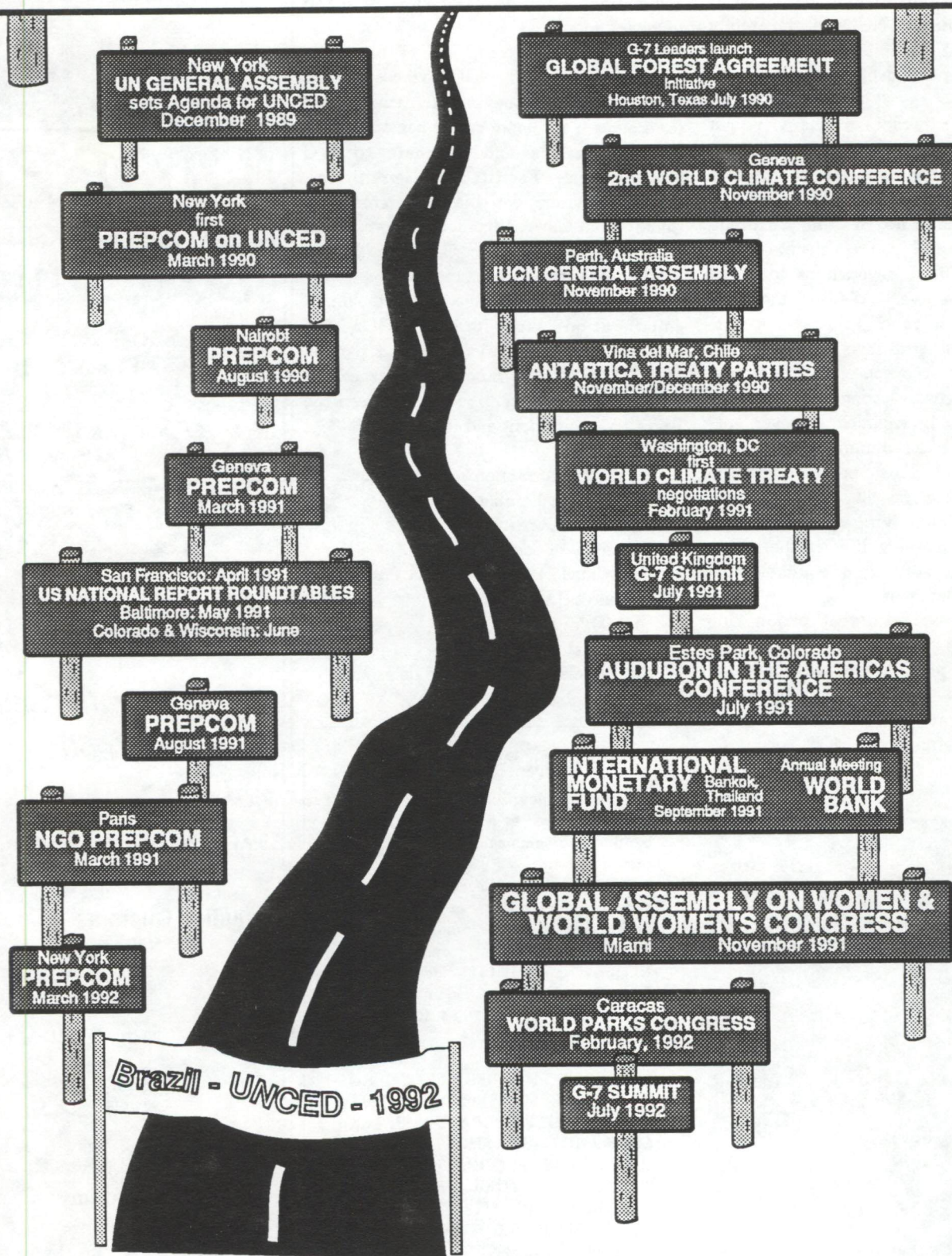
- a) three or four new conventions (climate and forests, biological diversity, possibly biotechnology and ocean pollution from nonpoint sources),
- b) Agenda 21, which will include coordinated and independent actions by all sectors of society, regionally and globally, to achieve the summit goals,
- c) a redefinition of roles and responsibilities for several United Nations agencies, and
- d) an Earth charter of environmental rights.

The issues that will be discussed at the summit include: climate change, transboundary air pollution, deforestation, desertification, biodiversity, biotechnology, ozone depletion, marine pollution, living marine resources, freshwater, poverty and environmental degradation, toxic waste disposal, urban environment, environment and health, new/renewable energy sources, financial resources, technology transfer, legal instruments, institutions, economic instruments, and education and information.

In addition to the June 1992 meeting of the Parties, a meeting of Ministers is planned. Other meetings are planned for parliamentarians, scientists, industry, Non Governmental Organizations, and indigenous peoples. This is a potential bonanza for people and the environment, but preparation is the key to success.

As chair of the US Citizens Network on UNCED, Fran Spivy-Weber is deeply involved in the preparations for the 1992 conference. She can be contacted at National Audubon Society, 801 Pennsylvania Avenue, S.E., Suite 301, Washington, DC 20003

To Brazil (distance 16 months) United Nations Conference on Environment and Development



FORUM 1992

Brazilian nongovernmental environment and development organizations have created the National Forum of NGOs in preparation for the United Nations Conference on Environment and Development - Brazil 1992.

The Forum subscribes to the view put forward by many groups that a main task over the next 18 months will be to formulate a grassroots perspective on environmental and development issues, to bring a citizens' commentary to the policy debate, and to confront the official negotiations in Brazil with this perspective. We see the 1992 Conference not so much as an event unto itself, but as a stimulus to dialog and networking. The occasion of the conference provides us a focus for action and a deadline to meet. It must be regarded, however, only as a point on a continuum stretching far beyond June 1992. This process must lead to international networks of citizens groups dedicated to identifying priorities and strategies for preserving life on the planet through new paradigms of equitable and sustainable development.

The Forum is aware that undertaking these activities will require substantial resources. At present, we are contacting foundations and other funding sources in order to support our activities at both national and international levels.



Magda Lombardo

Brazilian NGO representatives were part of the NGO Climate Change Network observing the Second World Climate Conference in Geneva at the end of October 1990. Forum members were also represented at the second meeting of the International Facilitating Committee held at Geneva the following month.

The Forum is comprised of members, observers, and 400 NGOs whose shared objective is to promote an alternative model for economic development. It has nominated a representative and alternate to IFC (International Facilitating Committee), CELSI (Environment Liason International Center), and CIMA (Brazilian Governmental Commission of the Conference on Environment and Development).

The Forum has the duty to coordinate, in collaboration with foreign NGOs, the planning and organization of events parallel to the 1992 Rio de Janeiro Conference. It will also act as an intermediary between the Brazilian government and foreign NGOs.

For more information contact:

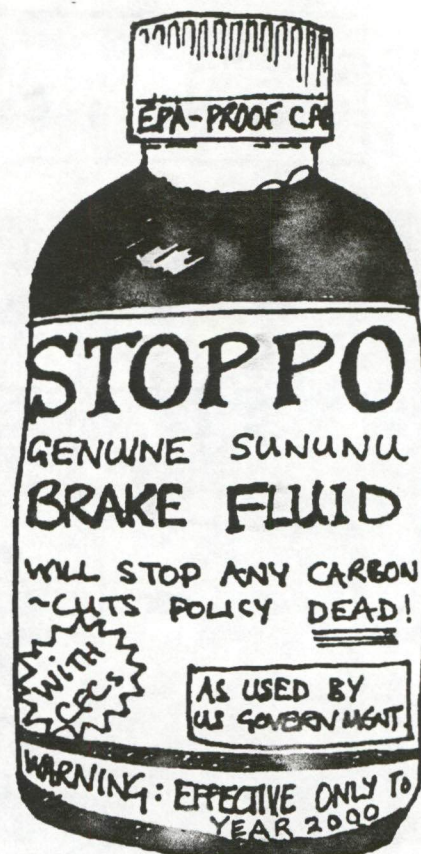
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ECO NEWSLETTER

This is the fourth issue of ECO newsletter, produced as a cooperative effort by the environmental NGOs attending the conference. ECO will accept contributions from delegates and others, and suggestions as to stories which should be covered or people who should be interviewed. ECO is produced at the National Wildlife Federation's Educational Facility in Virginia and can be contacted at (703) 790-4010/4012 or 4013, FAX (703) 790-4011.

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G. Bush, The White House,
Pennsylvania Ave., Washington D.C.

Environmental Defense Fund

The Environmental Defense Fund (EDF) is a US-based, non-governmental, non-profit organization with a membership of over 200,000, dedicated to creating innovative, economically viable solutions to major environmental problems by linking science, law and economics. EDF's international program has been a pioneer among US groups in connecting development issues to environmental protection by questioning some of the development policies of multilateral development banks on environmental grounds.

It's global atmospheric program comprises the largest assemblage of scientists, economists and lawyers of any national non-governmental organization working on climate change. This collection of expertise has placed EDF on the cutting edge of climate change developments. As examples, EDF's senior scientist chaired the Working Group on Limitation strategies for Greenhouse Gases of the Advisory Group on Greenhouse Gases (AGGG), and the organization's primary international lawyer represents EDF on two advisory bodies on atmosphere and oceans to the Secretary General of the UN Conference on Environment and Development. In addition, EDF attorneys have participated as observers at the meetings of the Intergovernmental Panel on Climate Change at the recently concluded Second World Climate Conference — actively contributing to both the Ministerial Declaration and Scientific and Technical Statement — and at a preparatory meeting for the current session of the Intergovernmental Negotiating Committee.

Climate Action Network

While undertaking independent studies on the scientific and institutional complexities of the climate change issue, the organization works closely within an international coalition of NGOs — the Climate Action Network. While the Climate Action Network has played an effective coordinating role over the last few years, its scope has, until recently, been limited to North America, Western Europe and Australia. Recognizing this limitation, EDF has recently undertaken to expand the network of NGOs working on climate change to include Central and Eastern Europe and

the USSR, and Asia, Africa and Latin America. Through a gradual process of identifying and soliciting the interest of individuals and groups in these parts of the world, a wide reaching network is currently being established.

As a result of this initiative, twelve NGOs from various Eastern European and Developing countries — encompassing scientific, legal and rural development expertise — attended the Second World Climate Conference in Geneva, and eleven NGOs from these regions are currently participating actively in the first session of the International Negotiating Committee for a Framework Convention on Climate Change. This initiative will continue and expand as the negotiations on a convention unfold up to June, 1992, and beyond 1992 to negotiation of related instruments and their implementation.

The benefits from participation of NGOs from Asia, Africa, Latin America and Eastern Europe in the Climate Action Network are considerable. First and foremost, strong representation from and involvement of NGOs from these regions is crucial to developing credible and balanced NGO positions on the range of climate change issues that can then be presented to delegates. Developing country NGOs bring detailed knowledge of the realities of development efforts and natural resource use — at community, regional, and national levels — that must be a fundamental part of any climate change limitation or adaptation strategies.

Second, participation in international negotiations and meetings serve to inform NGOs on the issues so that they can disseminate information on the subject to other NGOs and interested parties.

Regional Networks

However, since few NGOs in developing countries have ongoing programs on climate change, mere attendance at and participation in international meetings and negotiations is not sufficient to ensure full involvement of many in the issue. Recognizing this, EDF is currently expanding its international activities on climate change to assist local indigenous NGOs develop regional networks on climate change in Asia, Africa and Latin America. Regional networks will:

- disseminate effectively information on climate change issues to local NGOs and

- seek to raise public awareness of the issue;
- develop expertise among local NGOs on climate change issues, thereby strengthening their advocacy of long-run sustainable development policies in their own countries and internationally;
- organize research by local NGOs on climate related issues relevant to their region, and subsequently prepare working papers to address specific issues relevant to the climate change negotiation. Such research work will serve to inform and develop Climate Action Network positions so that they emphasize the legitimate aspirations of the people in developing countries.

EDF is committed to halting global warming. This commitment is put into practice by undertaking substantive research work on the scientific, economic and policy aspects of the issue, and by working closely with government agencies, and other NGOs within the Climate Action Network to positively influence climate change negotiation and discussions. Internationally, EDF has taken the lead in ensuring that NGOs from hitherto under-represented regions will have the necessary expertise and opportunities to represent their views on climate change to the world community.



A National Wildlife Publication

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Continued from page 1, column 3

reason why it may be difficult or impossible to agree on a climate treaty by the deadline set for the United Nations Conference on Environment and Development (UNCED) in 1992. Almost one million dollars (US \$946,000) are missing from the fund to date.

Delegates from virtually all industrialized countries — including M. Jean Ripert of France, the new chairman of the negotiations — have spoken of the need to ensure that work on a climate change convention and related protocols is a truly global effort. A Trust Fund has been set up to cover the travel and daily costs of representatives of developing countries participating in the negotiations. ECO understands however that contributions made to this fund indicate that the commitment of some industrialized countries is so far more rhetorical than actual.

The United Nations Secretariat, set up to organize the convention talks between now and the UNCED meeting in June, 1992, has calculated that \$2,140,000 is needed to ensure that two representatives from each of 63 countries (the Least Developed plus the Small Island developing countries), can attend the several 1991 negotiating sessions planned for the expected climate change convention. Total contributions to this point, as outlined below, are barely 50% of this total.

Observers point out that the shortfall is even more significant than it appears, due to four additional factors. First, it will not cover the costs of representatives from developing countries outside the 63. Second, it will not allow any developing country representatives to participate in the IPCC (Intergovernmental Panel on Climate

Change) process, the science grouping which preceded the negotiations and continues to assess new scientific findings to advise the negotiators. Third, it cannot support preparatory work in any developing countries, and fourth, it does not cover the costs of a third delegate from any of the 63 countries. Many such delegations point out that a third delegate might be useful when two sessions of the negotiations are being held concurrently. By contrast, the delegations from countries such as Japan and the US may include a dozen or more officials, enabling such countries to be represented on many committees and working groups.

Continued from page 1, column 2

EFTA Split

Meanwhile EFTA (European Free Trade Association) countries remain severely split over carbon reductions following the breakdown of an attempt to achieve a common position at the Second World Climate Convention. While Switzerland and Austria are committed to firm policies to reduce carbon dioxide emissions from traffic and other sources, the Nordic countries, normally among environmental leaders, are refusing to commit themselves to measures to achieve a freeze on the gas by 2000 in line with the EC position. Finland in particular is believed to be a problem to the Nordic group, although neither Sweden nor Norway have issued a clear policy statement showing that they will achieve cuts.

Thus, observers suggest, with a few exceptions such as Australia and New Zealand, key developed country blocs are presently proving ineffectual in developing political momentum to develop a climate

convention with teeth.

US Energy Bill Cut

In particular, despite internal chaos over climate policy, the United State Government has felt no particular pressure to adopt stronger or clearer policies. On Saturday, the Washington Post carried a leaked report showing that administration supporters had excised parts of a draft Energy Bill concerned with energy efficiency, which would be key to achieving any significant cuts in US carbon dioxide emissions, the worlds largest. The Administration had hoped to keep the draft Bill from becoming public during the climate negotiations which began with the publication of a widely criticized and vague US 'climate strategy.'

US Department of Energy officials who had drafted the deleted text, have been ordered to keep quiet. Observers believe that the Administration's opposition to specific mandatory measures to require increased energy efficiency is largely ideological. Last week the Congressional Office of Technology Assessment reported on a two year study which showed that the US could, using existing technologies reduce its CO₂ emissions 29-35%. "This is the abdication of any attempt to connect US energy policy to greenhouse negotiations," said Richard Mott, of WWF International. "It's much worse than had been feared — the eleventh hour elimination of energy efficiency provisions by a group of White House insiders has fended off all attempts by others, such as EPA, OTA, Department of Energy, and the State Department to get the Government more in tune with what's going on internationally."

'Magnificent Keystone' Missing?

If delegates fail to reach agreement on a draft treaty text at the Washington meetings, the next opportunity for an all-nation discussion will be at a Nairobi meeting scheduled for summer or winter 1991. The meeting schedule, already crowded, looks increasingly difficult to meet. A statement by UN Secretary General Javier Perez de Cuellar opening the current negotiating sessions said that it would be 'the most magnificent keystone in the building of a new world order' if a treaty was ready for signature at the June 1992 United Nations Conference on Environment and Development due to be held in Rio de Janeiro, Brazil. In the words of one observer 'it now looks as if the UN's 'new world order' may be missing its keystone unless governments get their act together in the next few days.'

Country	Commitment (\$US)
Switzerland	\$240,000
European Community	\$150,000
Netherlands	\$150,000
United Kingdom	\$108,900
Denmark	\$100,000
Germany	\$100,000
Sweden	\$ 85,000
France (and bilateral aid)	\$ 80,000
Norway	\$ 50,000
United States	\$ 50,000
Spain	\$ 50,000
Canada	\$ 30,100
TOTAL	\$1,194,000
TARGET	\$2,140,000

New Zealand and Australia: Committed to providing bilateral assistance to AOSIS members of the South Pacific throughout the negotiations.

Finland	No amount yet committed
Austria	No amount yet committed
Italy	No amount yet committed
Japan	No amount yet committed
Portugal	No amount yet committed
Belgium	Unknown
Greece	Unknown
Iceland	Unknown
Ireland	Unknown



ENERGY EFFICIENCY: A NEW AGENDA

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HOWARD S. GELLER
MARC R. LEDBETTER

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file

ENERGY EFFICIENCY: A NEW AGENDA

William U. Chandler
Howard S. Geller
Marc R. Ledbetter

The American Council for an Energy-Efficient Economy

1001 Connecticut Avenue, N.W.
Washington, D.C. 20036

July 1988

The American Council for an Energy-Efficient Economy (ACEEE) is a nonprofit organization dedicated to the advancement of energy-conserving technologies and programs. ACEEE scientists, engineers, and policy analysts gather, evaluate and disseminate information for business consumers, utilities and government.

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Executive Summary

Three major national priorities—environmental quality, economic competitiveness, and energy security—provide a new and urgent rationale for saving energy. None of these ends can be fully attained without also achieving an energy-efficient economy.

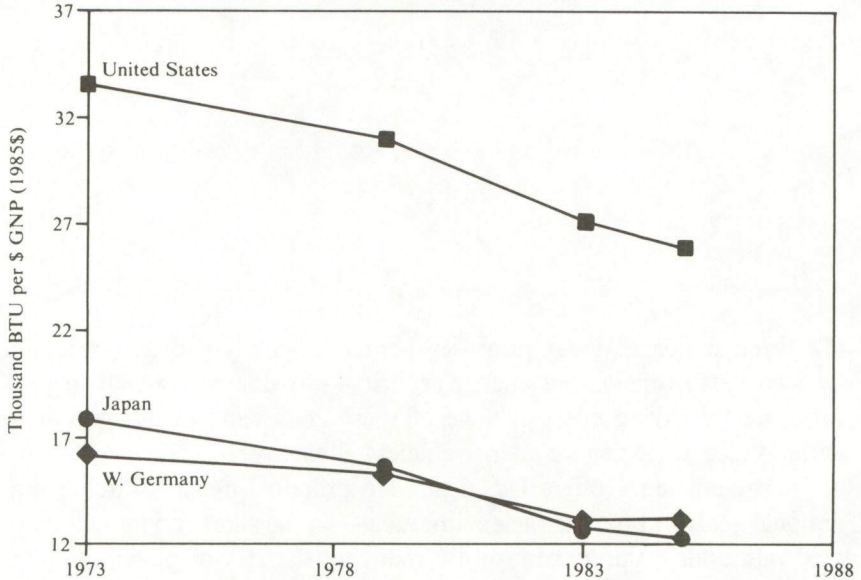
Energy efficiency offers U.S. leaders a practical means of achieving national goals. It protects the environment—in the short run by reducing acid rain and in the longer run by reducing the risk of global climate change. It strengthens U.S. security at a time when domestic oil production is declining and we are becoming excessively dependent on oil imports. Energy efficiency enhances the competitiveness of U.S. industries in world markets by reducing the cost of production, and serves the consumer by cutting lighting, cooling, and heating costs in homes and offices. It creates jobs and helps hold down interest rates. No energy supply option can provide all these benefits.

Energy efficiency works. It has permitted the United States to hold energy use to 1973 levels while expanding the economy by 40 percent. (See Figure 1.) Efficiency improvements now save the U.S. economy \$160 billion per year. If the nation pursues energy efficiency aggressively and adopts the policies proposed here, the economy can continue to grow while energy use remains constant or declines.

New policies are needed because the United States is losing momentum in energy efficiency. Automobile fuel economy has leveled off after improving steadily for ten years. Industrial energy intensity, correcting for changes due to structural shifts, leveled off in 1983. Japan and West Germany now use only half as much energy to produce goods and services as the United States, making them more competitive in interna-

Energy Efficiency

Figure 1: Energy Intensity Reductions, 1973-85



Energy Efficiency Works

Before 1973, most analysts thought that energy use and GNP moved together in lock-step. But energy demand has increased little since the early seventies, while GNP has grown by 40 percent. Energy-efficiency improvements now save the U.S. economy \$160 billion annually.

Nevertheless, Japan and West Germany use half as much energy per unit of economic output as the United States. This fact gives those nations a competitive advantage.

SOURCE: International Energy Agency

tional markets. Oil prices have fallen below their real cost to society, causing U.S. oil imports to jump 35 percent since 1985.

To protect and enhance the U.S. environment, its economy, and its security, we urge the United States to place efficiency at the top of its energy agenda. *We propose that the nation set a goal of reducing energy intensity—the rate of energy used per dollar of economic output—by at least 2.5 percent per year well into the next century. This rate would approximate the efficiency improvements of 1976-86, during which two*

Executive Summary

oil price surges accelerated energy-efficiency improvements. It can be achieved using available, cost-effective technologies, which are often overlooked because of low energy prices and market imperfections.

This report describes six energy-efficiency policy initiatives—and twenty-one specific policy actions—critical to meeting the energy-efficiency goal. (See Table 1.) Our list is not meant to be all-inclusive, for other measures can supplement the effort. Specifically, we propose that the nation:

- Apply energy-efficiency to protect the national and global environment;
- Double car and light truck fuel economy to cut oil imports;
- Promote least-cost utility services;
- Enhance industrial competitiveness with energy-efficiency research;
- Make buildings more efficient to improve their affordability;
- Help developing countries acquire skills and technologies for energy efficiency.

These policy priorities have been selected for four reasons. They address problems that the marketplace cannot completely solve. They represent the largest of many opportunities to save energy and accomplish other objectives cost effectively. They ameliorate critical problems that energy use causes for the global environment, the economy, and national security. And they are compatible with ongoing efforts to reduce the federal deficit—indeed, the revenues generated in implementing these policies will far exceed expenditures.

We do not advocate saving energy as an end in itself. It makes sense only when saving energy costs less than providing energy, including environmental damage and security risks in the comparison. (See Figure 2.) Moreover, energy efficiency does not require sacrifice. The challenge is to use public policy in ways that complement the market, enabling the nation to realize the multiple benefits of greater energy efficiency.

Energy Efficiency

Table 1. Policies for an Energy-Efficient Economy

Goal: Reduce U.S. energy intensity by 2.5% per year

Applying energy efficiency to protect the national and global environment

1. Reduce the risk of climatic change through an international energy-efficiency protocol.
2. Establish Soviet, American, and OECD cooperation to promote energy efficiency on a global basis.
3. Develop technologies that simultaneously save energy and protect the stratospheric ozone layer.
4. Use emissions ceilings for acid rain control.
5. Encourage integrated energy and environmental planning at the state and federal levels.

Doubling car and light truck fuel economy to cut oil imports

1. Raise gasoline and diesel fuels taxes by 10 cents per gallon for at least three consecutive years.
2. Raise car and light truck fuel economy standards to 45 and 35 mpg, respectively, by the year 2000.
3. Establish a gas-guzzler tax, gas-sipper rebate program.

Promoting least-cost utility services

1. Provide utilities with financial incentives to promote energy efficiency and least-cost energy services.
2. Allow energy-efficiency investments to compete with energy supply options in competitive bidding schemes.
3. Encourage least-cost planning through federal regulation of interstate power sales.
4. Conduct research and evaluation to improve utility, state, and local energy conservation programs.

Executive Summary

Table 1: Continued

Enhancing industrial competitiveness with energy-efficiency research

1. Increase the commitment to federal energy-efficiency research and development and re-establish the federal role in demonstrating new energy-efficient technologies.
2. Establish research centers for energy-intensive industrial processes.
3. Establish a program to monitor and distribute information on foreign energy efficiency research.

Making buildings more efficient to improve their affordability

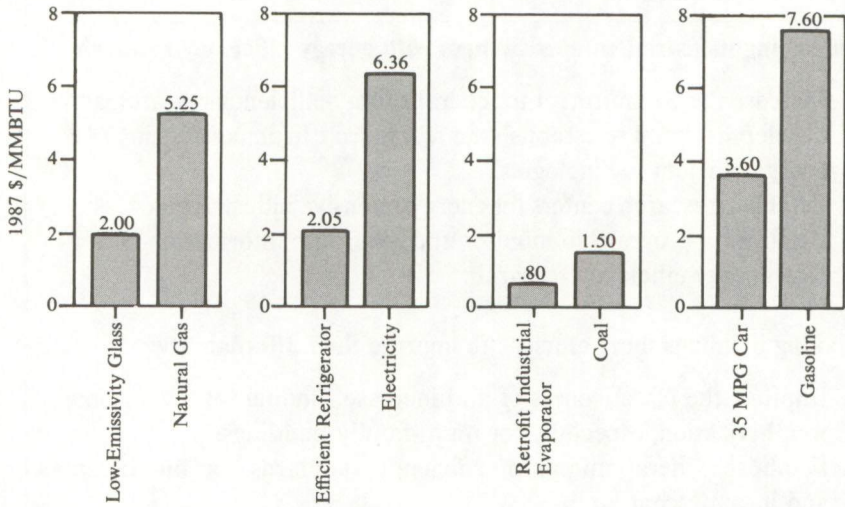
1. Improve the effectiveness of and increase funding for low-income weatherization, especially for multi-family buildings.
2. Establish federal minimum efficiency standards for fluorescent and incandescent lamps.
3. Improve the energy efficiency of federal buildings.
4. Expand federal technical assistance for conservation efforts.

Helping developing nations acquire skills and technology for energy efficiency

1. Modify the energy planning and lending policies of the World Bank and other multilateral lending and development institutions.
2. Provide technology and policy assistance for energy efficiency to developing countries through U.S. and other American agencies.

Energy Efficiency

Figure 2: Cost of Energy Saved vs. Cost of Energy Supply



Energy Efficiency: The Cost Advantage

The cheapest way to satisfy growing demand for energy services is to invest in energy efficiency. Home insulation costs far less than nuclear or coal-fired electricity. Auto fuel economy can be built into new cars for less than the price of gasoline. Industrial retrofits save money even with today's low energy costs. The cost advantage shown above does not even count the environmental and national security benefits that energy efficiency inherently offers.

SOURCE: American Council for an Energy-Efficient Economy

How can energy efficiency protect the environment?

Unchecked fuel use could irrevocably alter the global environment. Atmospheric warming caused, in part, by the greenhouse effect of fossil fuel emissions could shift rainfall patterns and raise sea levels. The U.S. breadbasket could be turned into a dustbowl. East-coast beaches might be eroded forever, and forests could deteriorate rapidly. Evidence is

Executive Summary

mounting that these changes are already underway, but the world need not wait for proof—energy efficiency can greatly reduce the risk of climate change *and* it can be justified entirely on its own economic merits.

We propose that the United States sponsor the first and most important of a series of protocols to control greenhouse gas emissions: An agreement among nations to reduce the energy intensity of the world economy. This initiative would inaugurate an international process for setting and periodically modifying energy-efficiency goals and reporting on implementation plans. A reasonable and effective goal is to reduce global energy use per unit of economic output by roughly two percent per year for at least the next three decades. We suggest that the United States set an example by pursuing a goal of at least 2.5 percent per year. In conjunction with this agreement, *we propose a major cooperative effort among the United States, the Soviet Union, and other countries to share research and information on technologies for improving the efficiency of energy use.*

Acid rain is already seriously damaging forests, lakes, crops, and materials in the United States. Energy efficiency is not a complete solution to the acid rain problem, but it can significantly cut emissions and pollution control costs. *We propose that energy efficiency be applied to reduce the cost of acid rain cleanup for the nation.*

In addition, we suggest that *a research program be undertaken to develop technologies that simultaneously save energy, reduce greenhouse warming, and protect the stratospheric ozone layer.* Such technologies are needed to avoid increasing energy use when chlorofluorocarbon (CFC) production is reduced, as agreed by the United States and other nations in 1987.

How can the United States strengthen its energy security and reduce dependence on oil imports?

Cars and light trucks account for one-third of U.S. petroleum consumption. Raising their fuel economy is essential to reducing energy security risks. The technical and economic potential already exists to

Energy Efficiency

double light vehicle fuel economy. Doing so will help the United States prepare for declining domestic oil production, and help avoid putting the nation at the whim of foreign oil producers.

We propose a complementary set of policies to double automobile and light truck fuel economy. Economic incentives are needed to pull the market; performance standards are needed to push it. Specifically, a new transportation fuels tax is needed to more nearly reflect the real, long-run cost of consuming non-renewable oil resources. We suggest *increasing federal gasoline and diesel fuel taxes by 10 cents per gallon yearly for at least three years*. We also suggest *raising the fuel-economy standards for new cars and light trucks to 45 and 35 miles per gallon, respectively, by the end of the next decade*. In addition, we suggest *expanding the gas-guzzler tax and providing direct rebates to buyers of highly efficient cars produced in North America*.

How can the United States reduce the costs of utility services?

Utilities accounted for nearly 15 percent of total U.S. investment in new plant and equipment in recent years. Moderating growth in electricity and natural gas demand would lower this level of investment, thereby reducing the risk of over-building expensive power plant capacity and lowering the cost of capital. Likewise, cutting the cost of heat, light, refrigeration, and other energy services saves consumers money, and helps the United States become more competitive.

To reduce investment by utilities and the cost of their services, utility commissions should redesign financial incentives provided to utilities. Specifically, *state utility commissions should offer financial incentives to public utilities based on their achievements in providing utility services at the least cost*. We also recommend that efficiency investments be allowed to compete with supply options in competitive bidding schemes; that long-term interstate power sales be made consistent least-cost utility plans; and that federal support be provided for experiments and evaluation to improve efficiency programs.

Executive Summary

How can government support industry's efforts to become more competitive?

Although the U.S. is pre-eminent in basic science, it lags in bringing new technologies to market. And it has lost market shares both in traditional areas of strength such as steel and automobiles as well as in some high-tech fields. U.S. industry, however, has the opportunity to open new markets in energy-efficient products. Furthermore, energy represents a major cost for many industries, and U.S. manufacturers must cut production costs if it is to compete internationally. Government can cooperate with industry to research, develop, and demonstrate new energy-efficient products and more efficient processes.

We recommend a renewed federal government commitment to cooperate and share the cost with industry of researching, developing, and demonstrating energy-saving products and processes. Special attention should be devoted to new technologies that simultaneously cut energy use and provide other benefits such as improved quality and productivity. This cooperative effort can be conducted by expanding the U.S. Department of Energy's conservation research and development program. In addition, we propose that the federal government together with private industry *create research centers in energy-intensive industrial processes.* These centers would investigate common industrial processes such as metal casting or chemicals separation—key elements of the industrial infrastructure.

How can buildings be made more efficient and affordable?

Because home energy costs account for one-fifth of poor people's income, energy-efficiency improvements could help make housing affordable for millions of households in this country. And in commercial buildings, which account for 27 percent of all U.S. electricity use, myriad savings opportunities remain.

We propose to improve energy efficiency in buildings through new or expanded policy measures. First, *we suggest efficiency standards for lighting products*, along the lines of the national appliance efficiency

Energy Efficiency

standards adopted in 1987. Second, *we recommend increasing funds for low-income housing weatherization programs.* We also recognize the difficulties this program has encountered and suggest ways of increasing its effectiveness. Third, *we urge the federal government to lead the way by substantially improving the energy efficiency of its own buildings.* Aggressive goals should be set and supported by special incentives, guidelines, and technical assistance and research.

How should the United States foster efficiency in the Third World?

The three-quarters of the world's population who live in developing countries account for only one-third of the world's energy use. Nonetheless, studies show that energy use in many developing countries is extremely inefficient. Adopting energy-saving technologies saves money and frees energy resources for other uses.

The United States has a major stake in the economic development of poor countries. Their growth means increased trade and jobs for the United States and repayment of foreign loans. Thus, the United States would benefit by speeding the transfer of technology and skills for saving energy to developing countries.

We propose exchange programs and assistance to develop lasting capabilities in energy efficiency among Third World engineers, industrial managers, and policymakers. We also recommend changes in the energy planning and lending policies of the World Bank and the other multilateral development institutions.

In sum, the United States possesses the technical ingenuity and institutions necessary to create an energy-efficient nation. But doing so requires political determination. Energy efficiency improvements will continue to slow in the absence of new leadership and coordinated national policies. By placing energy efficiency at the top of his energy agenda, the next President can help create a prosperous, secure, and environmentally-sound nation.

Energy Efficiency: A New Urgency

Reducing Risks

*E*nvironmental quality, economic competitiveness, and energy security provide a new and urgent rationale for saving energy. Environmental protection demands energy efficiency. Few human activities affect the natural environment more than energy use. And no recent environmental threat is more alarming than global atmospheric change. Concern is driven by new evidence that the global atmosphere may be heating up and by the speed with which a related atmospheric phenomenon—the “hole in the ozone”—appeared and expanded.¹

If current trends in greenhouse gas emissions continue, the earth may heat up 1.5 to 4.5 degrees C over the pre-industrial average temperature by 2050.² Even warming at the low end of the range will alter the Earth's climate beyond that experienced during the past 10,000 years. The major grain-producing regions of the United States, the Soviet Union, and China could suffer from reduced rainfall. U.S. beaches on the East Coast could be destroyed. U.S. forests could retreat northward as drought-induced forest fires, pests, and reduced moisture make survival difficult. Sudden, unexpected shifts in ocean currents could greatly compound the expected increase in extreme weather.

Energy use is the principal factor driving climatic change today. At least three-fourths of the carbon which remains in the atmosphere each year originates in fossil fuel combustion.³ Fortunately, energy-efficiency improvements can greatly slow the rate of warming over the next 100 years.⁴

The spread of acid rain damage adds to the importance of using energy more efficiently.⁵ Acid rain is already costing the U.S. at least \$10 billion per year in crop losses and materials damage, and the possibility of more

Energy Efficiency

serious damage cannot be dismissed lightly considering that half of West Germany's forests have been affected by air pollution.⁶ Energy efficiency is not a complete solution to the acid rain problem, but it can significantly reduce emissions and pollution control costs.

Economic competitiveness also demands greater energy efficiency. Cutting energy costs in manufacturing would permit U.S. companies to produce goods more cheaply, making them, by definition, more competitive. Nevertheless, U.S. industry has not cut its energy intensity as quickly or as much as its trade competitors, especially Japan, West Germany, and the United Kingdom.⁷

The energy problem in U.S. manufacturing reflects the larger problem of slow growth in productivity. The productivity problem, however, cannot be solved solely by conserving energy.⁸ In fact, innovation appears to occur more rapidly when new processes offer multiple advantages such as cutting labor or material costs, raising productivity across the board, or providing improved services.⁹ Thus, developing energy-efficient industry requires developing manufacturing processes that are efficient in many ways.

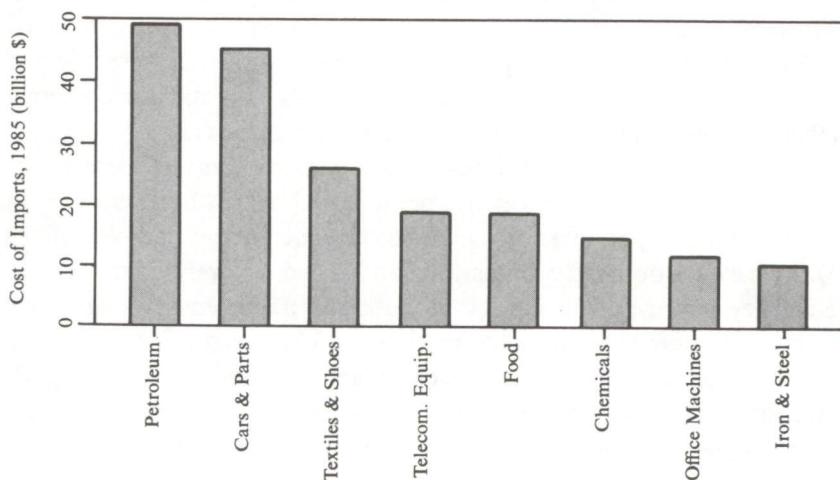
The United States, because it is the world's largest buyer of imported oil, can do much to keep OPEC from regaining control of the world oil market. But when, as now, the United States allows oil imports to climb rapidly, it risks putting OPEC back in the driver's seat. When world oil demand exceeds four-fifths of world oil production capacity, prices can soar.¹⁰ A round of rapid oil price increases could send the debt-burdened world—including the United States—into a serious economic tailspin. This possibility is exacerbated by poor prospects for increasing U.S. oil production, even if oil prices rebound.¹¹ By failing to control its demand for oil, in other words, the U.S. puts its own economy and the world's at risk.

The large U.S. trade deficit demands energy efficiency. Oil imports now account for about one-quarter of the U.S. merchandise trade deficit. (See Figure 3.) If government projections are correct, the annual U.S. oil import bill of about \$40 billion could increase to as much as \$100 billion per year by 2000.¹² Efficiency improvements can greatly cut this serious drain on our economy.

Energy efficiency also strengthens U.S. energy security—and national security. A handful of countries in the Middle East control over half of

A New Urgency

Figure 3: Petroleum and the U.S. Trade Imbalance



Oil Imports Account for One-Third of the U.S. Trade Deficit

Oil imports contribute more to the U.S. trade deficit than any other single item. If government projections are correct, the annual U.S. oil import bill of about \$40 billion could increase to as much as \$100 billion by the year 2000.

SOURCE: U.S. Department of Commerce

the world's oil reserves. As the United States learned in the 1970s, its oil supply can be disrupted when it relies too heavily on oil imports from this volatile region.

Regaining Momentum

The United States has made impressive gains in energy efficiency since the 1973 oil price shock. The nation has reduced energy intensity in every major energy-consuming sector. Industry has made the largest gains, cutting energy requirements per unit of output by 30 percent between 1973 and 1984.¹³ Households cut energy use by about one-fifth

Energy Efficiency

over the same period, while owners and operators of commercial buildings cut energy use per square foot by more than one-tenth. The fuel economy of automobiles improved by 35 percent between 1973 and 1985.¹⁴ Stringent national appliance efficiency standards were adopted in 1987 and will go into effect in the early 1990s. And the use of energy-efficient lighting products has proliferated in recent years.¹⁵

The country, however, is losing momentum in energy efficiency. The United States reduced energy use per dollar of output by an average of 2.7 percent per year between 1976-86. But the energy intensity of the U.S. economy dropped minimally in 1987, and an overall slowdown in efficiency improvements can be discerned in major energy end uses.¹⁶ Industrial energy intensity, correcting for changes due to structural shifts, leveled off in 1983.¹⁷ Automobile fuel economy also is leveling off. And light trucks, which now represent about 30 percent of new light duty vehicles, have exhibited almost no fuel economy gain since 1982.¹⁸

There are two main reasons for the slowdown in efficiency improvements. First, energy prices in general and the price of oil derivatives in particular have fallen in recent years. Corrected for inflation, the average price of gasoline in 1987 was nearly half that in 1980.¹⁹ Natural gas and electricity prices have also fallen. The price-driven impetus for consumers and businesses to conserve has thus been diminished.

The other reason is that the federal government substantially reduced its commitment to energy conservation during the 1980s. Automobile fuel economy standards were rolled back; conservation research funding and federal support for state and local conservation programs were dramatically reduced; and implementation of national building and appliance efficiency standards was resisted by the Department of Energy.

U.S. leadership has failed to fill the policy vacuum formed by unstable energy prices. Today's energy market does not reflect the real national security, economic, and environmental costs associated with energy use, and government has not moved to correct this deficiency. Filling the void requires a reasonable goal for energy efficiency and a means of achieving it. *We recommend a goal of reducing the energy intensity of the U.S. economy by at least 2.5 percent per year well into the next century.* This will mean holding energy use constant or achieving a small decrease in total energy use by 2000 if the economy grows at 2 to 2.5 percent per year as now anticipated.

A New Urgency

A 2.7 percent annual rate of reduction in energy intensity was achieved in the United States between 1976 and 1986. But the price shocks and many of the easier energy savings opportunities of the 1970s are gone. The U.S. Department of Energy forecasts relatively constant prices for coal and electricity, and only a 0.9 percent annual reduction in energy intensity through the year 2000.²⁰ Achieving at least a 2.5 percent annual rate of improvement well into the future will take political leadership and policies that will spur consumers, manufacturers, utilities, and other sectors of the economy.

Our efficiency goal is both technically achievable and economically justified. One study shows that it is technically and economically feasible to reduce the energy intensity of the U.S. economy even more—by 3.5 percent per year through 2020.²¹ Our goal reflects a more cautious view regarding the speed at which institutional barriers and other limitations on implementation can be overcome, and the rate at which the building and equipment stock can be replaced.

Our 2.5 percent goal can be accomplished by: (1) learning from experience with energy policy; (2) supporting existing policies and programs that already are improving energy efficiency; and (3) adopting the new policy initiatives described in the next part of this report.

Aggressively pursuing energy efficiency has potential pitfalls that should be recognized and avoided. The federal government should avoid over-management and an overly short-term perspective. Close cooperation between government officials at all levels and the private sector is essential. Equity problems—among regions of the country as well as income groups—should be resolved, for example, when devising fuels taxes. Moreover, these concerns can and should be addressed by policymakers, not used to justify inaction.

Learning from Experience

Regaining momentum will require careful attention to what public policy can accomplish. The most important lesson gained from the energy policy experience of the past 15 years is that *energy conservation works*. Nothing has so dramatically improved the American energy situation as energy efficiency. The United States today uses little more

Energy Efficiency

energy than in 1973, yet produces 40 percent more goods and services. Efficiency has, in effect, cut the nation's annual energy bill by \$160 billion. With little fanfare, efficiency improvements have become our most important energy resource.

Second, we have learned that *oil and natural gas price controls are counterproductive*. Energy price increases during the 1970s provided the basic impetus for the impressive U.S. conservation response. Two oil price shocks, oil and natural gas price deregulation, and escalating power plant construction costs each pushed up energy prices. Price increases helped to spark operating changes, technology improvements, and other conservation actions throughout the nation.

Third, we have proven that *technological ingenuity can substitute for energy*. A "quiet revolution" in technology has transformed energy use. Numerous efficient products and processes—appliances, lighting products, building techniques, automobiles, motor drives, and manufacturing techniques—have been developed and commercialized by private companies in the United States and other industrialized countries.²² Energy productivity rose as more-efficient equipment and processes were incorporated into our building, vehicle and factory stock.

Fourth, we now know that *complementary policies work best*. Federal, state, and local agencies, including public utility commissions and the public utilities they regulate, have demonstrated the effectiveness of policies and programs that supplement price incentives and technology developments. Such initiatives helped overcome some of the barriers impeding greater investment in conservation—barriers such as lack of awareness and low priority among consumers; lack of investment capital; reluctance among some manufacturers to conduct research and to innovate; subsidies for energy production; and the problem of split incentives, exemplified by the building owner or landlord who does not pay the utility bills.²³

Domestic appliances provide a good example of effective, complementary policies. First, the federal government established standardized test procedures, testing requirements, and a labeling program in the 1970s. Then, using these test ratings, states such as California and New York passed regulations prohibiting the sale of inefficient appliances. And these state efforts led to federal standards banning the production of less efficient models beginning in 1990. In addition, some utilities began

A New Urgency

to offer rebate incentives to stimulate purchase of highly efficient appliances. Moreover, public agencies such as the U.S. Department of Energy and the Gas Research Institute supported the development and demonstration of innovative, efficient appliance technologies. These combined efforts along with rising energy prices led to a 25-80 percent improvement in the energy efficiency of new refrigerators, freezers, and air conditioners between 1972-86, with further improvements expected.²⁴

Fifth, *conservation policies are not automatically successful*. A notable case of a poorly designed policy was the residential energy conservation tax credit. The credit proved to be the single most expensive federal conservation effort, yet little evidence exists to show the credit stimulated much additional conservation. Such incentives cannot easily be crafted to avoid rewarding consumers for actions they would take anyway as a consequence of price increases or to make homes more comfortable. And despite the large cost to the government, the subsidy was probably not large enough to induce substantial investments.²⁵ Similarly, the Residential Conservation Service and the Federal Energy Management Program did not provide sufficient incentives to encourage widespread energy-efficiency improvements.

Other policies have been highly successful, though. Without the automobile fuel economy improvements prompted in part by Corporate Average Fuel Economy Standards, fuel economy improvements would have been less impressive and U.S. automakers would have been less prepared to meet the surge in consumer demand for more efficient cars which arose after the oil shock of the late 1970s. Federal support for energy conservation research is another success, having contributed to the development and commercialization of numerous energy saving technologies during the past twelve years.²⁶

Sixth, *the private sector is the primary vehicle for delivering efficiency improvements, but government-industry cooperation is essential*. Experience has taught that governments must work with the private sector to foster conservation actions. Private companies produce the cars, buildings, appliances, and machinery that use energy. They retrofit conservation measures in buildings and factories, and consume energy themselves. Research and development efforts aimed at new energy-efficient technologies or methods will only succeed—that is, end up penetrating the market—if private companies are directly involved in the research

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and development process. Likewise, program managers and policy-makers will benefit from involving equipment suppliers, builders, and retrofitters in the design and implementation of efficiency standards as well as conservation information, financing, and incentive programs.

Seven, *some utilities have learned how to benefit from conservation.* A growing number of utilities and regulatory agencies view demand-side management as a legitimate means of avoiding costly and risky energy supply investments. Consequently, utilities are increasingly investing in efficiency and load management measures, with total spending now at least \$1 billion per year.²⁷

And, eighth, *we have seen that political leadership matters.* Leadership from the federal government is essential. Federal programs can strengthen and reinforce the efforts of states, localities, private businesses, and consumers. Many conservation efforts, including fuel economy standards and research and development, work best at the federal level. Other efforts, such as utility regulation and incentive programs, work best at the state and local levels. Overall, a renewed commitment to energy efficiency is needed at every level of government in the United States.

Priority Policies

Applying Energy Efficiency to Protect the National and Global Environment

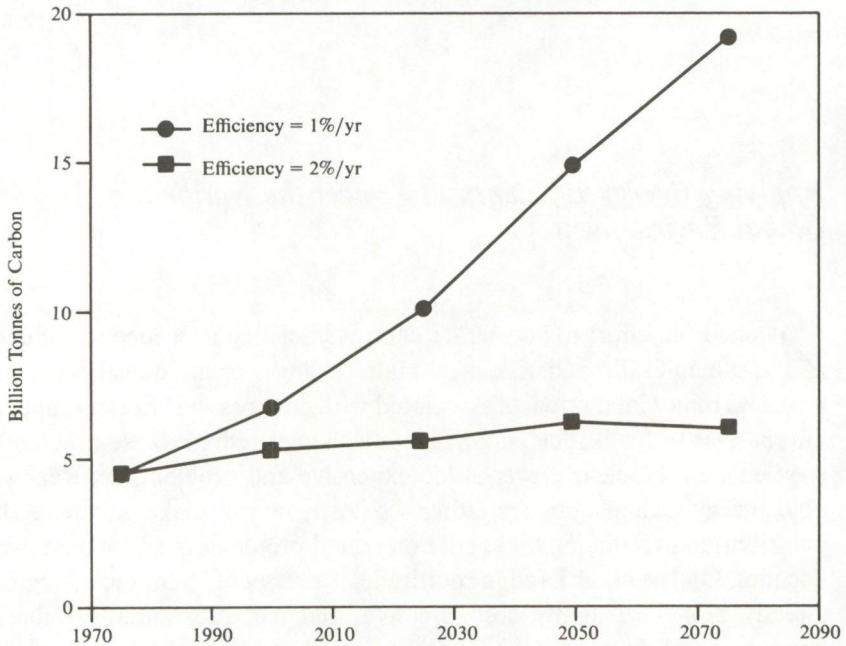
A concerted effort to accelerate energy efficiency is needed to reduce the magnitude and risk of climatic change, ozone depletion, acid rain, and major land impacts associated with energy use.²⁸ Energy supply alternatives to fossil fuels, unfortunately, cannot redress these problems soon enough. Nuclear power is too expensive and problematic. Renewable energy technologies are either too costly or can make only a small contribution to reducing these environmental problems over the next two decades. On the other hand, a multitude of energy-efficient technologies already exist, are highly cost effective, and can substantially reduce environmental damage.²⁹ These technologies can ease the transition to renewable energy sources.

Conservation of energy by itself cannot solve these major environmental problems; complementary efforts are necessary. For example, improved energy efficiency can only partly reduce sulfur emissions from burning coal; other sulfur control technologies such as scrubbers or clean generating technologies are still needed. Efforts must be undertaken to control other greenhouse gases and deforestation resulting from non-energy activities. But efficiency improvements will be most critical to reduce the risk of climatic change.³⁰

Fossil fuel combustion produces three-fourths of the carbon emissions caused by mankind. These emissions along with other trace gases act like a blanket in the atmosphere to hold in heat. This greenhouse effect could produce rapid climatic changes and profoundly disrupt American forests, farms, coasts, and energy supply systems.³¹ Traditional cultures in less-developed countries may be particularly affected because they do not have the means to adjust to changing rainfall and temperature pat-

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Figure 4: Global Carbon Emissions and Energy Efficiency



Energy efficiency: A Tool for Slowing Climatic Change

The above cases show two future carbon emissions scenarios which differ only in their assumption for the global rate of energy-efficiency improvement. Relatively high economic growth would be permitted in either case. To achieve the higher efficiency scenario, implementation of policies such as those suggested in this document would be necessary.

SOURCE: W. Chandler, "Carbon Emissions Control Strategies: The Case of China," forthcoming in Climatic Change.

terns or rising sea levels.³² Reducing energy consumption across-the-board offers the best hope to slow climatic change due to carbon emissions.³³ Efficiency gains would simultaneously slow climate change as well as reduce acid rain production, oil spills, and coal-mining impacts.

Significantly, energy efficiency can be justified entirely on its economic merits.³⁴ This advantage makes efficiency both an effective and

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appealing strategy for averting global environmental problems. Because energy efficiency bolsters economic growth *and* offers an immediate, practical means of reducing the risk of environmental degradation, we urge the United States to lead a global initiative to promote energy efficiency.

Proposal: Reduce the risk of climatic change through an international energy-efficiency protocol.

This proposal would establish a process for an international protocol to reduce the energy intensity of the global economy. The process would have twin goals: reducing the risk of climatic change and promoting economic growth. The resulting protocol would produce an agreement to reduce global energy use per unit of economic output to a technically achievable and economically justifiable level by a specified date. By the year 2025, most countries should be able to reach the 1985 efficiency levels of Denmark, Switzerland, or Japan, which rank best today.³⁵ This level of efficiency can be accomplished with available technology and is justified at current energy prices.³⁶ It could be reached by continuing rates of energy-efficiency improvements experienced by many nations over the past 15 years. All nations, including less-developed countries, would achieve higher rates of economic growth by accelerating their rate of energy-efficiency improvement.

Discussions are needed to identify workable protocol criteria, promising areas for cooperation, and mechanisms for promoting compliance. The resulting agreement could establish energy-intensity reduction goals for individual nations, and provide for periodic review of the adequacy of goals and implementation plans. The United Nations Environment Programme offers an appropriate forum for these discussions.

While the agreement could involve different goals for different nations, we suggest a minimum 2 percent annual rate of reduction in energy intensity for the world as a whole. Twenty-one industrialized nations achieved this rate between 1973 and 1985, with the United States, Japan, and Belgium doing substantially better.³⁷ China has reduced energy intensity 3.7 percent per year since 1979, and plans to continue rates of intensity reduction greater than 2 percent.³⁸ Note that we propose a

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higher rate of intensity reduction—at least 2.5 percent per year—for the United States.

Certain nations that have both very low income and low energy-intensity levels could be exempted from the protocol. These nations typically have made little progress in the transition from traditional to commercial fuels. This category, however, does not include the most populous developing countries such as China, India, and Brazil which have large industrial sectors. Nations such as Japan and Switzerland, which are relatively efficient, could be expected to continue improvements over the period, but at a rate commensurate with the greater difficulty of gaining efficiency from an already low level of energy intensity. Additional issues such as the different climates of each country and trade in energy-intensive materials will require attention as an agreement is hammered out, but should not present insurmountable problems.

The Montreal Protocol On Substances That Deplete The Ozone Layer, signed by 38 countries in September, 1987, presents an important precedent for such an agreement. If fully implemented, this agreement could cut global emissions of chlorofluorocarbons (CFCs) by as much as 40 percent by the year 2009.³⁹ Like the proposed energy-efficiency accord, the Montreal Protocol represents an international effort to control a threat to the global environment based on long-term projections of environmental damage. An energy-efficiency protocol may be more difficult to achieve, though, because energy use pervades virtually every aspect of human life.

Implementing the proposed protocol would substantially reduce projected world energy demand, which some analysts expect to rise from roughly 300 quadrillion BTU at present to more than twice that amount by the year 2025.⁴⁰ Reducing energy intensity 2 percent per year would cut this growth by about two-thirds, saving 225 quads per year by the end of the period.⁴¹ And as a result, global carbon dioxide emissions would be at least one-third lower than projected for 2025.

This achievement would increase economic well-being. Cutting energy intensity at the 2 percent rate could save world economies \$500-750 billion in 2025, the equivalent of 5 percent of projected global economic output in that year. Econometric modelling results indicate that every region of the world, including the United States, would be richer with higher energy-efficiency levels.⁴²

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Proposal: Establish Soviet, American, and OECD cooperation to promote energy efficiency on a global basis.

An energy-efficiency protocol would establish efficiency goals and a means of encouraging compliance. A complementary component of international cooperation will be essential. Indeed, we consider energy efficiency in developing countries to be so important—for improving living standards as well as protecting the environment—that we deal with it separately, later in this report. Here we propose extensive Organisation for Economic Cooperation and Development (OECD) and Eastern Bloc collaboration to promote energy efficiency.

The countries would by formal agreement exchange scientists, industrial leaders, technicians, and students to promote the creation and use of energy-efficiency techniques in their own and other countries. The nations would sponsor both short and longer-term visits by qualified personnel to research institutes, universities, factories, and government agencies. The focus of these exchanges would be technologies for saving energy, means of fostering energy-efficiency policy, and the application of energy conservation to ameliorate environmental problems, particularly the greenhouse effect. The pervasive and decentralized nature of energy-efficiency techniques would offer the opportunity for many useful exchanges.

The United States has a long tradition of sponsoring scholarly exchanges with other nations in order to improve relations. The Fulbright scholarships program is the premier example. The United States and the Soviet Union first signed a bilateral agreement for exchanging scientific and technical personnel in 1954. During the Kennedy era, the Partners program sponsored exchanges with Latin American nations, setting up "sibling" universities between the United States and other nations of the Western Hemisphere. Many of these exchanges continue.

U.S. cooperation with West Europe and Japan and the newly-industrialized nations on the Pacific rim should be expanded, particularly in joint efforts involving cooperative research and information exchange on state-of-the-art conservation technologies. Precedents include the International Energy Agency agreement to share information and conduct joint research on heat pumps. The United States could benefit, for example, from learning about European advances in energy-efficient manufac-

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tured housing, or from collaborative research on the highly efficient Elred and Plasmasmelt steel-making techniques. Other promising areas for cooperation include building retrofit techniques, automotive technologies, and energy-intensive industrial processes. Cooperation with Eastern European countries could also be fruitful, for those nations are particularly inefficient and need capital and technology to reduce their energy intensity.

Proposal: Develop technologies that simultaneously save energy and protect the stratospheric ozone layer.

Chlorofluorocarbon (CFC) emissions deplete the stratospheric ozone layer shielding the earth from harmful ultraviolet radiation and contribute to greenhouse warming.⁴³ CFCs are important to energy conservation efforts because they are used as the working fluid in refrigeration and air conditioning equipment, and as the blowing agent in foam insulation. Roughly 40 percent of CFCs produced in the U.S. in 1985 was used in energy-related applications.⁴⁴

Currently available substitutes for CFC-11 and CFC-12, the compounds which most seriously deplete ozone, are less energy efficient. For example, replacing CFC-12 in refrigerators or mobile air conditioners could result in a 10-20 percent increase in unit energy consumption. Replacing all uses of CFC-11 and CFC-12 with presently available substitutes could increase U.S. energy use by 4 percent.⁴⁵

To avoid these energy penalties, we propose that the Department of Energy and the Environmental Protection Agency (EPA) undertake an urgent research, development, and demonstration program on promising technologies which could both reduce or eliminate CFC use and increase efficiency in energy-related applications. Some possibilities include:

- Evacuated panel insulation—highly insulating panels that could replace foam insulation.
- Alternative refrigeration systems and less damaging CFCs such as R-22 and R-134a.
- Advanced automotive glazing—improved windows and other techniques for reducing automotive air conditioning requirements.

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Evacuated panel insulation appears promising because it requires no CFCs to produce and it could cut the electricity use of refrigerators and freezers by 25-50 percent. Although evacuated panels might add \$75-100 to the initial cost of a refrigerator or freezer, net economic savings should total \$300 or more over the life of the appliance due to large energy savings.⁴⁶ U.S. private companies are not developing evacuated panel insulation and some of the other options because they are technically unproven, highly novel, somewhat long range, and high risk. An intensive search is underway for direct CFC substitutes, but this research tends to overlook the potential for new systems—refrigeration cycles, insulation, and glazing, for example.

This critical research should be supported by a combination of federal and private funding. The effort would integrate and expand smaller, separate research projects on CFC substitutes and energy efficiency now conducted by federal agencies.

Proposal: Use emissions ceilings for acid rain control.

Acid rain, caused in large part by sulfur emissions from coal-fired power plants, now seriously affects many areas of the United States and Canada.⁴⁷ The most commonly proposed ways to reduce acid rain are to cut emissions by installing flue gas scrubbers, switching to low-sulfur coal, or using some of the "clean coal" technologies under development.

Opponents of acid rain control proposals have stalled legislation for years by arguing these control measures are too expensive. But acid rain control need not be expensive. In fact, a combined program of electricity conservation and acid rain control can yield cheaper electricity services (the cost of the electricity plus the cost of conservation measures) than if neither program were adopted.⁴⁸ Electricity services can be less expensive under the combined program for two reasons. Conservation programs that pay for themselves through energy savings reduce the demand for electricity, which reduces fuel consumption and emissions at power plants. And conservation programs can defer construction of expensive new power plants, saving more than enough money to pay for other control measures.

Unfortunately, many federal legislative proposals would discourage

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states from incorporating electricity conservation into their acid rain control programs because these proposals use statewide average emission rates to limit emissions. Statewide average emissions rates are calculated by summing a state's emissions from major pollution sources and dividing by fuel consumed at those sources. Statewide average emission rates discourage conservation because conservation can lead to reduced use of power plants whose emission rates are below the statewide average emission rate. This will cause the statewide average to rise, even though total emissions decrease. In other words, conservation-induced emissions reductions will move a state away, not toward, its emissions reduction target.

The problem can be avoided if federal acid rain legislation uses emissions ceilings instead of statewide average emission rates. Emissions ceilings simply impose a limit on the total tons of pollutants that can be emitted in a state. Thus, emissions reductions achieved through any measure, at any power plant, whether it be from conservation or direct pollution controls, will be fully credited toward a state's emission reduction goal.⁴⁹

Combining ceilings with the least-cost approach to acid rain control and power supply could stimulate conservation and cut electricity use perhaps 10-20 percent over the next 15-20 years in states such as Indiana, Ohio, and West Virginia.⁵⁰ Over the same period of time, major acid rain-producing states could save \$10-20 billion.

Some opponents of emissions ceilings have argued that ceilings may limit economic growth because they put a cap on total emissions. Rapid economic growth does not necessarily mean high growth in electricity demand, however. California has demonstrated that conservation programs can hold growth in electricity demand well below economic growth rates.⁵¹ Furthermore, a wide variety of emissions control technologies are available for limiting emissions without constraining economic growth.

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Proposal: Encourage integrated energy and environmental planning at the state and federal levels.

The functions of planning and managing energy conservation programs, energy supply facilities, and environmental protection in most states are housed in separate divisions and agencies. Environmental agencies, for example, regulate power plant emissions but are not involved in decisions regarding whether a new plant is needed and whether there are more cost-effective alternatives. Likewise, energy authorities order and approve conservation programs but usually do not consider the environmental impacts of energy production and use—as in coal surface mining, for example—or how greater efficiency can serve environmental objectives. Similar divisions exist at the Federal level.

Acid rain control is one area that could benefit greatly from integrated energy and environmental planning. Federal and state acid rain legislation could encourage state energy and environmental agencies to work together to consider efficiency improvements and least-cost utility strategies when developing statewide environmental protection plans. To promote such cooperation, federal acid rain legislation might include, for example, funding for the development of state least-cost utility plans. The EPA could provide grants to states for integrated planning, with states required to provide matching funds. If regional planning is appropriate, states could be permitted to pool their federal grants.

A few states already recognize the importance of integrated environmental and utility planning. In Wisconsin, the Department of Natural Resources and the Public Service Commission jointly developed a regulatory strategy for implementing the state's acid rain bill, and prepared a study of the potential to reduce compliance costs through efficiency improvements.⁵² State officials in Wisconsin are strongly promoting electricity conservation, in part to reduce pollutant emissions.

Similar integrated planning recommendations and assistance could be of value for addressing pollution problems other than acid rain. Attainment of urban ozone standards, for example, has been extremely difficult in smog-prone areas such as Southern California. Improving vehicle fuel economy through efficiency standards or incentives should be considered as one strategy for meeting existing or tougher ozone and ozone precursor standards.

Energy Efficiency

Doubling Car and Light Truck Fuel Economy to Cut Oil Imports

A growing gap between oil production and demand threatens U.S. energy security. If current trends continue, U.S. oil production will fall by one-third by the end of the 1990s—a drop from 9 to 6 million barrels of oil per day.⁵³ Meanwhile, U.S. demand for oil is growing rapidly again. As a result, oil imports have increased 35 percent between 1985 and 1987, from 4.3 to 5.8 million barrels per day. The Department of Energy projects that oil imports could reach 8 to 12 million barrels per day by the end of the 1990s, with an annual import bill of \$100 billion.⁵⁴

Vehicle fuel economy ranks first in priority for reducing oil imports. Cars and light trucks account for the largest share of U.S. oil use—fully one-third, a volume equal to imports.⁵⁵ Even though the fuel economy of cars has improved since the 1973 oil crisis, many opportunities for improving automobile fuel efficiency and performance remain to be implemented.⁵⁶

The 1973 oil crisis awakened American interest in automobile fuel economy. Consumers demanded more fuel-efficient cars faster than the U.S. automakers could supply them. And in 1975, the U.S. government passed its most effective and forward-looking energy legislation, the Energy Policy and Conservation Act (EPCA), which required new car fleets to obtain an average 27.5 mpg by 1985. The EPCA standards, though recently reduced to 26 mpg, helped sustain momentum in fuel efficiency even after the oil price collapse of the early 1980s. In fact, fuel economy improvements in the U.S. light vehicle fleet since enactment of the fuel economy standards contributed about one-fifth of all the oil savings achieved by OECD countries after 1973.⁵⁷

The technical and economic potential for again doubling fuel economy of cars and light trucks already exists.⁵⁸ The electronics revolution has made possible the use of sensors and microprocessors for more precise engine control. New transmissions will be able to continuously shift the gear ratio to match the most-efficient engine speed with the desired speed of the wheels. Though it would work at first only for small cars, this continuously variable transmission would provide a smoother ride and improve fuel economy about 12 percent. Numerous other fuel saving technologies could help double auto fuel economy.⁵⁹ (See Table 2.)

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Table 2. Technologies for Automobile Fuel Economy Improvements

<i>Technology</i>	<i>Percentage Gain in Fuel Economy by Mid-1990s</i>
New Engine Designs (e.g., improved shape of combustion chamber)	4
Variable Valve Timing	8
4 Valves Per Cylinder	8
Multi-point Fuel Injection	7
Improved Lubricants and Friction Reducing Materials	4-5
Electronic Transmission Control	3
Continuously Variable Transmission	12
Improved Tires	5
Improved Aerodynamics	5
Efficient Accessories	2

Note: Percentage gains are not additive.

SOURCE: *Energy and Environmental Analysis*, "Analysis of the Capabilities of Domestic Auto Manufacturers to Improve CAFE," 1986.

A major barrier to the introduction of these new technologies is first cost. Cars twice as efficient as the current generation of cars will cost perhaps \$200-800 more.⁶⁰ And though this first cost would be more than recovered through fuel savings over the life of the car, manufacturers

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probably will not install features if consumers will balk at their added cost at the time of purchase.⁶¹ On the other hand, some innovations will both save fuel and cut manufacturing costs.

Accomplishing the goal of doubling fuel economy will require bold new policy initiatives. We have examined the effectiveness of a fuels tax, an oil import fee, a gas-guzzler tax, and fuel economy standards as means of doubling automobile fuel economy. We conclude that no single approach can accomplish the desired improvements in fuel economy. Raising gasoline and diesel taxes high enough to stimulate demand for 45 mpg cars would be politically difficult. Enforcing fuel economy standards in the absence of economic incentives such as rebates would also present problems. We therefore recommend a complementary set of policies that will both push and pull the market.

Proposal: Raise gasoline and diesel fuel taxes by 10 cents per gallon for at least three consecutive years.

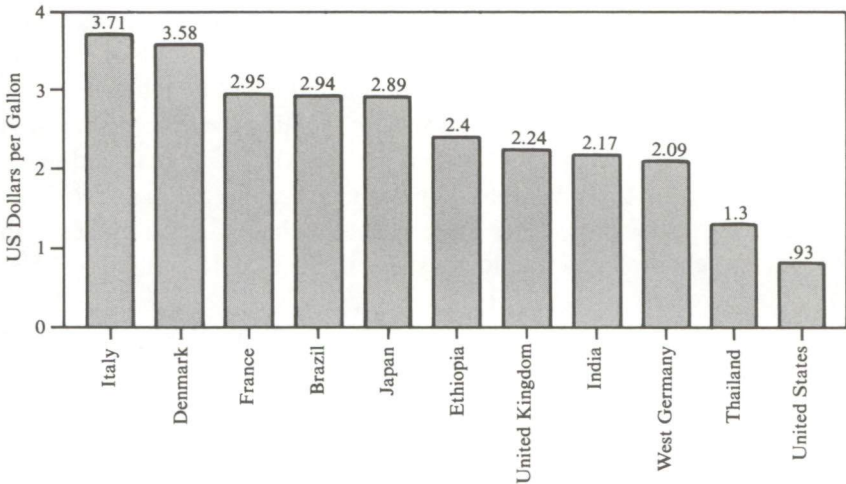
The market price for imported oil does not reflect its real cost to the U.S. economy. Some studies estimate that the national security cost of importing oil amounts to at least \$10 per barrel.⁶² The costs of air pollution and the risks of climate change from using oil make the real costs even higher.

Logically, these costs should be internalized through a tax on oil regardless of where it is used in the economy. A tax on transportation fuels, however, would be more practical. The potential for increasing the efficiency of oil use in the transportation sector is large. Taxes on transportation fuels would cause fewer problems for competitiveness and employment than taxes in other sectors. Moreover, the collection mechanism is already in place for a new tax on gasoline and diesel fuel.

Thus, we propose a tax on vehicle fuels sufficient to capture a portion of the long-run costs of high oil use, coupled with rebates for low-income persons. Specifically, we urge the application of a tax on gasoline and diesel equal to 10 cents per gallon beginning in 1990. If world oil prices remain low (under \$30 per barrel), the tax should be increased 10 cents each year until it reaches a maximum 50 cents per gallon. If oil prices rise substantially higher, the tax should be increased 10 cents each year to a

Priority Policies

Figure 5: Gasoline Price Levels, Selected Countries, 1987



Foreign nations tax gasoline heavily, encouraging efficiency

Gasoline in Italy and Denmark costs four times as much as in the United States. This difference is due almost entirely to differences in gasoline tax levels. Low U.S. gasoline prices encourage consumption and place the nation at risk of new oil supply disruptions, price hikes, and reduced flexibility in foreign policy.

SOURCE: International Energy Annual, 1986 Energy Information Administration, U.S. Department of Energy, October, 1987.

maximum of 30 cents per gallon. The intent of such a tax structure is to make the tax responsive to market changes so that whatever happens, consumers are given a price signal that better reflects the real cost of the resource and encourages conservation.

Precedents abound for taxing fuel to reduce its consumption. The price of gasoline at the pump in countries as diverse as Japan, Italy, and Brazil is two to four times that in the United States, mainly because of tax policy.⁶³ (See Figure 5.) The United States also has imposed gasoline taxes, both at the federal and state level. Generally, the intent of such taxes has been to raise revenues to pay for road construction and repair rather than to strengthen national energy security or some other national

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goal. The current average combined federal, state, and local gasoline tax is only 30 cents per gallon in the United States.

A fuels tax will have the major drawback of adversely affecting low-income people since they spend a disproportionate fraction of their income on energy. A portion of the tax collected could be rebated to low-income households. Many mechanisms for rebating the tax are already in place. For the working poor or retired persons, the income tax and social security systems could be used. For those not paying taxes or receiving social security benefits, other mechanisms such as aid to families with dependent children and public housing subsidies could be used to offset the tax increase.

The federal budget deficit demands reduction and may provide impetus for enacting a fuel tax. A 30-50 cent tax in the year 1995 would generate about \$40-60 billion in revenues, and even after rebates to the poor, would provide significant new sources of revenue to the government.⁶⁵ Part of the revenue could be used to continue filling and perhaps expand the Strategic Petroleum Reserve, fund other energy conservation programs, or support maintenance of roads, bridges, and other elements of the U.S. transportation infrastructure.

Proposal: Raise car and light truck fuel economy standards to 45 and 35 mpg, respectively, by the year 2000.

Fuel efficiency regulations will be essential to capture the full potential of automobile and light truck fuel economy. The incremental savings attributable to fuel economy levels above 30 mpg are small compared to the total cost of owning and operating a car.⁶⁶ Moreover, it may take auto manufacturers years to respond to anticipated fuel price increases in the 1990s.

We propose that the government require new passenger cars and light trucks to obtain, on average, 45 and 35 mpg, respectively, by the year 2000. Interim standards should also be set. The penalty for failing to meet the standards would be a substantial tax on the manufacturers, based on the number of vehicles failing to meet the requirement and the amount of the shortfall. This approach differs from the original legisla-

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tion which placed manufacturers in violation of the law for failing to meet standards.

We emphasize that light trucks are a high priority for fuel-economy policy. Purchases of light trucks have grown at an annual rate of over 6 percent during the 1980s. Most people now use these trucks as they would cars—for commuting, running errands, and recreation. As a result, the fraction of total gasoline consumption attributable to light trucks over their lifetimes is climbing toward 50 percent. Present law, however, requires that light trucks attain an average of only about 20 mpg. Light truck fuel economy could be increased with the same technologies available for improving the fuel efficiency of cars.

The proposed legislation would provide an opportunity to correct certain flaws in the original Energy Policy and Conservation Act. By setting an industry-wide standard that all manufacturers had to meet, the law discriminated against mainly American, full-line manufacturers that produced a range of car models, in favor of mainly Japanese automakers that produced mostly small cars. Annual increases in the fuel economy standards proved particularly burdensome because manufacturers do not change model lines nearly so frequently.

Careful structuring of new fuel economy standards could avoid these and other problems of fairness. The standards could, for example, require the same percentage increase in fuel economy for each manufacturer, or a fuel efficiency level based on interior volume.⁶⁷ We recommend that the final formula be established only after careful analysis and discussions with the auto industry to minimize unintended effects.

Opponents of fuel economy standards have argued that the standards reduce automobile safety.⁶⁸ But this need not be so. The United States doubled new car fuel economy since 1975 while cutting traffic fatalities per mile by one-third. Had fatality rates continued at 1975 levels, an estimated 17,000 more persons would be dying each year on American roads. The reduced fatalities came about in part due to lower speed limits and the crack-down on drunk driving, but better safety design also contributed. The 2,000 pound Volkswagen Rabbit, for instance, has a better safety record than the Chevrolet Impala and Ford Crown Victoria, which weigh almost twice as much.⁶⁹

Additional auto safety improvements are possible without compromis-

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ing fuel economy. For example, installing air bags or automatic seat belts in all cars and light trucks would avoid an estimated 12,000 deaths annually. Improved protection against side collisions could save over 4,000 lives per year. The key issue for safety—as it is for fuel economy—is design.⁷⁰

Proposal: Establish a gas-guzzler tax, gas-sipper rebate program.

The fuels tax and fuel economy standards would raise average fuel efficiency, but would not address two important problems. The first is the need to discourage production of very inefficient cars and trucks—gas guzzlers—and the second is the need to encourage the production of highly efficient vehicles. A gas-guzzler tax would address the first problem; a rebate mechanism would address the second.

Since high fuel economy levels do not greatly reduce the costs of driving, U.S. manufacturers face a high barrier to fuel economy innovation. Manufacturers thus run considerable risks with innovative vehicles and have little prospect for rewards in the marketplace.

To help assure a market for super high-efficiency cars, we propose that a rebate like those offered by car dealers in promotional campaigns—on the order of \$1000—be offered to consumers purchasing high-efficiency vehicles. The rebate would be paid by the federal government, using revenue collected through the gas guzzler tax. Manufacturers could qualify a limited number of vehicle models for the rebate by producing cars that meet a specified level of fuel economy, such as 50 percent higher than the most efficient models now available, and other important criteria, such as safety and low emissions. Different fuel-economy criteria could be set for different size classes of cars, and eligibility would be limited to models produced in significant quantities. Eligibility might be restricted to cars manufactured primarily in North America, but it should not be restricted only to U.S.-owned firms.

In addition, the existing gas-guzzler tax ought to be modified. The current tax mainly affects extremely inefficient luxury cars. A new tax schedule should be adopted that applies to vehicles with higher levels of fuel economy than presently covered by the tax. Tax levels in the schedule need to be increased, too. The combination of changes in the tax

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schedule and level should be sufficient to generate at least enough new revenue to fund the gas-sipper rebate program.

Together, these proposals can lead to oil savings of approximately 1.0 to 1.5 million barrels of oil per day by the end of the century. Such savings would cut U.S. oil imports in 2000 by 10-15 percent and would directly cut the import bill by \$9-16 billion, based on government forecasts of future energy supplies and prices.⁷¹ Furthermore, the savings represent 20-30 percent of the anticipated increase in oil use in all countries outside the Soviet Union, Eastern Europe, and China between 1985-2000.⁷² A successful effort to raise vehicle fuel economy would significantly reduce pressure on world oil markets.

Promoting Least-Cost Utility Services

Energy supply facilities such as power plants and transmission lines are highly capital intensive. During the late 1970s and early 1980s, utilities accounted for nearly 15 percent of all investment in new plant and equipment in the United States.

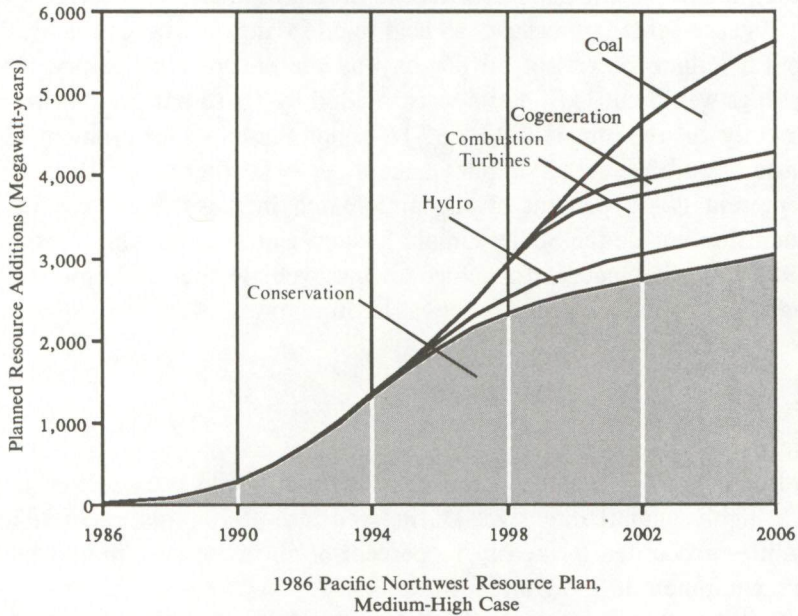
Utilities absorb more capital than any sector of the economy other than real estate. And some utility supply investments—recently completed nuclear power plants, for example—have turned out to be financial disasters. Increasing efficiency reduces the need for investment in energy supply, which reduces the risk of wasteful power supply investments. It also frees capital for investment elsewhere, for example in industrial modernization. Efficiency improvements are helping the utility industry cut its capital expenditures from \$50 billion in 1982 to around \$17 billion per year expected by 1990.⁷³

A least-cost utility services approach has emerged in recent years as a means for reducing capital investments in the power sector. The objective is to provide services such as heat, light, refrigeration, and motor power—not energy per se—at the lowest possible cost.⁷⁴ For meeting new needs for power, a kilowatt-hour saved from waste is indistinguishable from a kilowatt-hour delivered by a new power plant.

Under the least-cost utility services approach, all feasible conservation and other “demand-side” resources are evaluated along with new energy supply options and are ranked according to cost effectiveness. Since

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Figure 6: Least-Cost Planning in the Pacific Northwest



Least-Cost Planning in the Pacific Northwest

The Pacific Northwest Power Planning Council thoroughly analyzes supply and demand-side electrical resources. It developed least-cost power plans in 1983 and 1986. Utilities in the region have acquired the capability to implement efficiency measures in order to avoid constructing numerous costly power plants, should the need arise. If population and economic activity grow moderately, the most recent plan calls for cutting electricity use 13 percent by 2006 at an average cost of about 2 cents per kilowatt-hour.

SOURCE: "1986 Northwest Conservation and Electric Power Plan," Northwest Power Planning Council, Portland, OR, 1986

energy-efficiency measures typically cost less than generating or purchasing a commensurate amount of energy, investing in efficiency becomes a top priority for utilities using this approach. And when flexibility, safety, environmental impacts, and social concerns are included in the analysis, efficiency looks even more attractive.

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The least-cost approach was first adopted in 1980 in the Pacific Northwest.⁷⁵ (See Figure 6.) Since then, at least 16 states have adopted least-cost planning policies and requirements.⁷⁶ Some utilities have demonstrated that they can significantly reduce load growth in a cost-effective manner. For example, the Austin, Texas, municipal utility, Northern States Power Company, and Southern California Edison Company have been able to reduce electricity use and peak demand by 0.4 to 1.4 percent per year by offering rebate incentives to purchasers of efficient appliances and other equipment. This represents a 20-40 percent reduction in the rate of electric load growth. Utilities with rebate programs are paying only \$200 to \$300 per kilowatt saved, thereby acquiring savings at a fraction of the cost of new power supplies.⁷⁷

But the least-cost approach to providing energy services is still not routine in the utility industry. Only a handful of utilities are committing more than a few percent of their total budget to conservation and load management. The majority is still encouraging load growth.⁷⁸ Furthermore, some forecasts predict or call for rapidly increasing investment in power supply facilities during the 1990s in order to avoid shortages of electric generating capacity.⁷⁹ This strategy could be very costly and risky, and it could result in utilities once again absorbing large amounts of investment capital.

The proposals in this section are intended to enhance economic growth and competitiveness by advancing the United States toward least-cost energy services, to increase support among utilities for energy efficiency, and to strengthen their ability to implement effective conservation programs. The proposals are addressed to the U.S. Department of Energy (DOE) and the Federal Energy Regulatory Commission (FERC) as well as to state officials and utilities. Electricity is the main focus, but a number of the proposals also apply to gas utilities.

Proposal: Provide utilities with financial incentives to promote energy efficiency and least-cost energy services.

Regulators should encourage utilities to pursue least-cost energy services by linking a utility's profitability to its progress in acquiring cost-effective sources of generating capacity and end-use efficiency. Utility

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commissions should also abandon ratemaking procedures that financially reward utilities for increasing short-run sales of electricity and gas.

Financial incentives and penalties could take a number of forms. For example, if a utility performs well in acquiring conservation resources, it may be appropriate to increase that utility's rate of return or earnings. If, on the other hand, a utility performs poorly in acquiring conservation resources, regulators could penalize the utility by lowering its allowed rate of return. Establishing performance-based incentives will safeguard consumers from paying for ineffective or overly expensive conservation, load management, and alternative generation programs. Regulators could base incentives (or penalties) on the amount of savings achieved, the cost effectiveness of conservation programs, or on a utility's ability to reduce the total energy bill of its customers.

A few state utility commissions have used incentives and penalties and rate adjustments along the lines suggested here. In 1979, the California utility commission penalized Pacific Gas & Electric Company (PG&E) for failing to make reasonable efforts towards developing the cogeneration potential in its service territory.⁸⁰ PG&E subsequently contracted for large amounts of cogeneration and independent power. The Massachusetts utility commission reduced the allowed rate of return for Boston Edison Company (BECO) in 1986 because of its poor record in developing and implementing conservation and load management programs and performing integrated planning.⁸¹ Since then, BECO has established or expanded about 20 demand-side management programs.⁸² Also, Wisconsin is using performance-based incentives as part of its effort to stimulate much larger and more effective conservation programs among its utilities.⁸³

Adjusting electricity and gas rates provides another means of encouraging efficiency. Utility rates are usually based on near-term projections of electricity and gas sales. Utilities generally profit if sales are greater than projected in the last ratemaking case. This situation can be avoided by periodically adjusting rates so that profits are decoupled from fluctuations in sales volume. The California utility commission has established such a revenue adjustment mechanism.⁸⁴ State commissions could go even further by increasing or decreasing a utility's revenues and profits in proportion to the degree it is able to lower sales or energy service costs.⁸⁵

Giving utilities a financial stake in encouraging cost-effective effi-

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ciency improvements is not without difficulties. Some states reward utilities for conservation program expenditures rather than for achieving energy savings or lower service costs. Paying incentives based on program expenditures is much easier but is far less desirable than incentives based on performance. Experimentation and careful evaluation will be required if incentives are going to be based on conservation program performance or a utility's overall progress in reducing customers' bills.

The federal government can assist state utility commissions in addressing these problems. We propose that DOE analyze alternative incentive schemes, including conducting case studies of recent initiatives through its Least-Cost Utility Planning project. Also, DOE or FERC could provide recommendations to states on how to structure incentive schemes and disseminate information on emerging least-cost strategies.

Proposal: Allow energy-efficiency investments to compete with energy supply options in competitive bidding schemes.

Providing utilities with incentives for pursuing least-cost energy services encourages comparison of energy supply and conservation options. A parallel strategy would allow energy conservation projects to compete with new energy supply projects through bidding procedures. This form of market testing would aid utilities in developing least-cost plans.

In early 1988, FERC proposed new regulations to stimulate greater competition in new power generation by allowing non-utility sources of energy such as cogeneration projects to bid competitively for rights to provide power to utilities. But FERC devoted minimal attention to the role that conservation projects could play in meeting resource needs at least cost. We propose that FERC remedy this shortcoming by directing or encouraging states to allow conservation projects to compete with proposals for additional generating resources.

Utilities in both Maine and Massachusetts have solicited bids for electricity savings.⁸⁶ Central Maine Power is paying 1 to 2 cents per kilowatt-hour saved in response to its pilot demand-side bidding program.⁸⁷ The utility offers to pay up to 50 percent of the initial cost for conservation projects in order to shorten the payback period to two years. Actual payments depend on measured savings. Conservation projects

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implemented through this program include installation of efficient motors by a wood products manufacturer and installation of an energy management system at a college. In late 1987, Central Maine Power received approval to allow supply and efficiency projects to compete directly.

Because there has been limited experience with conservation bidding and because there are a number of questions concerning how it would work, it is essential to experiment with the concept and carefully monitor impacts. Utilities must establish methods for determining savings, minimizing transaction costs, and maximizing program impacts. Also, special efforts are likely to be needed if demand-side bidding is to elicit conservation in hard-to-reach markets such as low-income and multi-family housing. DOE and FERC should assist states and utilities by evaluating demand-side bidding experiments and pilot programs and by disseminating information to further this concept.⁸⁸

Proposal: Encourage least-cost planning through federal regulation of interstate power sales.

FERC regulates interstate power transfers which account for approximately 30 percent of U.S. electricity sales. We propose that FERC require buyers and sellers of electricity to demonstrate that proposed long-term power sales be consistent with either least-cost plans for the region involved, or with least-cost planning principles where such plans are not available. Adoption of regional plans would be encouraged by creating expedited approval processes for transactions covered by the plans. An amendment to the Federal Power Act may be needed to adopt this policy because FERC has refused to review proposed power transfers on the basis of environmental or least-cost impacts.⁸⁹

These requirements would ensure that: (1) sellers of bulk power do not construct costly central station power plants to support transactions until all less expensive demand-side or generating measures are implemented; (2) conservation entrepreneurs can compete on equal terms with power suppliers for out-of-state markets; and (3) buyers do not substitute interstate purchases for less costly end-use or supply resources in their own system.

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Our proposal does not apply to short-term power transfers, which account for the bulk of FERC-regulated commerce. However, there is increasing interest in power transfer arrangements covering three years or more, which are both more lucrative and more significant from environmental and resource planning perspectives. The approach recommended here is consistent with that already used by the Bonneville Power Administration in its long-term power marketing.⁹⁰ Moreover, our proposal will not interfere with efforts to increase access to the transmission grid for municipal utilities and power customers.

Proposal: Conduct research and evaluation to improve utility, state, and local energy conservation programs.

Utilities, states and localities are spending at least \$1 billion per year on conservation and load management programs. Only limited research, however, has been conducted on alternative forms of program design and delivery. Considerable uncertainty remains about the significance of different program elements, response rates, and the net effects these programs have on energy demand and peak loads.⁹¹

DOE provides limited support for experimentation and evaluation related to state and utility conservation programs. But a much more intensive effort is called for to improve both the quality and understanding of conservation programs. Although not very costly, this effort is important and should not be overlooked by energy policymakers.

We propose that DOE establish and manage this program together with the Electric Power Research Institute, Gas Research Institute, utility commissions, and state energy agencies. The program should: (1) develop guidelines for conservation program experiments and evaluations, (2) provide technical assistance to utilities, states, and local agencies, and (3) conduct research and demonstrate new techniques for evaluating the impacts of conservation programs. As an added benefit, this program will improve the ability of states and utilities to conduct least-cost planning.

A number of states and utilities have proven that careful program evaluation and experimentation are well worth the effort. For example, Wisconsin used evaluations and experiments to greatly increase energy

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savings and lower costs in its low-income weatherization program.⁹² A well-funded and prominent national evaluation effort could provide similar benefits throughout the country.

Enhancing Industrial Competitiveness with Energy-Efficiency Research

American industry has faced few challenges as serious as today's international competition. Efficient foreign manufacturers have deeply penetrated American markets that were once the exclusive domain of domestic manufacturers. Since the early 1970s, the market shares of U.S. manufacturers have declined in a wide variety of product areas, including automobiles, steel, machine tools, telecommunications equipment, and semiconductors.⁹³ To meet the challenge, American industry must improve its efficiency as well as the value and quality of its products.

Energy costs American manufacturers over \$100 billion each year. Despite impressive gains in the last decade, U.S. industry is far less energy efficient than most of its major trade competitors. (See Table 3.) Improving the energy efficiency of American industry, especially energy-intensive industries, can make U.S. industry more competitive by reducing the final cost of products. Innovative energy-efficient technologies such as thin strip steel casting (which eliminates a cool-down/reheat step in steel making), foam processing for textiles (which substitutes foam for water in textile processing and thus reduces energy needed to dry fabric),⁹⁴ and impulse paper drying (which mechanically forces moisture out of paper, leaving less moisture that must be evaporated with energy-intensive processes)⁹⁵ can greatly reduce production costs for industry.

Several studies suggest that successful innovations tend to offer benefits not just in energy use, but in labor, materials, capital, and product quality. The innovations listed above all provide multiple benefits.⁹⁶ Foam processing, for example, can greatly improve a textile mill's production rate. Thus, energy efficiency will be advanced by industrial process innovation aimed at solving many problems simultaneously.

Improving the efficiency of energy-consuming *products* sold by American industry is also an important means of making American industry

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Table 3. Industrial Energy Intensity, Selected Countries

	<i>Industrial energy use per unit of industrial value added (a)</i>	<i>Average annual change during 1973-85 (b)</i>
<i>Country</i>	<i>1985</i>	<i>(%)</i>
West Germany	0.18	-3.0
Italy	0.23	-2.7
Japan	0.21	-4.7
Sweden	0.29	-1.9
United Kingdom	0.24	-3.0
United States	0.43	-2.4

(a) Expressed in tonnes of oil equivalent per 1000 1980 U.S. dollars.

(b) Based on each country's own currency.

SOURCE: Energy Conservation Indicators in IEA Countries, *International Energy Agency*, OECD, Paris, 1987.

more competitive. The vast array of industries that manufacture energy-consuming equipment, including the makers of residential appliances, commercial heating and cooling equipment, automobiles, and electric motors stand at the threshold of an enormous international market for advanced, energy-efficient products. Japanese and American researchers, for example, are engaged in a race to develop gas-fired residential heat pumps, which promise to be about twice as efficient as the best gas furnaces available today. And a few strong-selling new technologies such as low-emissivity windows (which use super thin, transparent metallic coatings to reduce heat radiated through windows) have demonstrated the market potential for energy-efficient products.

Unfortunately, U.S. industry significantly under-invests in technology development.⁹⁷ This under-investment stems from a number of factors, including the uncertainty that research will bear fruit, its long payback period, difficulties in capturing the benefits of research, and the expense of maintaining research programs during economic downturns. Frag-

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mented industries are constrained in R&D spending because relatively small companies have little incentive to conduct research that benefits more than their small part of the market. And in mature industrial sectors, large firms often are not inclined to develop products or processes that make their investment in existing plant and equipment obsolete. Therefore, the private sector cannot be expected to conduct the full range of research the country needs.⁹⁸

Just as important, U.S. industry often has difficulty commercializing new technologies it develops. Among the notable examples are video cassette recorders and industrial robots, both of which were developed by U.S. companies but commercialized primarily by Japanese companies. We propose the following policy measures to enhance the technological capabilities of industry and its ability to introduce new technologies in the market.

Proposal: Increase the commitment to federal energy-efficiency research and development and re-establish the federal role in demonstrating new energy-efficient technologies.

During the past seven years, the DOE conservation R&D budget has been slashed by more than 50 percent. This occurred despite its many successful R&D projects which will eventually yield billions of dollars of energy savings.⁹⁹ Textile foam processing, impulse paper drying, and low-emissivity windows all have been supported by this program. Andersen Windows, the largest U.S. window maker, estimates that low-emissivity windows now account for more than half of the company's window sales.¹⁰⁰ Electronic ballasts for fluorescent lamps, another technology advanced by the program, cut electricity use for fluorescent lighting by about 25 percent and are expected to save consumers about \$2 billion per year by the mid-1990s. Many opportunities remain for similarly impressive advancements. The federal energy conservation R&D program should, therefore, be substantially expanded.

The federal government should also recommit to conducting low-cost demonstrations of new energy-efficient technologies. Such demonstrations will give scientists and engineers an opportunity to apply and prove innovative technology in the real world. Demonstrations are often neces-

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sary to encourage risk-averse companies to adopt new technologies. Small-scale demonstrations played an important role in establishing the market viability of many of DOE's successful conservation R&D projects.¹⁰¹ Unlike most energy supply technology demonstrations (for example, synfuels and the liquid metal fast breeder reactor), conservation technologies have the advantage of being relatively inexpensive to demonstrate.

The proposed demonstrations should be conducted in close cooperation with industry, and industry should share substantially in the cost. This requirement should limit premature demonstrations. As technologies are advanced, and risks are reduced, the government's share of costs should decrease, or in some circumstances, be eliminated. The appropriate level of cost-sharing should be determined on a case-by-case basis and be influenced by such factors as the ability of the proposer to share the costs, the vested interest of the proposer, the residual rights required by the proposer, and the risk of project failure. The government should approach demonstrations cautiously.

Both the Gas Research Institute (GRI) and the Electric Power Research Institute (EPRI) recognize the importance of demonstrations in the innovation process. GRI, which spends about half of its \$170 million budget on efficiency projects, has researched and demonstrated such important technologies as pulse combustion furnaces, advanced commercial cooking equipment, and industrial heat recovery devices.¹⁰² EPRI supported research and demonstration of a highly innovative, efficient variable-speed heat pump, which Carrier Corporation plans to market soon.¹⁰³

Demonstration programs, and the research that precedes them, should also be based on a long-term commitment of funding as long as technical milestones are met. Industry is generally reluctant to participate in research and demonstration without such commitments because federal programs are often scaled down or re-directed after they have begun. Some countries with which the United States competes have multi-year funding commitments for research. The Japanese government's energy conservation R&D program approves project funding levels for up to ten years. Hence, the U.S. government should explore alternatives to annual R&D appropriations with provision for oversight.

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Proposal: Establish research centers for energy-intensive industrial processes.

Energy-intensive industries can benefit the most from new, energy-efficient industrial processes. But like most American industries they under-invest in research. We therefore propose that the federal government establish research centers for energy-intensive industrial processes.

The proposed centers would conduct basic and applied research on common industrial processes, such as removing contaminants from post-consumer steel scrap and processing it into high-quality products; membrane separation processes; chemical processing in a molten metal bath; metal casting, forging, and powder forming; fuel refining; and paper making. Over 50 areas in manufacturing processes merit federal support in the form of basic technology centers.¹⁰⁴ The centers would not focus exclusively on energy-efficiency research. Rather, they would research these processes to develop multiple improvements, one of which would be energy efficiency.

The centers would serve initially as the catalyst and later as the core of a larger industry research effort. Assurances of a high degree of cooperation and coordination from industry would be sought before each center would be established. The centers could be organized as "national user facilities," in which government would provide research facilities that industry could use for conducting proprietary or public domain research. A strong technology transfer program would be an essential element in each center.

The research conducted by the National Advisory Committee for Aeronautics (NACA) after World War I is a good example of this kind of research effort. NACA did not design aircraft or its components, but it researched technologies that were fundamental to the aircraft industry, such as airfoil shapes. After being changed to NASA, it led in the development of noise-suppression techniques and turbofans for jet engines.¹⁰⁵

The Combustion Research Program operated by Sandia National Laboratories is a paradigm of the proposed centers. This program fills a niche between universities and industry and is a catalyst for an aggressive, focused, national program. It conducts basic research on combus-

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tion phenomena and applied research on combustion processes occurring in internal combustion engines, furnaces, and coal combustors. The insight generated through its research is incorporated into computer models which can guide the development of more-efficient, fuel-flexible combustion hardware. Industry is deeply involved in research and management of the program. The center's core budget is provided by the government, but companies such as General Motors, Ford, and Cummins Diesel supplement those funds and conduct research of their own at the facility.

Results from the Combustion Research Program are being widely disseminated through a very active visiting scientist program, and more directly through industry involvement in research. The scientific results of the program are typically in the public domain, although proprietary work can also be conducted by firms using the facilities.

Selection of technologies for the proposed R&D centers should not be confined to applications of newly discovered scientific phenomena such as lasers, bioengineering, or superconductivity. Many older processes remain critical to the nation's industrial infrastructure and are ripe for technological innovation. In fact, new high technology capabilities have revolutionized research itself and have created opportunities for new understanding of phenomena incorporated in traditional industrial processes.

Many technologies, of course, have a clear high-technology focus. Some of these are being addressed in the Engineering Research Centers created by the National Science Foundation (NSF) and in the University Research Initiative of the Department of Defense. Care should be exercised not to overlap these efforts.

Creating technology research centers of high quality will require a gradual but ambitious process. It will also require careful selection of a lead agency (which could be the Department of Energy or the NSF) and cooperation among federal agencies. We envision a multi-year program, with each center assured of long-term support. The average federal contribution per center would be about \$5-10 million dollars annually. Private industry would be expected to contribute heavily to the centers. We recommend that about ten such centers be established by the early 1990s. If early experience is positive, the program could be expanded.

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Proposal: Establish a program to monitor and distribute information on foreign energy-efficiency research.

The United States has been the well-spring of new technologies for so long that it often ignores foreign technology research and innovation. Meanwhile, foreign countries have closely monitored new technology developments in the U.S. The rapid rise in technological capabilities of many foreign countries now makes it necessary for the U.S. to monitor more closely their new technology developments.

This initiative would establish a program to monitor and distribute information on foreign research and development activities for advanced energy-efficient technologies. It would complement the previous two proposals by providing current information on key foreign technical activities related to energy efficiency.

The program would evaluate foreign energy research, technology developments, and advanced system installations, and would assess the impact of foreign technology development on the United States, especially with regard to U.S. technical standing in world markets. This information would help identify the technological needs of domestic firms, guide federal research investments, and identify the export potential for energy-efficient products and process technologies produced in the United States. The research monitoring program would also maintain an information service capable of supporting foreign literature and patent searches and make industry aware of its services.

This effort would accelerate the development of conservation technology and would increase opportunities to apply advanced U.S. or foreign technology. Understanding foreign energy use and research activities would help the government to avoid "reinventing the wheel."

Making Buildings More Efficient to Improve Their Affordability

Each year the United States spends about \$170 billion on energy for buildings, nearly half of the total annual U.S. energy bill. High energy costs are especially hard on the poor, who tend to live in old, poorly maintained, and inefficient buildings. Families below the poverty line

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spend an average 19 percent of their income on home energy costs, which is more than four times the percentage spent by middle-income families.¹⁰⁶ According to federal guidelines, a third of renters and almost half of low-income families are cost-burdened—that is, they pay an unacceptably high percentage of their income for housing.^{107, 108} A recent analysis estimates that an across-the-board 25 percent reduction in residential energy use, an amount both technically and economically feasible, would make housing affordable for an additional 2 million households, more than half of which would be low-income households.¹⁰⁹

The potential for improving the energy efficiency of U.S. buildings is large. If all cost-effective conservation measures were employed, energy consumed in buildings could be reduced by 30-50 percent.¹¹⁰ But many obstacles impede further efficiency improvements. For example, split incentives between builders and building owners, and between landlords and tenants discourage conservation investments. Builders are more concerned with minimizing first costs than life-cycle costs, and landlords whose tenants pay their own energy bills have little incentive to make improvements.¹¹¹ Consumers also often lack the information and capital necessary to invest in efficiency improvements or to demand energy-efficient construction.

Many programs to help overcome these and other obstacles already exist. Utility conservation programs, such as rebates to consumers who purchase efficient appliances and lighting products are proliferating. New efforts to provide least-cost utility services will lead to improved building efficiency. But these efforts should be expanded, and new efforts are needed if the United States is to tap even part of the enormous conservation potential in buildings.

Indoor air quality, an important issue related to energy efficiency in buildings, also merits further attention. Any adverse effect that caulking and weatherstripping have on the concentration of indoor pollutants can be dealt with by addressing pollutants at their source. Researchers have found that indoor air pollution concentrations have a much stronger relationship with pollutant sources and source emission rates than with air infiltration rates.¹¹² Most tight, energy-efficient houses have acceptable air quality, while leaky homes are not immune to poor air quality. With home heating and cooling bills averaging about \$500 per year, haphazard leakiness can be an expensive way to have, at best, limited

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control over indoor air pollution. Indoor pollutants are best controlled at their source.

The following recommended policy measures are insufficient to reap all of the potential for energy conservation benefits in the buildings sector, but they could make a major contribution. These recommendations support and complement the many successful efforts being made by state regulatory agencies, utilities, builders, and consumers.

Proposal: Improve the effectiveness of and increase funding for low-income weatherization, especially for multi-family buildings.

At the current rate of weatherization, at least 40 years will be needed to weatherize the existing stock of eligible low-income homes. Weatherization programs operated by the federal and state governments, utilities, and other organizations reach only a small percentage of the more than 17 million low-income homes that need to be weatherized.

We propose that federal, state and local governments, and utilities expand their commitment to improving the energy efficiency of low-income housing. The federal government should at least double its annual investment in low-income weatherization. Doubling is far less than can be justified, but it would be an important step toward relieving the enormous energy cost burden of low-income homes. Furthermore, state and local governments can encourage increased market demand for more efficient buildings by requiring home energy performance rating systems, which enable potential renters and buyers to estimate energy costs before choosing a house or apartment.

The need for weatherization is especially acute in multi-family buildings, which have a high concentration of low-income families and have undergone few efficiency improvements. To help, the federal government should increase funds available through the federal Solar Energy and Energy Conservation Bank, and earmark them for multi-family housing weatherization. The Bank has been a small but important source of funds for multi-family weatherization programs because it offers highly flexible funding that allows local organizations to design approaches that best suit local needs. Its funds have been used to leverage much larger private investment in multi-family buildings. Massachu-

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setts, for instance, uses Bank funds to reduce the principal of private loans for conservation improvements to multi-family buildings. States wanting to participate in the multi-family program should commit matching funds. The combined federal and state funds would be used to improve the terms of private loans.

The loans could be channelled through existing and newly established non-profit energy service companies modeled after successful efforts such as the Citizens Conservation Corporation in Boston, the Center for Neighborhood Technology in Chicago, and the Energy Resource Center in Saint Paul, Minnesota. These organizations are suggested as models because they have been particularly effective at reducing energy use in multi-family buildings. The Citizens Conservation Corporation, for example, provides both technical and financial services to multi-family buildings through arrangements that use energy savings to service weatherization loans, and in some cases to reward tenants for conserving. The organization reports average energy savings in the 20-50 percent range.¹¹³ Other types of organizations such as local housing agencies could also help administer the program.

But before greatly expanding funding for weatherization, the technical ability to weatherize buildings needs to be improved. Evaluations of the low-income weatherization program indicate that much room for technical improvement remains.¹¹⁴ A recent research project in Wisconsin showed that using new technologies and a new procedure for choosing weatherization measures could produce twice the energy savings of the old Wisconsin Weatherization Program at about 25 percent less cost.¹¹⁵ Another research project in Minnesota tested innovative weatherization procedures and found that dramatic improvements in the cost effectiveness of weatherization could be achieved.¹¹⁶ Based on the success of these and other research efforts, we recommend that a weatherization research program be established in the U.S. Department of Energy, with a goal of increasing the energy savings to investment ratio of the low-income weatherization program by at least 50 percent.

Weatherization programs should also be modified to improve indoor air quality in low-income homes. National data indicate that at least 15 percent of all households have elevated levels of radon and other indoor air pollutants.¹¹⁷ Weatherization organizations are in an ideal position to assess indoor air quality in low-income buildings. With adequate training,

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they could test for radon and combustion gases during weatherization visits. Measures to mitigate identified problems could be installed by weatherization crews or other contractors specializing in indoor air quality.

The seriousness of the low-income weatherization and housing affordability problem demands the nation's attention. Rather than continue with minimal weatherization funding, and little attention to improving its effectiveness, it is time to redouble our efforts to make housing more affordable for those most in need. Improving energy efficiency is key to that effort.

Proposal: Establish federal minimum efficiency standards for fluorescent and incandescent lamps.

Lighting accounts for one-fifth of all the electricity consumed in the U.S. Although high efficiency lamps and lighting equipment are very cost effective for consumers—with simple paybacks on the order of one to three years—consumers do not routinely purchase efficient lamps because they lack information, they fail to examine life-cycle cost, and because lighting equipment buyers frequently are not the people who pay for the energy this equipment consumes.¹¹⁸

Similar problems impede the purchase of more efficient consumer appliances. To address the problem, Congress adopted minimum efficiency standards in 1987 for refrigerators, water heaters, air conditioners, and other appliances. These standards are projected to reduce peak electricity demand in the year 2000 by 22,000 megawatts, equivalent to the output of about 22 large nuclear power plants.¹¹⁹ Further upgrading these standards, as required by the law, could provide even greater savings.

We propose that Congress adopt similar national minimum efficiency standards for a number of common lamps. The standards for fluorescent lamps should be strong enough to ensure that only lamps as efficient as those that use improved phosphors could be produced. Standards for incandescent lamps should be set so that only those as efficient as krypton-filled lamps could be produced. Such standards would be highly cost-effective for consumers and could be met by many products already

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commercially available. The standards should be periodically reviewed by the Department of Energy and strengthened if justified.

The proposed lamp standards would complement efficiency standards for fluorescent lamp ballasts. California, Massachusetts, New York, and Florida have already enacted ballast efficiency standards. Congress recently passed a bill that set national minimum efficiency standards for ballasts.

The lamp standards we propose could by the year 2000 reduce electricity consumption by 25 billion kilowatt hours per year, save consumers about \$1.9 billion per year, and reduce peak electric demand by 5,000 megawatts, equivalent to the peak demand of about two and a half million households.

Proposal: Improve the energy efficiency of federal buildings.

Federal buildings, excluding public housing, annually consume about \$4 billion worth of energy. Largely because of limited resources and lack of government-wide support, the 12-year-old Federal Energy Management Program has had little effect on federal government energy consumption. In addition, efficiency improvements in federal buildings have been severely hampered by lack of incentives for federal facility managers to reduce energy costs, lack of capital to make improvements, and lack of model federal facilities to demonstrate the effectiveness of energy-efficiency measures.¹²⁰

We propose a serious and comprehensive commitment to improve the energy efficiency of federal buildings. The effort should establish new incentives and guidelines for federal officials. Agency managers, for example, could be allowed to retain part of their energy savings to meet other budgetary needs of their agency. Guidelines for investment in conservation measures should unambiguously require minimum life-cycle costs. New aggressive energy conservation goals for federal buildings should be set, such as 25 percent savings per square foot of floor space within ten years. And model federal facilities can be used as showcases to bolster the overall effort.

The effort should also include technical and institutional research and information programs, taking advantage of the expertise residing in the

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national laboratories and other research centers. The program should also seek improvements for indoor air quality and thermal comfort.

Although the conservation potential in all government buildings has not been analyzed, the age of the buildings, the lack of incentives to make improvements, and the relatively low-level of conservation retrofit investment indicate that considerable energy saving potential exists. Reducing its energy bill could help the federal government reduce its budget deficit, and help establish the viability of new conservation technologies and procedures, which, in turn, could lead to improvements in the efficiency of private buildings.

The biggest challenge of this effort is to train and motivate federal facility managers to make energy-efficient, cost-effective improvements, show them how to finance these improvements, and help them institutionalize the process for making these improvements. Government employees responsible for implementing successful conservation projects should be recognized and financially rewarded.

Increased energy-efficiency efforts should also be directed at federally-assisted housing, which has a \$2 billion annual energy bill. The responsible agency—the Department of Housing and Urban Development—has a dismal record in energy conservation. Evaluations of past energy retrofit performance and technical assistance for future retrofits are badly needed.

Proposal: Expand federal technical assistance for conservation efforts.

The experience of the last 15 years has shown that any effort to improve energy efficiency in buildings should be firmly based on strong technology development, program evaluation, and technical support.¹²¹ New technologies are regularly expanding the bounds of energy saving potential. Program evaluation verifies whether anticipated energy savings are achieved and provide important feedback for making improvements. Technical support usually makes the difference between successful and unsuccessful conservation programs.

We suggest two particularly important technical support initiatives. A national technical assistance effort should be established to support utilities and local and state governments adopting building labeling and

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information programs. Building labeling rates the energy efficiency of buildings to enable prospective buyers and renters to make more informed decisions. Building efficiency labels are akin to the automobile fuel economy labels and appliance energy guide labels required by the federal government. The technical assistance program would provide: guidelines for program design, implementation, and evaluation; access to simple and accurate building design tools; evaluation reports on the experience of related programs; and direct consultation with program experts.

We also propose that the federal government provide technical and managerial support for state and local governments adopting energy-conserving building codes. Building energy codes are a convenient and effective mechanism for accomplishing large energy savings at low cost in new buildings because it is easier and less expensive to build energy efficiency into new buildings than modify existing ones. Building codes also offer one of the few institutional mechanisms that brings together all people involved in the construction of a building—owners, developers, builders, lenders, design teams, and government regulators.

Many state and local governments, however, experience difficulty in developing and enforcing advanced codes because of their technical complexity. The federal government, which gained substantial expertise by developing Federal Building Energy Performance Standards, could provide compliance methods, educational materials for builders and code officials, and other technical support. This low-cost effort could have a major impact on the energy efficiency of new buildings, as demonstrated by California's success with codes containing stringent energy-efficiency requirements.¹²²

Helping Developing Nations Acquire Skills and Technology for Energy Efficiency

Energy poses serious problems for developing countries and, consequently, the world at large. In the early 1980s, many developing countries spent 20-60 percent of their export earnings on imported oil.¹²³ Many countries suffer from shortages of electricity or fuels; others find it difficult to obtain the financing for costly energy supply projects. Utility

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borrowing in many developing countries already accounts for over one-third of total foreign debt.¹²⁴ And fuelwood and crop residues—the traditional energy sources of the poor—grow increasingly scarce.¹²⁵

Increasing energy efficiency can reduce the urgent energy problems in developing countries, stimulate their economic growth, raise living standards, and improve environmental conditions. Opportunities for cost-effective efficiency improvements abound.¹²⁶ In Brazil, for example, potential exists to cut electricity demand in 2000 by 20 percent at one-fifth the cost of new power supply facilities.¹²⁷ A recent U.S. Agency for International Development (AID) report indicated that through conservation, developing countries could avoid \$1.4 trillion in power supply expansion costs by 2008.¹²⁸ For the majority of citizens in developing countries who still use biofuels for cooking, increasing efficiency or shifting to modern cooking fuels can greatly reduce energy use, fuel costs, and the long hours spent collecting fuel.¹²⁹

Why should policymakers in the United States take an interest in the energy priorities of developing countries? First, increasing efficiency in developing countries will improve their economic productivity and free foreign exchange for essential imports and debt service. Second, rising oil demand in developing countries—which could account for over half of the additional demand for oil among all non-communist countries during 1985-2000—places upward pressure on world oil prices.¹³⁰ Third, the need for energy efficiency in developing countries has the potential to create a new export market for the United States. Finally, developing nations could be responsible for one-third of worldwide coal use and over one-quarter of total commercial energy use by 1995.¹³¹ Thus, their energy efficiency will significantly affect the rate of global warming and other environmental problems.

But implementing greater efficiency on a large scale in developing countries requires involvement of governments, utilities, the private sector, and international lending and aid agencies. Unfortunately, energy efficiency receives very little support from the multilateral development banks, AID, and other organizations providing assistance to developing countries. The ongoing energy crisis in developing countries calls for a major reorientation. Bilateral and multilateral assistance agencies should make energy efficiency the centerpiece of their energy programs.

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Proposal: Modify the energy planning and lending policies of the World Bank and other multilateral lending and development institutions.

U.S. officials should attempt to reform the energy lending and assistance policies of the World Bank, the regional development banks, and relevant United Nations organizations. These institutions provide much of the funding and technical assistance for energy projects in developing countries. In some cases, these institutions strongly influence the energy policies of host countries. The United States is a major donor to these multilateral institutions and can advocate a fundamental reorientation in energy planning and lending.

We propose that U.S. representatives on the boards of the multilateral development banks advocate the following reforms.

- Apply integrated least-cost planning principles to energy planning and lending activities.
- Provide substantial financing for improving the efficiency of energy production and use where technically and economically feasible.
- Provide technical assistance for establishing and implementing conservation programs.
- Provide support for policies within developing countries that encourage conservation and efficiency improvements—pricing and taxation policies which reflect the real costs of energy, standards and labeling policies to help overcome market imperfections, for example.

The Foreign Assistance Appropriations Bill for 1989 passed by the House of Representatives proposes some measures along these lines.¹³² To adopt these provisions as U.S. policy, Congress may have to amend the Foreign Assistance Act and the International Financial Institutions Act.

The first reform mentioned above institutionalizes comparison of end-use efficiency options with new energy supply options and establishes least-cost energy services as a primary objective for the multilateral organizations. Of course, other critical objectives such as job creation, infrastructure building, and self-reliance need to be considered as well when setting energy priorities. Likewise, energy costs should be consid-

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ered when evaluating a wide range of development options—expansion of energy-intensive industries or transportation systems, for example.

The second and third reforms ensure that developing countries receive the funds and technical assistance necessary to implement greater efficiency on a broad scale. Besides funding investments in energy efficiency, it will be necessary to establish efficiency research, financing, incentives, standards, education, and monitoring programs within developing countries. These are unfamiliar areas to developing countries and assistance agencies alike. Moreover, due to the diffuse nature of efficiency implementation, new mechanisms for accomplishing these tasks—for example, ways to disperse funds and manage programs for greater energy efficiency—must be developed. Consequently, technical and policy support, institution building, and program experimentation will be critical.

The fourth reform concerns policies within developing countries, such as energy pricing, equipment duties, sales taxes, product standards, and building codes. While not solely pertaining to energy efficiency, all can strongly influence levels of conservation and efficiency improvement.

A few precedents exist for these initiatives. The United States often applies leverage to alter the policies of the multilateral development banks.¹³³ In the past, the World Bank has supported industrial energy conservation and fuel substitution programs in a number of developing countries.¹³⁴ The World Bank also helped to establish a national electricity conservation program in Brazil.¹³⁵ Despite these precedents, conservation still receives minimal funding and attention from the World Bank and the regional development banks.

Proposal: Provide technology and policy assistance for energy efficiency to developing countries through U.S. AID and other American agencies.

We propose that AID and other U.S. government organizations, such as the Trade and Development Program and the Export-Import Bank, expand their efforts to help developing nations acquire technologies, policies, and programs for greater energy efficiency. But rather than take a traditional project orientation, this initiative would focus on building

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the capabilities of individuals and institutions within developing nations in both their governmental and non-governmental organizations.

This effort would draw heavily on the wealth of conservation expertise in the United States among utilities, state and local agencies, the private sector, non-governmental organizations, universities, and national laboratories. U.S. experts would be made available to their counterparts in developing countries. These individuals could help to strengthen local capability while assisting in activities such as development of least-cost energy plans, adapting conservation technologies to local conditions as well as new technology development, and organizing conservation programs. Similarly, appropriate institutions in the United States should be encouraged and funded to host and train professionals from developing countries.

U.S. AID should set an example for other assistance organizations, both within the United States and from other countries, by adopting a least-cost energy services approach and involving representatives from developing countries in setting energy assistance priorities. In addition, AID should support related activities such as R&D on efficient fossil fuel or biofuel-based technologies, technical and program data bases, and information exchange among developing countries.

Increasing private sector involvement in energy efficiency in developing countries is also needed. Organizations such as the Overseas Private Investment Corporation, the Export-Import Bank, and the Trade and Development Program should actively encourage U.S. companies to market and establish joint ventures in energy-efficient technologies and services in developing countries. Also, these agencies and AID should support, in part, the development and adaptation of American technologies to local conditions.

Energy conservation assistance and capability building is already supported to a limited degree by AID. For example, Lawrence Berkeley Laboratory is assisting Southeast Asian nations with the evaluation of conservation potential in commercial buildings and establishment of building codes. Technology R&D and market studies related to more efficient use of biomass residues are underway. And a new AID project supports research and development of technologies for the efficient supply and end use of energy in India.¹³⁶

But AID and the other governmental organizations have not made the

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strong, long-term commitment to “person-to-person” exchange and institution building that is proposed here. We suggest funding on the order of \$50-100 million per year for a number of years in order to make a significant contribution towards establishing energy conservation capability and efforts in developing countries. This is a modest proposal considering that the United States spends about \$12 billion per year for non-military assistance to developing countries—but it could provide multiple benefits that serve the vital interests of the U.S.

Conclusion

No doubt policymakers will want to know what will be accomplished if the measures recommended here are implemented. How much energy savings will result and how much money will consumers save? How much will it cost or save the federal government? And how will our national security, industrial competitiveness, and environment be affected?

It is difficult to answer these questions. The impacts from some proposals—such as vehicle and lighting efficiency standards—can be calculated. But the impacts of many of the other proposals such as expanded R&D efforts and incentives for promoting least-cost utility services are highly uncertain.

Rather than attempting to quantify the energy savings of these specific policy proposals, we have estimated what might occur if the national goal of reducing energy intensity by 2.5 percent per year is realized. In this section, we present three scenarios for energy use in the United States at the turn of the century—the current Department of Energy forecast, a moderate efficiency case, and a high efficiency case.

Both the moderate and high efficiency scenarios are derived from other recent studies that consider what might occur given varying degrees of emphasis on energy efficiency.¹³⁷ The moderate efficiency scenario is based on existing policies and market trends, while the high efficiency scenario assumes expanded policy initiatives in support of conservation and widespread adoption of cost-effective efficiency measures. In short, the high efficiency scenario is consistent with adoption of our policy agenda.

The moderate efficiency scenario shows energy use increasing to 81

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Table 4. Scenarios for U.S. Energy Use in 2000

<i>Sector</i>	<i>Energy Use (Quads)</i>			
	<i>Actual 1987 (a)</i>	<i>High efficiency 2000 (b)</i>	<i>Moderate efficiency 2000 (b)</i>	<i>EIA base case 2000 (c)</i>
Residential	15.7	15.6	17.3	18.3
Commercial	11.9	13.3	14.7	15.1
Industrial	27.2	23.8	28.0	33.8
Transportation	<u>21.2</u>	<u>18.5</u>	<u>21.0</u>	<u>22.3</u>
Total	76.0	71.2	81.0	89.6

Notes:

(a) "Monthly Energy Review," DOE/EIA-0035(87/12), Energy Information Administration, Washington, DC, Dec. 1987. This source combines residential and commercial energy use; the division shown above is based on the 1985 breakdown.

(b) Based on Reference 137.

(c) "Annual Energy Outlook 1987," DOE/EIA-0383(87), Energy Information Administration, Washington, DC, March 1988.

SOURCE: American Council for an Energy-Efficient Economy.

Quads by 2000. (See Table 4.) This outcome is still nearly 10 percent less than the most recent "base case" forecast by the Energy Information Administration (EIA) of the Department of Energy.¹³⁸ In all cases, GNP is assumed to grow at an annual rate of 2.0 to 2.5 percent. Consequently, the moderate efficiency scenario represents about a 1.7 percent annual rate of decrease in energy intensity between 1987-2000.

Our high efficiency scenario shows the United States consuming 71.2 Quads in 2000, 12 percent less than the moderate efficiency scenario and 21 percent less than the 89.6 Quads forecast by the EIA. The average rate of reduction in U.S. energy intensity during 1987-2000 is about 2.7 percent per year in the high efficiency scenario. The United States

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actually achieved this rate of energy intensity reduction between 1976 and 1986.

The appendix to this report estimates the impact on the federal budget of our policy proposals. By implementing the measures we recommend, the U.S. government would receive far more revenue (primarily through the vehicle fuels tax) than it would spend. The net revenue gain of our policy agenda could reach about \$30 billion by 1992.

Following the high efficiency path would enhance our economic well-being, competitiveness, national security, and environment. Specific benefits that would accrue from lowering energy use at the turn of the century by 10-18 Quads follow.

- The United States would save \$1.3-2.2 trillion over the next 20 years (1987 dollars). The total investment in conservation measures required to achieve this savings would be on the order of \$300-500 billion.
- The nation would reduce the projected increase in oil imports by 2.0-3.6 million barrels per day. This would cut the U.S. oil import bill by \$18-40 billion, and significantly reduce the likelihood of OPEC regaining control of the world oil market, hiking oil prices, and possibly threatening the flow of oil to the United States and its allies.
- U.S. industries would improve their competitiveness through lower energy costs. Deferring the need for investment in new power plants alone could free more than \$100 billion for capital investment in other U.S. industries.
- The poor would benefit from lower energy costs, additional jobs, and more affordable housing.
- Americans would reduce environmental damage and the need for costly pollution control measures. For example, carbon dioxide emissions would be 12-20 percent lower in 2000 in the high efficiency scenario compared to the moderate efficiency scenario or EIA's forecast.
- Last but perhaps most important, the United States would do its part in a worldwide energy-efficiency campaign. Such a campaign will be

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especially important to the three-quarters of the world's people who live in less-developed countries.

The United States possesses the technical ingenuity and institutions necessary to create an energy-efficient economy. But doing so requires political determination. Energy-efficiency improvements will continue to slow in the absence of new leadership and coordinated national policy. By placing energy efficiency at the top of his agenda, the next President can help create a prosperous, secure, and environmentally sound nation.

Appendix

Table A-1 presents estimates of the direct costs and revenues to the federal government for implementing the energy-efficiency policy agenda. The costs and revenues do not consider indirect impacts due to changes in tax revenue or interest rates, for example. For many policy proposals, the budgetary impact will depend to a large degree on the specific details of the policies. The values in Table A-1 should be viewed as approximations.

Table A-1 shows that by implementing the proposed policies, the federal government could receive far more in new revenue than is required as federal expenditures. The gasoline and diesel fuels tax alone would provide about \$30 billion by the third year of the program, even with part of the tax revenue rebated to low-income persons. Thus, pursuing energy efficiency can help the U.S. government to balance its budget, besides providing many other benefits.

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Table A-1. Impact of the Policy Proposals on the Federal Budget
(million dollars)

<i>REVENUES</i>		<i>fiscal year</i>				
<i>Policy proposal (a)</i>	<i>1990</i>	<i>1991</i>	<i>1992</i>	<i>1993</i>	<i>1994</i>	
Vehicle fuels tax (b)	6,100	18,400	30,600	36,700	36,700	
Gas guzzler tax	220	340	500	800	1,100	
TOTAL	6,320	18,740	31,100	37,500	37,800	
<i>EXPENDITURES</i>		<i>fiscal year</i>				
<i>Policy proposal (a)</i>	<i>1990</i>	<i>1991</i>	<i>1992</i>	<i>1993</i>	<i>1994</i>	
International energy efficiency protocol	2	5	10	10	10	
International efficiency cooperation	5	10	15	15	15	
Research to lower energy use and protect the ozone layer	5	10	15	15	15	
Integrated energy and environmental planning	2	5	5	5	5	
Gas sipper rebates	—	—	—	—	1,000	
Utility incentives	1	1	2	2	2	
Competitive bidding	1	1	2	2	2	
Research and evaluation of utility conservation programs	5	10	10	10	10	
Federal research, development and demonstration	250	300	300	400	400	
Industrial research centers	20	40	60	80	100	
International R&D monitoring	2	2	2	2	2	
Low-income weatherization	200	240	280	320	350	
Energy efficiency in federal buildings (net of energy savings)	260	380	570	710	730	
Technical assistance for energy-efficient buildings	1	1	2	2	2	
Energy efficiency assistance for developing countries	20	50	100	100	100	
TOTAL	770	1,060	1,370	1,670	2,740	

(a) Policy proposals without budget impacts are not included.

(b) Net revenue taking into account rebates to low-income persons, assuming the tax is limited to 30 cents per gallon. Greater revenue would be collected in 1992 and 1993 if the tax increases to 50 cents per gallon.

SOURCE: American Council for an Energy-Efficient Economy

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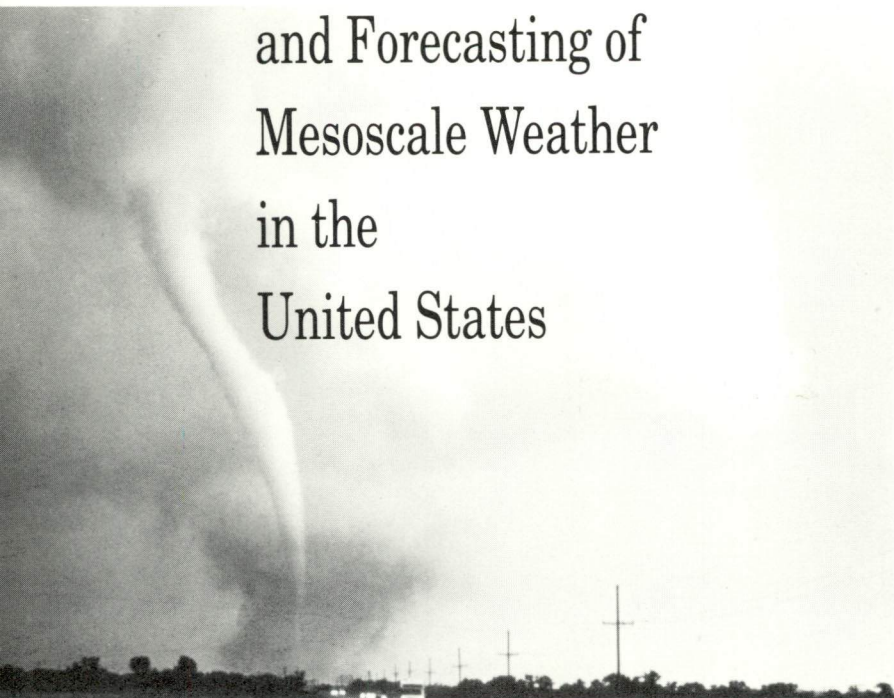
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Cover: Photograph of an intense tornado that struck Union City, Oklahoma, on May 24, 1973. Observations of this storm on experimental Doppler radar and simultaneously by the Tornado-Intercept Project team of the National Severe Storms Laboratory provided the initial impetus for planning the next-generation weather radar (NEXRAD) system. (Courtesy of Joseph H. Golden of the National Oceanic and Atmospheric Administration.)

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Preface

Much of the weather that affects human activity has mesoscale dimensions. In addition, there is growing recognition that atmospheric circulations on this scale (2 to 2000 km) interact importantly with meteorological processes on both larger and smaller spatial scales, including, at the largest scales, global climate. However, mesoscale weather events are often too small and short-lived to be observed by the relatively widely spaced and infrequently reporting radiosonde and surface observing sites that constitute the present operational observing network. Thus an improved mesoscale observational network, along with a research effort that takes advantage of it, should lead to greater understanding of mesoscale weather events and their interactions with processes on other scales and to advances in our understanding of the atmosphere as a whole.

Scientists now recognize that, while there is still much to learn about the dynamics of weather processes, existing limitations in weather predictions and warnings are primarily due to limitations in observations, computers, computer models, data assimilation, and dissemination of forecast information. These limitations are being reduced as new observing systems, improved computer capabilities, advanced models, and communications technologies emerge. These new capabilities will enable us to observe and predict the weather in unprecedented detail and accuracy provided we develop the necessary knowledge and skills to use the new capabilities advantageously.

Taken together, the development of enhanced technological capabilities, the scientific and socioeconomic importance of mesoscale weather

events, and the new opportunity to make progress all point to the need for implementing the National Stormscale Operational and Research Meteorology (STORM) Program. This program will capitalize on the new observing systems and will create the knowledge base needed to improve forecasts in all seasons and all sections of the country.

The framework for the National STORM Program grew out of a series of workshops held by the atmospheric sciences community in the early 1980s. An essential aspect of the program is that it has both research and operational components. The need for STORM, and its underlying precepts, was endorsed by the NSF-UCAR Long-Range Planning Committee in their report *The Atmospheric Sciences: A Vision for 1989-1994* (National Science Foundation, Washington, D.C., 1987). This report recommends that the program be carried out as planned.

The reader may ask why another report urging that the planned National STORM Program be implemented is needed at this time. The answer is twofold: (1) Despite much planning effort over the last several years, as indicated in Chapter 1, this very important program has been overshadowed by other programs and has not made the expected progress toward implementation, and (2) the imminent modernization of the National Weather Service, involving bringing sophisticated new observing systems on-line, will not achieve the maximum possible improvement in weather forecast and warning services without a complementary scientific program of research and development. This report restates the need for such a program and argues that the planned STORM program is well designed to fulfill this need.

I am grateful to the Panel on Mesoscale Research and its successor, the Committee on Meteorological Analysis, Prediction, and Research, for their thoughtful and stimulating discussions of the issues and for articulating the needs and opportunities in mesoscale meteorology. We are all indebted to the staff of the Board on Atmospheric Sciences and Climate of the National Research Council for their help and counsel and especially to Kenneth Bergman and Doris Bouadjemi for their assistance in preparing this report.

Peter S. Ray, *Chairman*
Committee on Meteorological Analysis,
Prediction, and Research

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Executive Summary

Significant advances in our understanding of mesoscale¹ atmospheric processes are needed in order to increase the accuracy of predictions and warnings of important weather events that occur on this scale. The opportunity exists to improve the 0- to 48-hour prediction of precipitation and severe weather through an enhanced fundamental understanding of precipitation, the hydrologic cycle, and other mesoscale processes, and through full utilization of the advanced observing systems that will soon be available.

Mesoscale weather systems play a significant role in global atmospheric circulation through transport of heat, moisture, and chemicals. The effects of clouds generated by mesoscale weather systems are the largest variable in the global energy budget. Therefore, improved understanding of mesoscale processes is essential for improved understanding of climate processes and climate change. A recent report, *Meteorological Support for Space Operations: Review and Recommendations* (NRC, 1988), recognizes the importance of mesoscale weather events to the nation's space program; thus enhanced understanding of mesoscale processes should contribute in this arena as well.

¹ Mesoscale processes are those that occur on scales of 2 to 2000 km, such as thunderstorms, tornado outbreaks, local heavy rain and snowstorms, flash floods, windstorms, downslope winds, and significant air pollution events.

In order to achieve the goals of improved understanding and prediction of mesoscale weather processes, we need to fully exploit new observing systems, such as the Demonstration Wind Profiler Network, the next-generation weather radar (NEXRAD) Doppler radars, instrumented commercial aircraft, and the GOES NEXT satellite; new data-processing methods, such as the Advanced Weather Interactive Processing System for the 1990s (AWIPS-90) and four-dimensional data-assimilation techniques; and a new generation of computers and numerical prediction models. These improved capabilities must be used as an integrated system in order to gain the maximum benefits from each component.

The new mesoscale observing systems that will soon be deployed as part of the National Weather Service's modernization have been chosen to greatly enhance the present national weather observing capability. The new systems will be critical for understanding and predicting precipitation and severe weather and for understanding interactions of meteorological processes on different spatial scales. The new observations will also contribute to improvement of numerical weather prediction models through use in initialization and verification of the models.

In order to advance understanding and improve weather forecasts, this report recommends that

- The planned development and deployment of the new weather observing systems and technologies should continue and be kept on schedule.
- The capabilities of new instruments should be systematically assessed in order to maximize their utility for short-term forecasting and warning and for initializing and testing numerical prediction models.
- Investigation into possible additional applications of the new data streams should be undertaken in order to realize the full benefits of new observational technologies.
- The data from the new observing systems should be processed, archived, and made available to a wide range of users in an efficient, timely, cost-effective, and easy-to-use manner.
- Data-assimilation techniques should be developed to combine the many kinds of data into coherent, gridded data sets suitable for a wide range of weather forecast and research tasks.
- Numerical prediction models should be improved to more accurately account for physical and chemical processes, including those involved in the hydrologic cycle; sensible, radiative, and latent heating throughout the troposphere; and energy exchange at the earth's surface.
- Large observing programs, timed to take advantage of the newly deployed observing systems, should be conducted. These programs should make use of the new observing systems to look at the multiscale interactions arising from mesoscale weather events. Additionally, observing

programs that cover smaller regions and specific weather phenomena and that complement the larger-scale programs should also be planned and carried out.

- Forecasters should be retrained and, where necessary, university curricula in the atmospheric sciences should be revised, updated, and expanded to produce a sufficient supply of new meteorologists capable of using the new observing systems and scientific concepts to best advantage.

The necessary actions to fulfill these recommendations are embodied in the National Stormscale Operational and Research Meteorology (STORM) Program (*STORM Program Plan* [NCAR, 1990]).

Therefore this report recommends that the National STORM Program be implemented as soon as possible.

By building on the large investment already committed to new observational technology and capabilities, the National STORM Program will provide the focus for important advances in basic understanding of mesoscale weather processes and in the country's operational abilities to forecast weather events.

1

Introduction

THE PROBLEM

Each season reminds us of our vulnerability to destructive or incapacitating weather events such as tornado outbreaks, windstorms, hailstorms, heavy snowstorms, and flash floods. Our society relies increasingly on technology that is vulnerable to the weather, thereby increasing the need for improved weather predictions and warnings. There is, for example, heightened awareness of the crucial role played by weather in major air and space transportation accidents, such as the Dallas-Ft. Worth airliner crash, the Centaur Atlas launch lightning accident, and the Challenger space shuttle disaster. The costs of inadequate warnings of tornadoes, floods, and other severe weather can be very large.

Events of 1989 alone dramatically reminded many Americans of their vulnerability to severe weather events. In addition to Hurricane Hugo's costly (21 U.S. mainland deaths and about \$7 billion in damage) strike into South Carolina, the nation reported a near-record 845 tornadoes that caused 48 deaths and much property damage. The outbreaks that caused the most deaths occurred on November 15 near Huntsville, Alabama, (21 deaths) and on November 16 in New York State (9 deaths), the latter tornado activity being very atypical in terms of location and time of year. Heavy rains brought flash floods to parts of Kentucky in February, Pennsylvania in May, Louisiana in both June and November, and northern Florida in October, when up to 40 cm (16 in.) of rain fell in one day. Fargo, North Dakota, recorded a record snowfall of 62 cm (24.4 in.) from

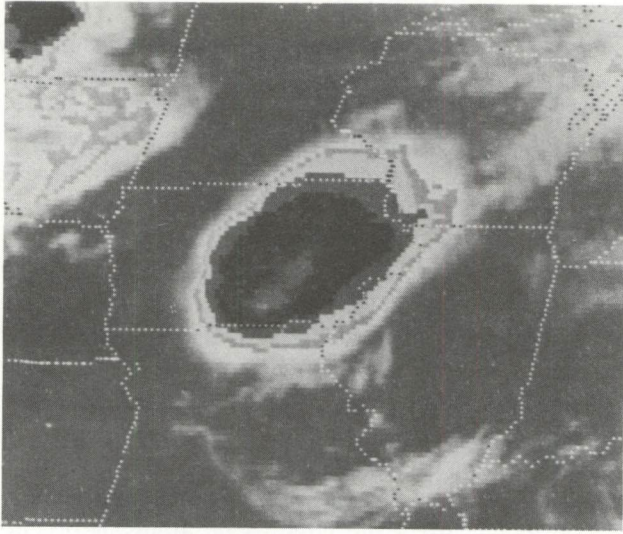
a local snowburst embedded within a severe blizzard-producing storm in January. Similar severe weather events, many of them mesoscale, occur every year, have similar impacts, and typically cause some billions of dollars in economic losses as well as significant loss of lives.

A singular characteristic of heavy precipitation and severe weather is that they are often highly localized events that occur over small areas and for limited times. These mesoscale weather events are the ones that most directly affect humans, yet many elude detection by the present upper-air weather observing network, which is built around 12-hourly balloon soundings at sites some 500 km apart, and even by the surface observing network, which has typical site spacings of 100 to 200 km. Moreover, these events cannot at present be reliably predicted with numerical models.

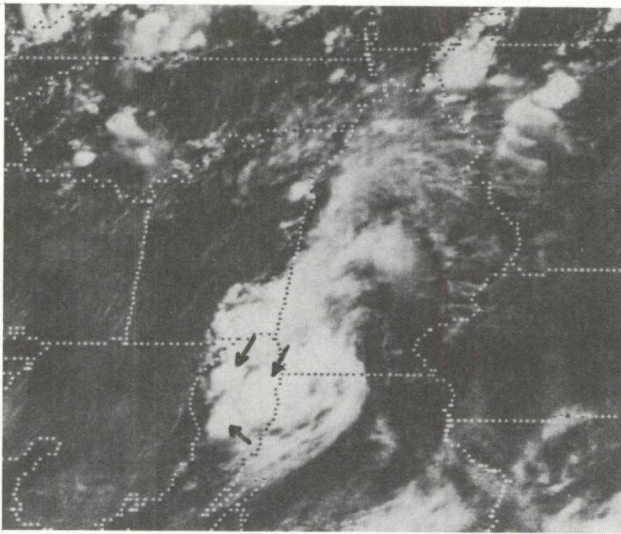
Mesoscale events result from complicated, nonlinear processes that themselves occur across a wide spectrum of spatial and temporal scales extending from variations in the global atmospheric circulation pattern to microscale physical processes in individual clouds. In addition, mesoscale systems, once initiated, affect the larger-scale atmospheric circulations in which they are embedded. For example, Figure 1.1a shows an enhanced infrared image of a mesoscale weather system as seen from a satellite vantage point over Iowa at 0730 UTC on July 16, 1982. Although the cloud cover depicted in this image suggests a single weather entity with a scale of about 300 to 400 km, radar observations of this system made at approximately the same time (Figure 1.1b) and subsequent visible satellite imagery (Figure 1.1c) indicate that the system was composed of several clearly distinguishable elements of distinctly different scales, that is,

1. a broad, roughly circular zone of stratiform precipitation with a diameter of about 200 km,
2. cyclonically curved bands of heavier precipitation (≈ 50 km wide and about 200 to 300 km long), and
3. individual thunderstorms, each on the order of 2 to 20 km in scale.

In addition to displaying these directly evident multiscale features, this system substantially altered the flow field of its larger-scale environment and produced a large anticyclonic wind perturbation that spanned nearly 1000 km (Figure 1.1d). At smaller scales, high-resolution aircraft observations of such systems suggest that microphysical processes such as freezing, melting, drag, and evaporation of hydrometeors significantly affect the circulations of such systems. These inherently complex systems have so far defied complete scientific understanding, largely because it has not been possible to simultaneously measure how the many different scale components of such systems interact with each other and with their large-scale environment. As a consequence, consistent and accurate prediction of these systems has remained elusive, as in the present example (see Figure 1.1), where over



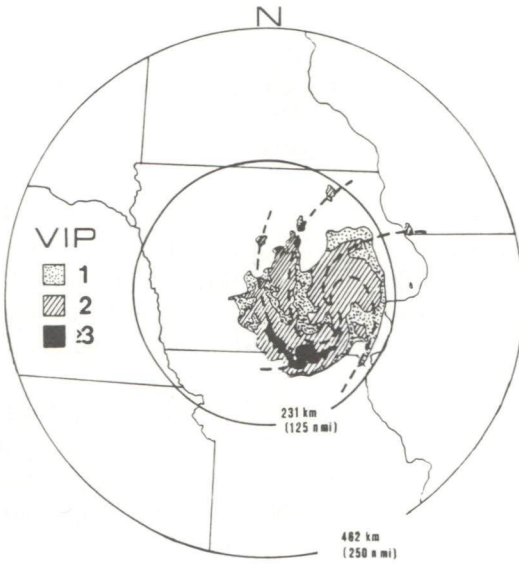
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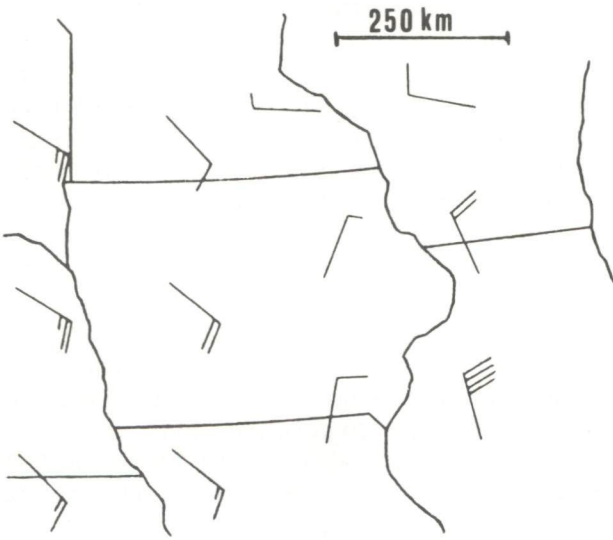
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FIGURE 1.1 (a) Enhanced infrared satellite image for 0730 UTC, July 16, 1982. (b) Des Moines, Iowa, radar horizontal display for 0700 UTC, July 16, 1982. Levels of precipitation intensity (VIP) are shown along with axes (dashed) of maximum precipitation, suggesting rotation. (c) Visible satellite image for 2130 UTC, July 16, 1982. Arrows indicate individual

7



b



d

thunderstorms developing within the vortex. (d) 200-mb perturbation wind field produced by the mesoscale convective complex shown in (a); valid time, 1200 UTC, July 16, 1982. Full barb = 5 m/s. (Reprinted, with permission, from Murphy and Fritsch, 1989. © 1989 by the American Meteorological Society.)

10 in. of rain with attendant flash floods occurred as the system moved into southern Michigan. This example is just one of many such occurrences of complex mesoscale systems that have resulted in unpredicted severe weather.

A massive capital investment in technology now under way as part of the National Weather Service's modernization will permit weather observations of increased detail in space and time. These observations should greatly enhance our ability to observe small-scale weather systems such as the one discussed above. However, as with all new observing systems, research on how they can best be used is required to realize the systems' full potential and bring about improved understanding and prediction of mesoscale weather.

Mesoscale systems also significantly affect the exchange of water between the earth and the atmosphere and form a critical link in the hydrologic cycle. The improved basic understanding of the hydrologic cycle resulting from a mesoscale research program will support improved water resource policies and contribute to our understanding of global climate change.

HISTORICAL PERSPECTIVE

Meteorological observations form the basis of our understanding of the weather. The improvement of numerical weather prediction and the illumination of physical processes depend on the frequency, accuracy, and spacing of available observations. Significant weather events can form on scales as small as 2 km, much smaller than the existing operational networks can resolve, and hence their origins are often not detected. Mesoscale weather events also tend to be episodic rather than periodic, which further decreases the chances of their detection. Furthermore, mesoscale weather phenomena interact importantly with larger-scale weather systems, but the exact nature of these interactions is not well understood.

As early as 1969, scientists recognized the need for special programs to observe and study mesoscale weather phenomena and their interactions with larger weather systems. As an outgrowth of this recognition, scientists in 1973 proposed a multiscale program, the Severe Environmental Storms and Mesoscale Experiment (SESAME; NOAA, 1976), which was designed to specifically address the vital scale-interaction problem mentioned above. However, a lack of sufficient resources and observational capability prohibited carrying out a multiscale field experiment. Instead, the program was separated into two phases: the first phase concentrated on the larger synoptic and meso- α scales (200 to 2000 km), while the second focused on the smaller meso- β (20 to 200 km) and meso- γ (2 to 20 km) scales. Also in 1973, the Cyclonic Extratropical Storms (CYCLES) Project attempted to examine meso- α - and meso- β -scale disturbances embedded in winter

cyclones. These projects were followed in 1975 through 1980 by the High Plains Experiment (HIPLEX) series of field studies and in 1981 by the Cooperative Convective Precipitation Experiment (CCOPE), both of which recognized the importance of mesoscale processes and scale interactions in their plans. However, resources and observational capabilities remained inadequate for detailed study of scale interactions. Over the years, the scientific community has nonetheless remained steadfast in its call for a multiscale, scale-interaction experiment that focuses on understanding and predicting mesoscale weather processes.

About a decade ago, the associate administrator of the National Oceanic and Atmospheric Administration (NOAA) requested the National Research Council (NRC) to "conduct a brief survey of the current mesoscale meteorological research being conducted throughout the federal government and to develop a preliminary assessment of the adequacy of this research in terms of the important opportunities that exist in this area of scientific endeavor." The ensuing NRC report, *Current Mesoscale Meteorological Research in the United States* (NRC, 1981), recommended the establishment of a national mesoscale program of basic and applied research directed toward better understanding and improved prediction of mesoscale weather events.

In 1982, a group of atmospheric scientists met at the National Center for Atmospheric Research (NCAR). They concluded that significant improvements could be achieved in local weather forecasts and warnings of severe weather as a result of then recent and planned developments in space- and ground-based observing systems. In addition to enhancing early warning capabilities, these new observing systems were considered to have the potential for greatly improving physical understanding of small-scale weather processes. Advances in computer technology, by enhancing the ability to numerically model weather processes, would enable the new observations and improved understanding to be translated into better local weather forecasts and warnings. The scientists recognized that in order to realize the potential for improved understanding and prediction of weather, a coordinated, national effort was needed. The proposed effort was named the National Stormscale Operational and Research Meteorology Program, or simply the National STORM Program (UCAR, 1982).

The technical opportunities and scientific basis for a national effort centered on mesoscale meteorology were discussed in detail in *The National STORM Program: Scientific and Technological Bases and Major Objectives* (UCAR, 1983a). It was recognized that the proposed national program required two parallel efforts: one centered on improved understanding of the physical processes involved, and the other on applying this knowledge to improving weather services. *The National STORM Program: A Call to Action* (UCAR, 1983b) supported the recommendations of the previous

two documents, urged the community to capitalize on the emerging observational technology, and called for implementation of the two components of the National STORM Program.

In 1986, the National Science Foundation's Division of Atmospheric Sciences (ATM) and the University Corporation for Atmospheric Research (UCAR) were advised by a specially appointed committee on the important priorities for atmospheric research over the next decade or so. In the committee's report, *The Atmospheric Sciences: A Vision for 1989-1994* (NSF, 1987), progress in mesoscale meteorology was highlighted as one of the top two research priorities. Also, in 1988, the UCAR, in conjunction with the Council of the American Meteorological Society, identified the protection of life and property through improved weather prediction as one of two top priorities for the United States to pursue in the immediate future (AMS, 1988).

RECENT DEVELOPMENTS

Many of the recommendations found in the documents referenced above have been or are in the process of being implemented. The deployment of an advanced national weather observing system has received particular emphasis. This system, representing an investment of more than \$1 billion, includes the next-generation weather radar (NEXRAD) Doppler network, the Automated Surface Observing System (ASOS), the Demonstration Wind Profiler Network, the next generation of geostationary satellites, and the Advanced Weather Interactive Processing System for the 1990s (AWIPS-90). However, the parallel research and application efforts needed to maximize the benefits to be derived from this impressive array of instruments have largely been lacking. To help address these needs, the National STORM Project Office has recently been established to coordinate improvements in the National Weather Service's (NWS) operational systems with the nation's weather research program and to plan for a national mesoscale program that will further both understanding and predictive capability.

Experts in numerical modeling, in observational research, and in operational forecasting from the government, academia, and the private sector have been involved in planning for the National STORM Program. This process has resulted in a community consensus on goals, objectives, and schedules for the program. The preliminary program plans have been reviewed by this committee and its predecessor, the Panel on Mesoscale Research.

The proposed National STORM Program has two equally important goals:

- Improve the 0- to 48-hour prediction of precipitation and severe weather events.
- Advance fundamental understanding of precipitation and other mesoscale processes and their role in the hydrologic cycle.

As this report makes clear, the atmospheric community is now well positioned to address these goals. The new technologies for observation, data analysis, and information dissemination will soon be operational. An effective administrative framework has been established. The atmospheric sciences community is in agreement on the goals, objectives, and method of attack. Therefore, a well-focused program of basic and applied research directed toward achieving the full potential of the new observing technologies for operational prediction and warning is urgently needed.

PURPOSE AND SCOPE OF THIS REPORT

As noted above, little progress has been made in undertaking a well-focused basic and applied research program that will exploit the full potential of the new observing technologies for improved fundamental understanding of mesoscale interactive processes. Without this fundamental understanding, the full benefits of the new technologies for operational prediction and warning cannot be realized. It is the purpose of this report to make recommendations that will assure that the full potential of new observing technologies is realized in terms of improved understanding and better forecasts. In this report, the committee urges the implementation of a national mesoscale program that will provide both the scientific understanding and the development of the operational techniques required to make the best use of the large investment in instrumentation and technology, leading to improved weather predictions in all parts of the nation.

This report discusses several new technological capabilities relevant to mesoscale meteorology and their relationship to advances in scientific understanding; important relationships between mesoscale meteorology, atmospheric chemistry, and climate are also identified (Chapter 2). The potential implications of the new technologies for improved operational meteorology are summarized (Chapter 3).

The report concludes with statements of needs and recommended actions for capitalizing on the opportunities that now exist (Chapters 4 and 5). The recommended actions should lead to major progress in understanding scale interactions, a virtually unexplored frontier in mesoscale meteorology. This increased understanding should have the direct, positive impact of improving weather forecasts and products delivered to the public. In addition, understanding of the role of mesoscale processes in the global circulation, in the transport of greenhouse gases and other trace constituents, and hence in climate should be much improved.

The message is clear. The community has prepared itself well to undertake a national mesoscale program. There is broad agreement on the goals, objectives, and plan of attack, and the technological components are being put into place. This is the optimum time to begin such an effort. The program should result in a major leap forward in understanding of mesoscale processes and in developing markedly improved weather forecasting services for all segments of our society.

2

Status of Technology and Science in Mesoscale Meteorology

EMERGING OBSERVING SYSTEMS AND NEW TECHNOLOGIES

Since the first plans for the National STORM Program were formulated in the early 1980s, there has been progress in the development of new in situ observing systems as well as ground-based and space-based remote sensors. In addition to those described below, accurate wind reports from commercial jet aircraft and satellites are available for meteorological use, several national ground-based lightning detection networks are in place, and lightning detection from satellites is planned. Great progress has also been made in the ability to integrate and use these and similar observations. The spectacular advance of computer capabilities and digital electronics has dramatically improved the technical capability for processing heterogeneous meteorological data for use in forecasting and research.

A key to progress is the ability to process so-called raw observations, such as radar reflectivity, radar Doppler velocity, and satellite-observed infrared radiance, into meteorological information, such as three-dimensional wind velocity, temperature, and moisture. For example, fields of radial velocity from Doppler radars have been combined with data from multiple wind profilers to derive upper-atmospheric wind fields having much higher horizontal resolution than do those obtainable from traditional wind-observing systems. Similarly, techniques to process satellite infrared soundings have improved, yielding higher horizontal resolution of temperature and moisture fields.

The new wind profiler provides an improved capability to observe winds through the troposphere and lower stratosphere. These wind measurements are normally derived every hour, although for special studies it is possible to increase the temporal resolution to 6 minutes. A demonstration network of such profilers, now being established in the central United States (Figure 2.1), will vastly increase information on the kinematic structure of the atmosphere.

The next-generation weather radar (NEXRAD) system network will shortly become operational and will cover most of the continental United States (Figure 2.2). NEXRAD radars are over 100 times more sensitive than existing network radars and can detect both liquid- and ice-phase precipitation much more effectively. Therefore, the NEXRAD radars will be far more useful than existing systems in defining wintertime snowstorms. The enhanced sensitivity of NEXRAD systems also permits the measurement of air motions in parts of the boundary layer where precipitation is not occurring. Recent research indicates that these measurements will be useful in detecting the initiation of convective storms as much as 2 hours before the first clouds appear. NEXRAD system capabilities are summarized in Appendix Table A.1.

Another area of significant progress has been the development of data-assimilation procedures, which allow the integration of data of differing accuracies and spatial and temporal resolutions into consistent meteorological fields. Workshops on data assimilation have been held, and a national effort is being coordinated to bring together data from both standard synoptic and nonstandard heterogeneous sources. Computerized atmospheric models are planned that will integrate diverse observational data in a physically and dynamically consistent manner, resulting in improved accuracy and predictive capability, but much additional research and development are needed to achieve this goal.

The prospects for rapid technological progress in the observing and processing of mesoscale meteorological data are bright, and new ideas continue to be proposed. The Radio Acoustic Sounding System (RASS) is a simple and inexpensive addition to a radar wind profiler that produces very accurate measurements of temperature in the lower several kilometers of the atmosphere. The Doppler velocity of air motion excited by an acoustic wave is measured by a wind-profiling radar. The measurement gives the speed of sound as a function of height. Since the speed of sound is directly related to air temperature, computations of temperature with accuracies from 0.15 to 0.30°C are possible. Excellent vertical and temporal resolution allows delineation of important lower-tropospheric structures such as temperature inversions and fronts. The Japanese have used a powerful RASS to obtain accurate temperature soundings from the surface to an altitude of over 20 km.

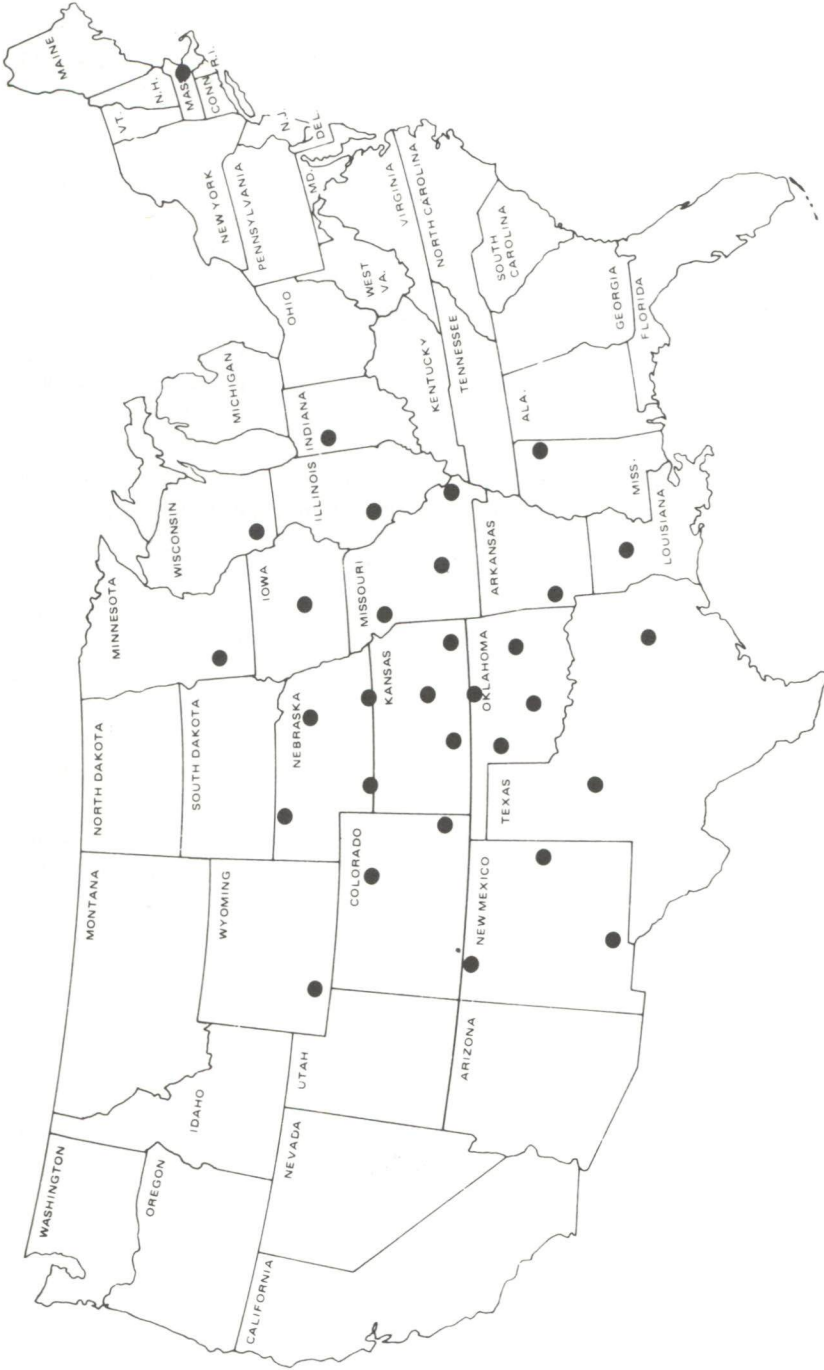


FIGURE 2.1 Site locations of the Demonstration Wind Profiler Network. (Courtesy of the National Weather Service.)

Another promising technique is the use of interferometers to increase the amount of meteorological information that can be derived from infrared radiation measurements. Plans have been proposed that would use the GOES NEXT satellite platform in the late 1990s to sense radiation at infrared wavelengths in over 2000 channels rather than the 20 channels currently used. This 100-fold increase in channels will permit construction of vertical profiles of atmospheric temperature and moisture with much greater resolution than is currently possible. Infrared interferometers may also be very cost-effective as ground-based thermodynamic profilers.

Advanced airborne Doppler radars are being developed to observe, over great distances, the evolution of mesoscale systems over both land and oceans. The latest design synthesizes three-dimensional air-motion fields through the use of innovative antenna scanning while the aircraft flies along a straight-line track safely outside of severe storms. A high-altitude, downward-pointing airborne radar design will measure vertical air motions in unprecedented detail. Advanced ground-based radar techniques use polarization diversity for discrimination of the ice and water phases, detection of hail, and better estimation of very heavy rainfall.

Other remote sensing techniques being investigated include the measurement of temperature, moisture, and winds from ground-based lasers. Significant advances in laser technology promise much more powerful lasers at greatly reduced cost. A summary of the principal new observing system technologies and their current status is given in Appendix Table A.2.

Clearly, the new observing technologies described above require concomitant advances in data-processing technologies. The increase in computer performance per unit of cost during the 1960s and 1970s has maintained its pace in the 1980s. Industry experts predict that personal computers with power comparable to that of the CRAY-1 will be available before the mid-1990s. Atmospheric analysis and prediction are particularly amenable to parallel processing, in which different parts of a program are run simultaneously on different processors. There are commercially available computers with high-speed performance in the range of several gigaflops (10^9 floating-point operations per second), and prospects are good for computers with processing capability in the teraflops range in the late 1990s.

Important concurrent advances in computer software have been at least as important as improvements in hardware in increasing the speed and utility of computers. Examples include faster routines to solve elliptic boundary value problems, vectorization of computer codes, and algorithms for parallel processing of computer programs.

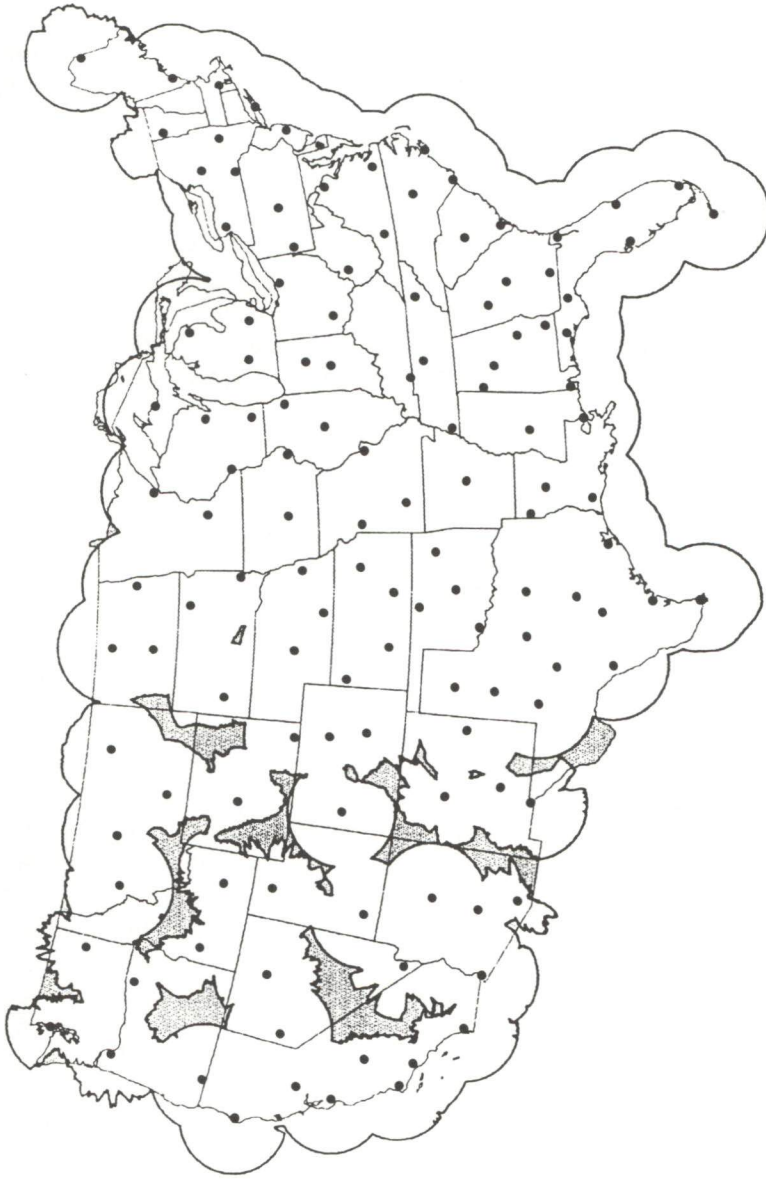


FIGURE 2.2 Site locations and total coverage (at 10,000-ft elevation) of the national NEXRAD network. Shaded areas are gaps, mostly in mountainous areas, in NEXRAD coverage. (Courtesy of the National Weather Service.)

NATIONAL WEATHER SERVICE MODERNIZATION

Beginning in 1990, a next-generation series of geostationary weather satellites will provide improved continuous weather surveillance of North America and its surrounding oceans. This will be supported by an even more advanced polar-orbiting weather satellite system that will begin operations in 1992. On the ground, the National Oceanic and Atmospheric Administration (NOAA) will deploy a network of wind-profiling radars that will provide data in unprecedented detail on the small-scale structure of intense atmospheric phenomena. Combined with temperature and moisture data from satellites and balloons, wind profiler observations will lead to improved forecasts of local weather.

Critically important for the detection of locally violent weather is the NEXRAD system, which is capable of sensing hazardous wind shears, tornadoes, and downbursts—major causes of loss of life and property in the United States. The implementation of the NEXRAD network will begin in 1990 and is to be completed by 1995.

In order to exploit the new observing systems, NOAA will implement a sophisticated data communication, analysis, and product display system in the 1990s. The Advanced Weather Interactive Processing System (AWIPS-90) will enable rapid communication and video display of weather observations and information to forecasters for the timely issuance of storm warnings. Also, to ensure the most effective use of the new technology, an organizational restructuring of the National Weather Service (NWS) is in progress.

A major purpose of NWS modernization is to improve weather warnings. The implementation of AWIPS-90, NEXRAD, and new space-based sensors on the planned GOES NEXT geostationary satellite is amply justified by the much-improved weather warnings these new systems will facilitate. Additionally, these same systems will serve as the basis for improving short-term forecasts, both directly and through their contribution to research studies that lead to improved weather predictions and warnings.

Research results based on these new observing systems will permit trained forecasters to use appropriate conceptual models of mesoscale weather systems. The conceptual models help the forecaster understand and make proper use of weather depictions produced by the AWIPS-90 integrated displays. Additionally, the results of research will allow the new observations to be incorporated properly into a variety of diagnostic and predictive computer models, ranging from comparatively simple algorithms to comprehensive high-resolution mesoscale models. In particular, a new operational mesoscale- α model with a domain that covers most of North America is planned at the National Meteorological Center as part of the overall NWS modernization. This model will have 80-km horizontal

resolution, consist of 16 layers, and contain the best available physical and topographical representations. This and other models will provide the basis for significant improvements in weather forecasts and warnings. Thus the full value of the NWS modernization will be realized only by pursuing a vigorous national mesoscale research program directed toward the optimal use of the new systems.

DEVELOPMENT OF NEW MODELS

Along with the huge increase in computer power during the past 3 decades has come a commensurate increase in numerical modeling activity. This increase is particularly evident in mesoscale meteorology, where models have been developed to investigate a multitude of different mesoscale phenomena. Regional models with domains ranging from a single state to the entire United States are able to simulate with fidelity hurricanes, thunderstorm squall lines, and other mesoscale convective systems. They also can simulate mesoscale features such as precipitation bands, sea breezes, regions of stratiform precipitation, frontal zones, orographic systems, polar lows, mountain-valley circulations, lake-induced vortices, internal gravity waves, and areas of heavy precipitation. The large breadth and extent of mesoscale modeling activity are evident from the great number and diversity of mesoscale models active in 1988 (Appendix Table A.3). It is clear that modeling has become an important tool in mesoscale research.

Recently some regional-scale models have been modified to assimilate continuing observational data, such as profiler winds, during a forecast period. These models have provided much-needed guidance for the design of data-assimilation routines and special observing networks. Other recent efforts in mesoscale modeling have focused on the refinement of existing computer models in order to better simulate individual storm systems. In particular, models of cumulus clouds have revealed subtle but complex interactions between gravity waves in the stable troposphere and the organization of clouds in the boundary layer. Such models have also produced realistic simulations of microbursts and low-level wind shear.

Three-dimensional models of cumulonimbus clouds have been used to simulate thunderstorm downdrafts, downbursts, and gust fronts produced by the outflow from downdrafts near the surface. They have also been used to clarify the processes involved in the formation of rotating thunderstorms and to study the effects of thunderstorm rotation on the formation of tornadoes. Some of these models now also include detailed microphysics, for example, the physics of ice-phase changes and hail formation. Electrification processes have been added to some cloud models so that the interaction of cloud-charging processes with storm motions can be examined. Other models include chemical reactions that occur in clouds

and precipitation. Explicit simulation of radiative heating and cooling rates associated with clouds has been added to some mesoscale models. These models have revealed that convective circulations are highly sensitive to radiative effects. Cloud models have also been expanded in horizontal scale to allow, for example, simulation of squall-line thunderstorm systems and mesoscale convective systems over the Rocky Mountains. Recent increases in computer speed and capacity have made possible the use of nonhydrostatic models to simulate convection on such mesoscale domains.

A new development in cloud and mesoscale modeling is the use of interactive, grid-nesting techniques. This approach allows larger scales of motion to affect smaller scales, and vice versa, and it permits otherwise impossible model simulations to be made by economically increasing resolution in the principal region of interest. Using this technique, regional models on the scale of the United States are designed to interact with finer-resolution models of motion on the scale of squall lines and mesoscale convective complexes. Because interactive grid-nested models allow smaller scales of motions to affect larger scales, the impact of mesoscale convective systems on larger scales of motion can be examined. Interactive grid-nesting techniques have also been useful in elucidating some of the fundamental physical processes involved in the entrainment of environmental air into individual cumulus clouds.

In recent years global-scale general circulation models (GCMs) have obtained sufficiently high resolution to permit exciting opportunities for studying interactions between global scales of motion and mesoscale weather systems. For example, the European Centre for Medium Range Weather Forecasts (ECMWF) has a global numerical weather prediction model with sufficient resolution for the routine prediction of relatively large mesoscale phenomena, for example, mesoscale convective complexes (MCCs). At the same time, cloud models have been expanded in scale so that they include much of the mesoscale domain. Thus we are entering a period when powerful new modeling approaches can be used to increase our understanding of storms and mesoscale phenomena. Despite these promising developments, much additional research on modeling the mesoscale domain needs to be done in order to translate the new developments into models useful for operational mesoscale weather prediction.

ADVANCES IN FUNDAMENTAL UNDERSTANDING

Using sophisticated new observing tools, advanced high-speed computers, and complex computer models, meteorologists have advanced our understanding of storm structure and dynamics and the physical processes leading to precipitation and severe weather. (See Appendix Table A.4, which summarizes the principal U.S. mesoscale observational studies and field programs that have led to these advances.)

A greater understanding has been obtained about the processes involved in the formation and evolution of mesoscale convective storms. Synoptic features such as jet streaks, short waves in the global circulation pattern, low-level jets, surface fronts, and dry lines have been shown to play an important role in storm initiation. At the same time, processes of storm initiation and evolution, such as the growth of convective cloud systems by individual cloud mergers, the behavior of intersecting gust fronts and gravity waves emitted by neighboring clouds, the development of large cold pools by evaporation of precipitation in downdrafts, the systematic release of latent heat in the upper troposphere by anvil clouds, and the role of topographic features such as mountains and land-water thermal contrasts, are all now better understood.

Much has been learned about the structure of individual convective storms and the processes governing storm intensity. The importance of nonhydrostatic vertical pressure gradients in driving convective updrafts and downdrafts is now recognized. Likewise, the contribution of vertical wind shear (change in horizontal wind speed and direction with height) to the development of nonhydrostatic vertical pressure gradients in storms and in establishing rotating storms has been clarified. Recent research has shown that boundary layer forcing is frequently the dominant mechanism for convective storm initiation. Progress has been made in understanding the genesis of tornadoes and strong surface winds, the formation of hailstones, and the relationship between thunderstorm dynamics and cloud electrification processes.

Significant advances have also been made in understanding the structure of mesoscale convective storm systems. Observational analysis and numerical simulation of squall lines have revealed that lines in the tropics and midlatitudes exhibit many common features. Both consist of a line of vigorous convective cells and showers along with widespread regions of steady rainfall. However, in the midlatitudes, where winds usually increase in speed and change direction with height, some squall lines exhibit features distinctly different from those of squall lines in the tropics. In the midlatitudes, a line of convective cells may consist of one or more persistent, severe, rotating cells along with more transient ordinary cells typical of those found in the tropics. The presence of persistent, rotating cells alters the kinematics of a squall line and increases the likelihood of severe weather such as tornadoes, large hail, and strong straight-line winds occurring with it.

A better understanding of the organization and structure of MCCs has also been achieved in recent years. An MCC is a comparatively large mesoscale weather system composed of both convective cloud regions and stratiform cloud zones. Seen from satellites, the MCC is characterized by a large, circular high (cold) cloud shield that may be several hundred kilometers in diameter (see Figure 1.1) and may persist at this size for 6

hours or more. The system frequently includes one or more squall lines and often exhibits a warm core vortex structure in the stratiform cloud region. In some instances, the vortex grows large enough and persists long enough to become inertially stable and is instrumental in initiating several new mesoscale convective systems over a period of several days. MCCs typically produce heavy rains and prolific lightning, and occasionally tornadoes and hail. Some 25 percent or more of the MCCs produce severe straight-line winds in swaths that may be 50 to 100 km in width and several hundred kilometers in length.

Progress has been made in understanding the role of radiative cooling at the tops of clouds in the formation and intensification of mesoscale convective systems. Also, the effects of gravity waves, excited by deep convective clouds penetrating the relatively stable middle and upper troposphere, on mesoscale convective systems are better understood. Interactions of gravity waves generated by neighboring clouds are now believed to be important in the growth of convective systems.

In general, mesoscale wind, cloud, and precipitation features are initiated by two mechanisms: (1) instabilities in the larger-scale environment and (2) forcing by inhomogeneities at the surface (such as terrain features). Recent observations and model simulations have revealed a great deal about mesoscale instabilities in the larger-scale environment. For example, mesoscale precipitation bands, associated with locally intense precipitation, form in both extratropical and tropical cyclones, and evidence has accumulated that many of the bands are manifestations of gravity waves or conditional symmetric instability (CSI). It is now recognized that CSI is capable of generating strong vertical motions of several meters per second. Such motions can account for the anomalously heavy snow bands associated with extratropical cyclones.

Terrain-forced phenomena, such as cold air damming, are also better understood. For example, subcloud-layer evaporational cooling not only enhances the thermodynamic conditions favorable for damming but also helps to establish a "wedge ridge" in the cold air. Rotationally trapped Kelvin waves can be instrumental in initiating cold surges that result in cold air damming.

Sometimes the two general mechanisms for producing mesoscale features are combined. This is the case with amplifying mountain waves that produce severe downslope windstorms. Recent studies have shown that, in addition to atmospheric thermal and wind stratifications, vertical moisture stratification is also important in the formation of mountain waves.

Progress has also been made toward understanding the processes involved in the genesis of intense cyclonic storms along coastal areas and in the lee of major mountain barriers. These storms often result in excessive snowfall and rainfall. In recent years field research programs along both the east and west coasts of the United States have revealed the potential

importance of scale-interaction processes in the explosive development of extratropical cyclones that produce severe winter storms. Besides confirming the role of large-scale, upper-level waves in intensification of surface cyclones, such studies have shown the important contribution of mesoscale processes to the strength of a storm. Intensification of coastal winter storms has been related to energy transfers from the warm ocean surface, latent heat liberated in convective and stratiform clouds, and dynamic instabilities associated with both lower- and upper-tropospheric wind maxima. Scale-interactive mesoscale processes can cause severe winter storms to develop in a surprisingly short period of time.

Although considerable progress has been made in the scientific understanding of mesoscale weather processes and in their simulation by numerical models, there are many areas where additional study is required to gain sufficient understanding and simulation capability that, in conjunction with the new observing capabilities, should lead to significantly improved forecasts and warnings. The step from understanding to accurate prediction is large and will require a focused national effort, involving both research and operations, if it is to be achieved.

RELATIONSHIPS TO CLIMATE AND ATMOSPHERIC CHEMISTRY

The scientific challenges of mesoscale meteorology are linked to a wide range of other underlying problems in climate and atmospheric chemistry. Mesoscale weather systems transfer momentum, energy, and water vapor horizontally and vertically; thus they are important components of the global atmospheric circulation. The latent heat realized through moist convection is an important source of energy in the maintenance of the global circulation. Moreover, mesoscale weather systems are the dominant precipitation-producing systems in the tropics and much of the summer midlatitudes; thus they are major components in the global hydrological cycle. They are a link between tropical sea-surface temperature anomalies and anomalies in the global atmospheric circulation.

A key factor for predicting global climate is the impact of cloudiness on the radiation budget of the earth-atmosphere system. Mesoscale weather systems often produce extensive layers of clouds that can persist for days, long after the systems themselves decay. Such residual clouds, along with clouds produced by active weather systems, greatly alter the radiative properties of the troposphere and, consequently, the global energy budget. Together with the release of latent heat, the radiative heating of layered clouds in the upper tropical troposphere is a significant source of energy for driving the global circulation. Moreover, changes in the global composition of atmospheric aerosol particles can alter the concentration of

cloud droplets and ice particles, which in turn affect the radiative budget of the atmosphere.

A detailed understanding of the behavior of mesoscale weather systems will contribute substantially to better formulations of the physical processes in general circulation models and to a better understanding of past, present, and future climates, including the influence of human activities on climate.

Convective systems also transport large amounts of trace chemical species, such as sulfur dioxide, nitrogen oxides, ozone, methane, and chlorofluorocarbons, from the earth's boundary layer to the free atmosphere above. In the process of transporting boundary layer air upward, the convective systems bring water, ice, and lightning into proximity with trace chemicals and act as atmospheric chemical reactors to process and transform the chemicals. High in the atmosphere, the chemical species and reactants disperse and may be transported over great distances by jet streams. The large amounts of residual pollutants in the middle and upper troposphere that are dispersed around the globe significantly alter the global chemistry of the troposphere. In the polar stratosphere, reactions involving the chlorine that derives from chlorofluorocarbons take place in the presence of ice crystals, thereby reducing the concentration of the earth's protective ozone.

The deposition of acidic precipitation over a region is frequently dominated by a few major mesoscale events. Organized mesoscale circulations, such as clusters of individual mesoscale convective clouds within extratropical cyclones, can sweep large volumes of polluted air into regions of moist convection, where the pollutants are transported aloft and scavenged through precipitation. One such system can scavenge enough acidic contaminants to dominate the annual average chemistry of a given watershed or local ecological system.

Lightning is also an important contributor to the production of certain chemical species such as nitrates and ozone. An assessment of the global chemical budget of these species requires a knowledge of the frequency of lightning events associated with different weather systems. Recent research has revealed that, for some areas, a single large mesoscale convective complex can account for as much as 25 percent of the total annual lightning occurrences in the area.

A detailed description of mesoscale weather systems will aid in the diagnosis and prediction of chemical distributions and reactions and of acidic precipitation. Conversely, detailed atmospheric measurement of trace chemical species can provide information on air motions within and around mesoscale storm systems.

3

Implications for Operational Meteorology

Operational meteorologists will have exciting new opportunities to improve weather forecasts and warnings in the 1990s as the National Weather Service (1) inaugurates its Advanced Weather Interactive Processing System (AWIPS-90), (2) begins to take advantage of radically new observing systems such as NEXRAD and the Demonstration Wind Profiler Network, and (3) modernizes and restructures its field offices in support of more detailed and timely forecasts. These improvements will permit more detailed weather information to be obtained in real time, with easy accessibility and display in a variety of formats including color and animation, and will permit more frequent analyses of surface and tropospheric conditions based on intensive use of new data sources.

Provided that these opportunities are matched by parallel research efforts and significant upgrading in the educational and training requirements for NWS personnel, they should lead to more detailed and accurate "nowcasts" and short-range weather forecasts.

This chapter describes briefly the potential impacts of increased capabilities in mesoscale meteorology.

OPERATIONAL DATA BASES

Data bases of the future will contain much more detailed information than they do now. The extremely high volume of data that is anticipated will force regular purging of most data after immediate use, yet facilities must be developed to archive data for selected weather situations either because

they affected the general populace adversely (and thus the data may have use in legal actions) or because they have other research and training value. Forecasters newly arrived at a station will have the opportunity to learn the local peculiarities of the weather if they have the capability to reexamine events in the same sequence as they originally unfolded.

HAZARDOUS WEATHER WARNINGS

Most weather forecasters acknowledge that radar data provide the most critical information when severe storms threaten. The NEXRAD radars will bring a new dimension to operational forecasting by depicting low-level winds in clear air during the convective season, as well as winds within storms, at all levels that the NEXRAD radar can survey. Warnings will be more specific regarding the location and size of the threatened area, the length of the critical period for severe weather, and the type and intensity of severe phenomena expected. Warnings are also more likely to be issued farther in advance of severe weather occurrences. Visible and enhanced infrared satellite images, portraying the evolution of clouds and cloud systems, will augment the radar information.

In winter, satellite images together with radar will depict the mesoscale organization of winter storms. Hourly wind profiler data will show, far better than rawinsonde winds, the temporal evolution of these weather systems. As a result, forecasters will be able to specify short-term variations in the intensities and types of storms and to be more accurate in predicting their locations and times of occurrence.

SHORT-TERM WEATHER FORECASTS

More accurate warnings of severe or dangerous weather will save lives and avert property damage, but increased accuracy of routine short-term forecasts will also have tremendous value. Instead of "Twenty percent chance of afternoon showers," people should expect to hear, "Thunder-showers are expected to develop southwest of Chicago this afternoon and move northeast across the south side of the city between 4:00 and 5:00 p.m., causing brief heavy rains, small hail, and gusty winds that may cause some minor damage. The storms should weaken rapidly as they cross the Lake Michigan shoreline." Instead of "Turning cloudy, windy, and colder tonight with a chance of rain changing to snow," people should expect to hear, "Mild and breezy prior to midnight, but then turning sharply colder with rapidly falling temperatures. Sprinkles of rain around midnight, changing within an hour to light snow and ending shortly before dawn. An inch of snow on the ground is likely when the rush-hour begins."

At present, meteorologists are reluctant to make such detailed forecasts because their limited information does not instill great confidence in predicting well in advance either the expected timing or sequence of events. Better information sources and improved communication and display capabilities will encourage all weather forecasters (NWS and private) to be more specific. As a basis for detailed forecasts like those above, the provision of hourly numerical guidance is highly desirable, especially beyond the time when simple extrapolation of the existing weather ceases to be useful.

WEATHER INFORMATION SERVICES

The information industry is burgeoning, and the public demand for weather information is part of the reason. Ten years ago, it was difficult to envision that a 24-hour-a-day television program devoted exclusively to national weather would be a financially rewarding venture. The *Weather Channel* on cable television and its many commercial sponsors are proof of the success of such a concept. Additionally, the weather report is often the most popular segment of television news programs.

Timely collection and dissemination of weather observations and computer-generated weather information are critical. Automated collection and quality control of data have assumed greater importance than ever before. Sophisticated interactive systems must give the data analyst ample opportunity to examine and, if necessary, alter weather information products before dissemination without requiring a large expenditure of the analyst's time.

Forecasters will benefit from having access to a greater variety of analyzed and predicted meteorological fields with higher spatial and temporal resolution. They will be able to translate this information into more specific public forecasts. Private-sector meteorologists will also benefit from an enhanced ability to tailor products to the individual needs of their clients.

Hydrology

A NEXRAD algorithm for the calculation of rainfall rate from radar reflectivity data is under active development. Rainfall rates that are deduced from reflectivity data will be frequently calibrated with automated rain-gauge data. Precipitation runoff models for watersheds can already generate credible estimates of streamflow, given accurate rainfall data. Within reach is the ability to estimate precipitation from a time-history of radar reflectivity over very small areas of a few square kilometers. Such areal estimates, which already agree within a factor of 2 or 3 with point rainfall measurements, will be of great value for flash flood warnings and

for water resources management (e.g., deciding whether or not to lower the supply of impounded water in a reservoir).

Agriculture

Many agricultural losses are unavoidable, such as crop destruction by wind-driven hail or lowered yields in a drought year. Yet many important decisions that can limit such losses—whether to spray pesticides, harvest early or late, pump water for irrigation, or protect vulnerable crops from an early or late frost—can be made with more confidence given better weather forecasts. Increased mesoscale information will improve the timeliness and accuracy of weather information on which the agriculture industry depends for many of its critical decisions.

Transportation

Transportation is sensitive to short-term changes in the weather. Rapidly deepening extratropical storms are a sudden hazard to shipping in coastal waters and on the Great Lakes, and hurricanes, the paths of which are often difficult to predict, occasionally menace ships along our Gulf and Atlantic coasts.

Aviation is highly vulnerable to hourly changes in the weather. Minimizing fuel consumption depends on accurate en route winds, favorable weather at both terminals, and careful timing of the departure. The safety of crew and passengers depends on avoidance of thunderstorms, icing, and clear-air turbulence en route, as well as avoidance of poor visibility, heavy precipitation, and wind shear during takeoff and landing. Roughly 1000 fatalities annually in general and commercial aviation are weather-related.

In 1986 the Aviation Weather Forecasting Task Force made these recommendations, among others, to the Federal Aviation Administration and the NWS (AWFTF, 1986):

- Implement an automated aircraft reporting system as one component of a national meteorological observing system.
- Increase the horizontal and vertical resolution of operational weather prediction models so as to permit more detail in the initial conditions on which model predictions depend and, in turn, provide forecasts with greater resolution and accuracy.
 - Update weather analyses and forecasts more frequently.
 - Provide more precise, timely, and consistent diagnostic and guidance products for aviation users.

The accuracy of analyses and short-term weather forecasts for aviation will improve as higher-resolution satellite images become available and

wind profiles, satellite soundings, and automated aircraft reports provide mesoscale detail in the initial conditions for models.

Foul weather associated with mesoscale systems can render road and rail travel hazardous or even impossible within an hour. Accurate and timely forecasts can alert motorists to the risk of sliding on icy highways, hydroplaning in deep puddles, being stranded in a blizzard miles from the nearest shelter, or being swept off the road by a flash flood in a narrow canyon. They can persuade truckers to stay off dangerous or impassable roads for the next 24 hours or to select alternate routes. They can alert snow removal crews in advance of a snowstorm or prevent them from being called out needlessly, and they can alert rail transportation facilities to the need to deice rails and equipment. Hence greater detail and accuracy in predicting the timing and location of significant weather hazards will significantly improve transportation safety and efficiency.

Construction

The building and paving industries are most concerned with the possibilities of precipitation, subfreezing temperatures, and, sometimes, strong winds. Pouring concrete, welding I-beams, excavating for a foundation, painting a house, repairing a roof, and framing exterior walls are all weather-dependent activities. The contractor who sends crews to an outdoor job in unexpectedly bad weather, or who loses a partially constructed house to a windstorm, is likely to blame an inaccurate weather forecast. Therefore, more accurate and detailed forecasts will permit construction industries to cope better with adverse weather conditions.

Outdoor Recreation

A major component of the average person's interest in the weather is connected with outdoor recreation. More accurate forecasts with finer space and time resolution will allow boaters to be warned to return to shore before a squall, swimmers to leave pools, golfers to return to clubhouses, and softball players to vacate playing fields before thunderstorms break. Hunters will be advised in more detail about heavy, early-season snows that could leave them stranded. Skiers who want to avoid travel during heavy snow but be on the slopes as soon as the snow ends will profit from forecasts with better timing of events. All these people will benefit from more accurate and more precise weather information. Furthermore, they will be able to make contingency plans for outdoor activities with greater precision if more accurate forecasts are available.

CONCLUDING REMARKS

Although some improvement in operational meteorology can reasonably be expected just from the availability of new observing systems, the improvement is likely to be very limited unless a systematic scientific program is undertaken to maximize the use of the new observations in increasing understanding of mesoscale weather processes. The resulting increased understanding should, in turn, result in a larger incremental improvement in mesoscale weather predictions and warnings and hence greater benefits to the nation than can be expected from the new observing systems alone.

4

Recommendations

Achieving a better understanding of mesoscale weather events and translating this understanding into improved weather services will depend greatly on the judicious application of resources to a wide range of activities. The following are actions required to complete the task that has been started with the implementation of the new National Weather Service (NWS) observing systems:

Recommendation: Continue and keep on schedule the planned development and deployment of the new weather observing systems and technologies.

Full and timely implementation of the new observational systems that form part of the NWS modernization will allow maximum development and improvement of analytical data bases, numerical prediction models, and operational forecast and warning capabilities. New research-oriented systems and technologies will augment the operational network during shorter-term intensive observing periods. These systems will enhance understanding of fundamental physical processes and permit extensive testing and validation of numerical prediction models.

Recommendation: Systematically assess the capabilities of new instruments in order to maximize their utility for short-term weather forecasting and warning and for initializing and testing numerical prediction models.

The instruments that are part of the NWS modernization effort must

be systematically evaluated to determine their strengths and weaknesses over a wide range of weather conditions. These assessments will be an important contribution to (1) four-dimensional data-assimilation efforts and (2) forecasters who need to understand the capabilities and limitations of the observing systems on which they base short-range forecasts and warnings.

Recommendation: Investigate possible additional applications of the new data streams in order to realize the full benefits of new observational technologies.

Unforeseen opportunities often arise to use new observing systems to solve problems that the systems were not originally intended to address. For example, satellite observations originally designed to measure sea-surface temperatures are now also being used to determine indices of vegetation and soil moisture. Many of the new observing systems discussed in this report may similarly be used profitably in new, unforeseen applications.

Recommendation: Process and archive data from the new weather observing systems, and make the data available to a wide range of users in an efficient, timely, cost-effective, and easy-to-use manner.

Advanced technology must be applied to the problem of archiving the massive data sets that will be produced by the new observing systems and to the subsequent distribution in standardized formats of these data to meteorological forecast and research centers, universities, and communication media throughout the country.

Recommendation: Develop data-assimilation techniques to combine the many kinds of data into coherent, gridded data sets suitable for a wide range of weather forecast and research tasks.

Data assimilation will allow improvement of existing numerical prediction models and development of new ones that explicitly simulate circulation features that range from global to cloud scales and that exert control over the development of severe storms.

Recommendation: Improve numerical weather prediction models to more accurately account for physical and chemical processes, including those involved in the hydrologic cycle, sensible, radiative, and latent heating throughout the troposphere, and energy exchange at the earth's surface.

The improved models will serve as a basis for data analysis, numerical simulation, weather forecasting, and diagnostic research efforts necessary to provide better weather forecasts.

Recommendation: Conduct large observing programs of mesoscale weather, timed to take advantage of the newly deployed observing systems and designed to examine multiscale interactions associated with mesoscale weather. Additionally, plan and carry out observing programs that cover smaller regions and specific weather phenomena and that complement the larger-scale programs.

Field programs in different parts of the country, involving enhancement of the operational data systems for a limited period of time, are needed to (1) document and understand the interactive processes that lead to severe storms, (2) design, develop, and verify new models capable of simulating stormscale systems, (3) establish independent data sets required to conduct the instrument evaluations noted above, and (4) address the geographic diversity of weather.

Recommendation: Retrain weather forecasters and, where necessary, revise, update, and expand university curricula in the atmospheric sciences to produce a sufficient supply of new meteorologists capable of using the new observing systems and scientific concepts to best advantage.

Educational and forecast training activities must be revised and modernized to ensure that the nation reaps the maximum benefits of advances in observational technology and meteorological understanding. Students, forecasters, and experienced meteorological researchers must work together more closely than in the past to ensure a mutual transfer of knowledge between the meteorological research and operational weather forecast communities.

Sufficient numbers of meteorologists must be trained or retrained through special programs such as that planned at the Cooperative Operational Meteorology, Education, and Training (COMET) Center at Boulder, Colorado, through raising the scientific and technical education requirements for forecasters, and through other such means. The future availability of highly trained professional meteorologists is a critical factor in realizing gains in understanding and prediction capability as a result of NWS modernization.

As Chapter 5 indicates, the necessary actions to fulfill these recommendations are embodied in the National Stormscale Operational and Research Meteorology (STORM) Program plan (NCAR, 1990).

This report therefore recommends that the National STORM Program be implemented as soon as possible.

5

Actions to Fulfill Recommendations

Planned actions that will ensure fulfilling all the recommendations listed in Chapter 4 are contained in the National STORM Program Plan (NCAR, 1990).¹ Designed over a number of years by a broad segment of the research and operational meteorological community, this program has been reviewed by this committee, which endorses its goals and the means proposed for achieving them.

Therefore the committee reiterates its primary recommendation that highest priority be given to implementing the National STORM Program in order to fulfill the recommendations made in Chapter 4. The goals of STORM are

- To advance the fundamental understanding of precipitation and other mesoscale meteorological processes and of their role in the hydrological cycle, and
- To improve the 0- to 48-hour prediction of precipitation and severe weather events.

The National Weather Service's (NWS) modernization, with its new

¹ After this report was completed, the authoring committee learned that a new mesoscale research initiative was under consideration by the Interagency Committee on Earth Sciences of the Federal Coordinating Council on Science, Engineering, and Technology. This new initiative was still being defined, but the committee understands that the initiative will likely include the goals and objectives of STORM, although it may have additional goals as well. Therefore, the committee expects that this report will be as relevant to goals of the new initiative as it is to those of STORM.

observing systems and improved processing and communications capabilities, will provide an opportunity for significant improvements in operational mesoscale weather prediction and warning services. However, maximum gains will *not* be realized from the modernization *unless* a complementary research program designed to take advantage of the modernization is carried out. The National STORM Program is designed to meet precisely this need. Compared to the cost (estimated to exceed \$1 billion) of the NWS modernization itself, the estimated cost of STORM (\$240 million over 10 years) is relatively modest but will support an essential incremental effort to ensure the successful outcome of the modernization.

The National STORM Program has several action components, some of the more important of which are described briefly below. The reader is referred to the *STORM Program Plan* (NCAR, 1990) for more detailed information.

- *Basic research.* STORM calls for an integrated program of basic research designed to increase fundamental understanding of the structure and evolution of the mesoscale phenomena that produce severe storms and precipitation. To achieve this, a series of *intensive field projects* are proposed for various parts of the country and in different seasons. The principal purpose of these studies is to gather the data necessary to understand how various scales of meteorological phenomena interact to produce severe weather.

- *Numerical models for weather forecasting.* STORM proposes that a *national numerical weather prediction test facility* be established at the National Meteorological Center. The principal purpose of this facility will be to test, in an operational environment, the most promising numerical weather prediction models developed by the research community. The STORM field projects will provide data needed to initialize, test, and improve these models. Out of these efforts should emerge mesoscale models for use in operational weather forecasting as well as a much better understanding of the theoretical and practical limits of predictability of mesoscale weather systems.

- *Assessment of new observing systems.* Another key activity of STORM is to test, validate, and assess the new NWS observing systems. The close cooperation between engineers and scientists that will be required to achieve these goals will be fostered by the STORM program. For example, the special data sets collected in the STORM field projects can be used for this purpose. Also, the STORM data management system (see below) will provide the framework within which proper assessment of the data can be carried out.

- *Data assimilation, access, and management.* The new meteorological observing systems will provide high volumes of diverse data that must

be assimilated into comprehensible and useful products. At present, no complete mesoscale data assimilation system exists. The *STORM Data Assimilation Working Group* will be responsible for developing such a system. STORM will also develop a *data management system* for the efficient collection, processing, storage, cataloging, retrieval, and distribution of mesoscale data.

- *Education and training.* If the data from the new meteorological observing systems are to be properly utilized to improve basic understanding and weather forecasts, there must be substantial programs of education and training in the universities, the federal government, and the private sector. STORM provides the natural framework in which to carry out this multifaceted task. For example, the STORM program includes the concept of *experimental forecast centers*, where operational meteorologists, researchers, and students can work together to develop strategies for effective operational uses of the new technologies.

This committee is convinced that STORM will provide an unparalleled opportunity to significantly increase our understanding of many atmospheric processes and phenomena. For the first time, it will be possible to observe and understand mesoscale processes on a multiplicity of scales that interact with one another. This new understanding will result in improved weather warnings and forecasts for industry, government, agriculture, national defense, transportation, and the general public. These benefits are large and will exceed greatly the estimated cost of the National STORM Program. For example, the potential savings in reducing property damage alone are estimated to be at least \$1 billion a year. When savings from improvements in efficiency in agriculture, industry, national defense, and transportation are considered, the potential annual benefits from STORM increase by several billion dollars.

While the economic benefits promised by a successful STORM program are substantial, the potential benefits of increased protection of human life are even more impressive. Currently, the combination of flash floods, lightning, tornadoes, and weather-related transportation accidents accounts for much needless loss of life and personal injury each year. Timely warnings and better forecasts will substantially reduce these losses.

The National STORM Program is clearly in the best interests of the nation. This program provides an effective mechanism for addressing the challenges and opportunities in mesoscale meteorological research and operations in the next decade. Virtually all segments of our society will benefit, and at a cost estimated to be far less than the value of the expected gains. The program is scientifically feasible, much of the planning has been done, and the atmospheric science community is ready to begin. All that remains is to do it.

The time to act is now. If full advantage is to be taken of the new observational capabilities and the mounting scientific expertise, and if this advantage is to be successfully translated into improved operational forecast and warning capabilities and into improved understanding of mesoscale processes important in global and regional climate, then the National STORM Program, first proposed in 1983, should be put into action without further delay.

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TABLE A.1 Summary of NEXRAD System Capabilities and Data Products

Capability	Data Products
Automated severe weather analysis	Vertically integrated liquid water and severe weather probability information Storm track information Storm structure information Mail index Mesocyclone and tornado vortex signature
Automated precipitation analysis	1-hour surface rainfall accumulation 3-hour surface rainfall accumulation Storm total rainfall accumulation Supplemental precipitation data
Automated momentum analysis	Velocity azimuth display (VAD) winds

TABLE A.2 Advances in Observing System Technology and Capability

New Measurement System	Features	Current Status	Funding Agencies ^a
Airborne Doppler radar	Measurement of three-dimensional kinematic fields within storms and precipitating systems; mobility of aircraft allows wide-area coverage over very large geographical areas	Operational on two NOAA P-3 aircraft in 1989; Next-generation airborne Doppler radar under construction at NCAR for operation on the NCAR Electra in 1992; down-looking Doppler radar being designed for the NASA ER-2 aircraft	NOAA, NSF, NASA
Cross-chain LORAN atmospheric sounding system (CLASS)	High-resolution radiosonde measurements using new LORAN navigational technology; operationally very simple to use; simplified balloon releases	Nine operational systems as of 1985	NSF, ONR
Automated shipboard aerological program (ASAP)	Automatic balloon releases from shipboard systems for radiosonde measurements	Operational	NOAA, NSF, AES-Canada
Next-generation drop-windsonde	Light weight, reduced cost, simplified operation, higher resolution, utilizing advanced navigational systems; can be safely dropped over land	Operational in 1989	ONR, NSF

Radio acoustic sounding system (RASS)	High-resolution remote sensing profiles of atmospheric temperature using combined radio and acoustic wave interactions	Research and development in 1989	NOAA
Raman Lidar	High-resolution water vapor profiling of the lower troposphere using Raman Lidar backscatter	Research and development	NASA
Multiple parameter radar	Combined use of Doppler polarization diversity and wavelength diversity provide for more quantitative assessment of the internal properties of hydrometeors in clouds; examples include being able to distinguish hail from rain and ice from cloud water	Research and development in 1989	NSF, NOAA
New airborne air-motion sensing	Aircraft radome hole gust probe; greatly simplifies high-frequency airborne air-motion measurements; probe less susceptible to icing in clouds, more easily maintained, and permits simultaneous operation with forward-looking navigational radars	Operational on NCAR aircraft in 1988; operational on NRL P-3 aircraft	NSF, NRL

TABLE A.2 continued

New Measurement System	Features	Current Status	Funding ^a Agencies
Lower tropospheric wind profiling	Relatively small UHF antenna systems permit profiling of tropospheric winds to altitudes of approximately 5 km; combined with other new remote sensing devices (e.g., RASS, Raman Lidar), permits complete profiling of the lower troposphere at relatively modest cost for use in augmenting surface network observations	Research and development	NOAA, NSF
Millimeter wave radar	For observations of newly developing clouds, for studies of liquid water distribution in clouds and marine stratus, and for studies of entrainment at cloud boundaries	Research and development	ARO, NOAA, NSF
Multichannel radiometry	High-resolution passive profiling of temperature and moisture	Research and development	NASA, NOAA

^a Acronym Key--AES-Canada: Atmospheric Environment Service-Canada; ARO: Army Research Office; NASA: National Aeronautics and Space Administration; NOAA: National Oceanic and Atmospheric Administration; NSF: National Science Foundation; ONR: Office of Naval Research.

TABLE A.3 Summary of Mesoscale Three-dimensional Models Active in 1988

Model	Domain	Approximate Horizontal Resolution (km)	No. of Vertical Layers	Emphasis	References	Users: Government, Universities, and Corporations ^a
NGM	Hemispheric (3 nested grids)	320, 160, 80	16	General*	Phillips, 1979; Tuccillo, 1988	NOAA: NMC, ERL
MASS	North America (3 nested grids)	156, 48, 12	20	General	Kaplan et al., 1982; Kocin et al., 1985; Koch, 1985; Zack et al., 1988; Uccellini et al., 1987	MESO, Inc., NASA (Goddard), ST. Systems Corp., General Sciences Corp., Florida State Univ.
MM4	Nested grids, variable from 30 x 30 to 109 x 109	Variable 1 to >200	Variable 10 to 30	General	Anthes and Warner, 1978; Hsie, 1987; Anthes et al., 1987; Zhang and Fritsch, 1986	Over 50 users
P3DM	60 x 50	Variable 2.5 to 20+	17	Sea breeze, lake vortices, lake snow bands	Pielke, 1984; Lyons et al., 1988; Pease et al., 1988	R* SCAN Corp., ASTER, Inc., San Francisco State Univ.
Pielke	32 x 29	15	26	Sea breeze, thermally forced flows	Pielke, 1974; Abbs and Pielke, 1986	Colorado State Univ.
Ross-Lipps	80 x 80 nested within 50 x 60	20, 5	15 to 30	Squall lines, fronts	Ross, 1987; Lipps and Hemler, 1986	GFDL

TABLE A.3 continued

Model	Domain	Approximate Horizontal Resolution (km)	No. of Vertical Layers	Emphasis	References	Users: Government, Universities, and Corporations ^a
Dudek- Molinari	North America (2 nested grids)	120, 40	15	Convective complexes	Dudek and Molinari 1988; Dudek, 1988	SUNYA
Soong- Ogura- Tao	96 x 96	1 to 3	29	Convective systems	Soong and Ogura, 1980; Tao and Soong, 1986; Tao et al., 1988	NASA (Goddard), General Sciences Corp., Univ. of Illinois (Urbana)
LAMPS	32 x 35	70	15	General	Perkey, 1976; Kalb, 1987	Drexel Univ., Florida State Univ., NASA (Marshall), USRA
NORAPS (ATCM)	109 x 82	80	10	Tropical cyclones	Hodur, 1987, 1988	NEPRF
MFM	51 x 51	Variable, usually 60	10	Hurricanes	Gerrity et al., 1988	NMC
OK	Nested grids, 49 x 27 coarse 72 x 50 fine	111, 35	9	Extra- tropical cyclones	Orlanski and Katzfey, 1987, 1988	GFDL
FSUGSM	7.5-41.25 N 120-86.25 W	100 (63 wave spectral)	12	Extra- tropical cyclones	Daley et al., 1976; Manobianco, 1988	Florida State Univ.
NRL	Arakawa C grid	50	10	Extra- tropical cyclones	Madala et al., 1987; Sashegyi and Madala, 1988	NRL, Science Applications International Corp.

Nickerson	26 x 26	10	15	Orographic clouds and precipitation	Nickerson et al., 1986	NOAA/ARL AFGL
Mudrick	38 x 14 50 x 26	100, 50	10	Polar lows, extra-tropical cyclones	Mudrick, 1982, 1987	Univ. of Missouri
NTCM	30 x 30 nested within 31 x 23	205, 41	3	Tropical cyclones	Harrison, 1973; Chan et al., 1987; Harrison and Fiorino, 1982	Naval Postgraduate School
CMM	40 x 50	100	12	Terrain effects, cyclo-genesis	Sasaki and Goerss, 1982; McGinley and Goerss, 1986	CIMMS
UW	75 x 75	7.5	1	Surface winds	Mass and Dempsey, 1985	Univ. of Washington
MVWM	17 x 18	8	22	Mountain-valley winds	Moore et al., 1987; Liu et al., 1979	Systems Application, Inc.
Klemp-Wilhelmson	90 x 60	2	25	Squall lines	Klemp and Wilhelmson, 1978; Weisman et al., 1988	NCAR
Hsu	17 x 25	30	18	Lake-effect snowstorms	Hsu, 1987	NCAR, Woods Hole Oceanographic Institution
Kurihara-Tuleya	144 x 120	25 to 30	11	Tropical storms	Kurihara and Tuleya, 1981; Tuleya, 1988	GFDL

TABLE A.3 continued

Model	Domain	Approximate Horizontal Resolution (km)	No. of Vertical Layers	Emphasis	References	Users: Government, Universities, and Corporations ^a
RAMS	Nested grids, 40 x 40 per grid	2, 70	17, 28	General	Tripoli and Cotton, 1989a,b	Over 10 users
SIGMET	Nested grids, 20 x 20	5, 50	Variable, usually 15	Terrain- forced circula- tions	Patniak and Freeman, 1983; Williams et al., 1986	U.S. Army/ASL
AFGL	26 x 26	20	16	Clouds, precipita- tion	Modica, 1987	U.S. Air Force/AFGL
ETA	Subhemispheric	30 to 80	16	General, orography, rapid de- velopment	Mesinger et al., 1988	NOAA (next opera- tional regional model)

NOTE: Includes only primitive equation models covering domains $\geq 10^4 \text{ km}^2$ with resolution of $\leq 100 \text{ km}$.

*Broad usage, e.g., convective systems, terrain effects, extratropical cyclones, and so on.

^aAcronym Key-AFGL: Air Force Geophysics Laboratory; ARL: Air Resources Laboratory; ASL: Atmospheric Science Laboratory (White Sands, New Mexico); CIMMS: Cooperative Institute for Mesoscale Meteorological Studies; ERL: Environmental Research Laboratories; GFDL: Geophysical Fluid Dynamics Laboratory; NASA: National Aeronautics and Space Administration; NCAR: National Center for Atmospheric Research; NEPRF: Naval Environmental Prediction Research Facility; NMC: National Meteorological Center; NOAA: National Oceanic and Atmospheric Administration; NRL: Naval Research Laboratory; SUNYA: State University of New York at Albany; USRA: Universities Space Research Association.

TABLE A.4 Summary of Mesoscale Observational Studies and Field Programs in the United States

Project	Objective	Location and Period	Funding Agencies ^a
<u>Warm Season</u>			
High Plains Experiment (HIPLEX)	To study feasibility and environmental impacts of summer cumulus cloud seeding	Mesoscale data collected at three high plains locations, 1975-1980. Cloud seeding experiment in Montana, 1979-1980	DOI/BUREC
Cooperative Convective Precipitation Experiment (CCOPE)	Oriented toward precipitation evolution and enhancement through measurement of micro-physics and dynamics of growing and mature convective clouds	Field observations near Miles City, Montana, during May to August 1981	DOI/BUREC, NASA, NOAA, NSF
Virginia-Illinois NOAA Program (VIN)	To investigate whether low-level convergence precedes convection in midlatitudes, as in Florida	Analysis of data gathered in 1979	NSF, NOAA/ERL, U.S. Army, U.S. Air Force
Joint Airport Wind Study (JAWS)	To develop surveillance for warning aircraft of hazard due to low-level wind shear, especially from downbursts	Observations in spring and summer 1982 at Stapleton Airport, Denver	NSF, FAA, NASA, NOAA

TABLE A.4 continued

Project	Objective	Location and Period	Funding Agencies ^a
<u>Warm Season continued</u>			
Severe Storms and Mesoscale Experiment (SESAME)	Initially oriented toward initiating and organizing mechanisms of severe thunderstorm systems; currently, increasing emphasis on heavy precipitation	Analysis of results of 1979 field program in central United States	NOAA/ERL, NASA/MSFC, NASA/GLAS, NSF, others
NSSL Spring Program	To elucidate interactions between motion, water, and electrical fields and to assess associated hazards to aircraft	Doppler radar, electrical rawinsonde, aircraft measurements in Oklahoma, April to June 1981 and subsequent years	NOAA/NSSL, FAA, DOD, NASA
Airborne Investigations of Mesoscale Convective Systems (AIMCS), 1984	To conduct preliminary investigations of nocturnal MCSs utilizing research aircraft	Central United States, May to June 1984; some analyses continuing in conjunction with Pre-STORM research	NOAA/ERL, NSF
Oklahoma/Kansas Preliminary Regional Experiment for STORM, Pre-STORM, 1985	To investigate the structure and dynamics of MCSs and help sharpen the scientific objectives of the STORM-Central Program	South-central Plains, May to June 1985; analyses continuing; results being used to define the central U.S. STORM-I Program	NOAA/ERL, NSF

Cooperative Huntsville Meteorological Experiment (COHMEX), 1986	A three-phase program to (1) understand precipitation processes associated with mesoscale and convective-scale systems to help define space-borne remote sensing, (2) investigate the structure of microbursts in humid regions, and (3) develop and test algorithms for wind shear detection	Southeastern United States, June to July 1986	NASA, NSF, FAA
Convection Initiation and Downburst Experiment (CINDE), 1987	A three-phase program to (1) improve understanding of boundary layer processes, particularly along convergence lines, leading to convection, (2) investigate, refine scale-dynamics of the downdraft, and (3) investigate the generation of non-supercell tornadoes	Denver area, summer 1987	FAA, NSF, NOAA
<u>Cold Season</u> Cyclonic Extratropical Storms Project (CYCLES)	To describe and understand the mesoscale structure of winter cyclones in the Pacific Northwest	Washington State coastal area, 1973 to 1986; major field program in 1982	NSF, U.S. Army, U.S. Air Force
Sierra Project	To assess potential to enhance winter-spring orographic precipitation in American River Basin; included mesoscale observations and seeding experiments	American River Basin in central Sierras, Calif.; multiyear project: 1976 through early 1987	DOI/BUREC
Lake Effects Studies, 1983/1984	To investigate the structure of the convective boundary layer in lake-effect snow situations	Analyses continuing	NSF

TABLE A.4 continued

Project	Objective	Location and Period	Funding Agencies ^a
<u>Cold Season continued</u>			
Gulf of Mexico Experiment (GULFMEX), 1988	To investigate the structure and character of the return flow of modified continental air from the Gulf of Mexico into the central United States in the winter and early spring	Data archive complete; analyses of data under way, Gulf of Mexico area, winter-early spring 1988	NOAA
Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA), 1988/1989	To understand the mechanism of the rapid intensification of cyclonic storms at sea	Atlantic off east coast of United States and Canada, December 1988 to February 1989	NOAA, NSF, ONR
Genesis of Atlantic Lows Experiment (GALE), 1986	To improve the understanding and prediction of the meso-scale features of East Coast winter storms	Observations made over the coastal and offshore Georgia-Maryland region, January to March 1986; analyses continuing	NSF, NOAA, NASA, ONR, U.S. Army, U.S. Air Force, DOE

^a Acronym Key--DOD: Department of Defense; DOE: Department of Energy; DOI/BUREC: Department of Interior/Bureau of Reclamation; FAA: Federal Aviation Administration; NASA: National Aeronautics and Space Administration, NASA/GLAS: Goddard Laboratory for Atmospheric Sciences, NASA/MSFC: (George C.) Marshall Space Flight Center; NOAA: National Oceanic and Atmospheric Administration, NOAA/ERL: Environmental Research Laboratories, NOAA/NSSL: National Severe Storms Laboratory; NSF: National Science Foundation; ONR: Office of Naval Research.



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