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Contents

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Changing times for oil imports and energy policy

Robert W. Fri

After several years of disuse, the nation's energy policy machinery is again clanking into motion. Past experience suggests that making energy policy, particularly involving oil imports, is a chancy business. To reduce the risk of making bad policy, it would be wise both to remember what we have learned about managing energy problems in the past and to consider how times have changed.

Some fundamental features of the worldwide oil situation have *not* changed very much since the late 1970s. For instance, the world's principal reserves of low-cost oil remain concentrated in the nations of the Organization of Petroleum Exporting Countries (OPEC). This concentration is increasing as the countries of the free world outside OPEC use up their oil reserves faster than OPEC. Moreover, 80 percent of OPEC's reserves are concentrated in six of its thirteen member nations: Kuwait, Saudi Arabia, the United Arab Emirates, Iraq, Iran, and Libya.

OPEC's pivotal position is not likely to change anytime soon, considering that two-thirds of the largest oil fields discovered to date are located in its member countries. Thus, OPEC will have a dominant market position for a long time to come. At issue is whether it can and will use its position to influence oil price and supply.

OPEC's behavior is largely shaped by its need for oil revenues. Thus, production that is well below capacity leads to cheating on production quotas, which in turn undermines effective cartel behavior.

Unlike the case of some cartels, however, capacity production by all of its members is not a prerequisite to OPEC effectiveness. Since the Arab Gulf states have small populations and large oil production capacities relative to other OPEC members, these Gulf states—and especially Saudi Arabia—can produce below capacity and still generate significant per capita revenues. It appears that when total OPEC production is around 80 percent of capacity, revenue needs are sufficiently satisfied to allow OPEC to behave as an effective cartel.

The need for oil revenues also appears to create a propensity to maintain OPEC production despite the inherent political instability in the Middle East. Only two political crises in the past twenty years have had a major effect on oil supply. It is worth noting that production curtailments in 1973 and 1979 were not among them.

Non-OPEC countries, by contrast, find themselves in a very different position on oil reserves. The general prognosis is that these countries currently possess smaller, higher-cost reserves, and that future exploration will yield up reserves of a similar nature.

The United States provides a good case in point. Proved U.S. reserves of about 30 billion barrels are now producing oil at less than 9 million barrels per day. By the end of the century, however, these existing reserves will support production of only 1 million or 2 million barrels per day, even at relatively high prices. So new reserves must be found to support domestic production.

U.S. oil will remain costly

The United States has substantial potential crude oil reserves of about 300 billion barrels. However, the oil yet to be discovered lies in relatively small and scattered fields. Tapping the oil potential in this country will require extensive drilling and expensive recovery techniques, meaning that the United States will remain a high-cost producer.

Outside the United States, non-OPEC production grew by almost 30 percent between 1979, when the last oil shock occurred, and 1985; however, these reserves do not appear to have much more growth potential. The general view is that the remaining crude resources in the free world are increasingly remote or deep and therefore costly to develop.

Overall, then, two fundamental features—the relative cost and location of oil reserves and the forces that shape OPEC behavior—have not changed very much in recent years. But another fundamental—the structure of oil markets—has changed significantly.

World oil markets are currently more efficient than they were before 1980. Creation of an active futures market and the growth of the spot market are both lessening the likelihood of frequent major price swings, although they probably encourage short-term price instability. Also, a large spot market reduces the chances of inventory panic, a major cause of the 1979 price spike.

Widespread use of netback pricing, that is, determining the price of crude oil based on product market prices, is another important development in world oil markets. It tends to make crude prices more volatile by more closely linking them to highly competitive product markets. The importance of netback pricing is underscored by OPEC's current attempts to return to posted prices.

Finally, it should be noted that large changes in oil supply and demand require large investments, which take time to put in place. These long lead times result in relatively low short-run elasticities that complicate adjustment to oil price changes. They also increase uncertainty and thus reduce the inclination to invest, a factor that is now limiting future capability to adapt to higher oil prices.

These fundamentals provide the basis for insights into the future price and availability of oil in the U.S. economy.

The characteristics of the marketplace suggest that oil prices are likely to remain moderately unstable but relatively low well into the 1990s. Though OPEC may try to impose production quotas to increase prices, the move is likely to have little lasting effect until excess worldwide production capacity is dried up. And efficient commodity markets in crude oil, coupled with strong product market competition, suggests that prices will fluctuate in the meantime.

After excess capacity has disappeared, OPEC will be better able to influence prices, which may then rise more sharply. It would be in OPEC's own interest to manage prices at a level somewhat below the marginal cost of new production elsewhere in order to maintain price stability at these higher levels. Excessive increases would again set loose the market forces that resulted in the price collapse of 1986.

The share that domestic oil supplies will contribute toward meeting U.S. demand appears to be increasingly limited. The current investment climate for oil and gas exploration is poor, and domestic production is predicted to shrink from its current level of about 9 million barrels per day to a maximum of 6 million barrels per day by the turn of the century. Absent a reduction in U.S. exploration and development costs, this downsizing of the U.S. oil industry seems highly probable.

Foreign sources of supply, therefore, will become increasingly important in the future. Results from recent studies commissioned by Conoco, the National Petroleum Council, the Gas Research Institute, and the Aspen Institute reflect the consensus that flat or slightly higher domestic demand combined with declining domestic production will likely result in imports rising to half or more of total U.S. consumption by 1995.

Why is the U.S. vulnerable?

The idea of U.S. vulnerability stemming from this increased dependence on foreign sources of supply needs to be closely examined. The potential supply of oil from foreign sources is adequate in quantitative terms, and efficient markets and ample transportation make it physically available. Moreover, rising oil prices need not have catastrophic economic consequences, as demonstrated by the Japanese economy after the 1979 oil price shock. Where, then, does U.S. vulnerability lie?

One cause could be a cutoff of imported oil. However, the likelihood of a supply disruption large and permanent enough to actually make oil unavailable for essential uses in the United States seems fairly remote in today's world.

OPEC's propensity to produce and the existence of a large and efficient spot market are factors that greatly mitigate the effects of minor supply reductions. A major supply disruption would most likely be precipitated by a political event whose ramifications extended well beyond energy policy per se.

The other form of potential vulnerability that should be examined is adverse economic effects arising from higher and unstable prices. Given projected price instabilities and ultimately higher prices dictated by OPEC, these adverse effects are quite likely—and so are worth worrying about.

In paying for imported oil, wealth is transferred out of the United States to oil producers, thus reducing income available to create domestic demand. Moreover, when oil prices rise, the economy must make adjustments, which in turn can lead to economic disruption. These adjustments are made more difficult if oil prices rise (and fall) rapidly. Finally, rising prices result in the movement of wealth from consumers to producers, which makes consumers unhappy whether the producer is at home or abroad.

Because oil prices are the same for oil from any source, the extent of these adverse economic effects depends only partly on the U.S. level of oil imports. This nation's vulnerability due to its dependence on foreign oil supplies is affected by at least two major factors in addition. The first of these—the total amount of oil used in the economy—is an even more important factor than the level of imports. The more oil we use, imported or not, the larger our input costs become as prices rise. The movement of wealth from consumers to producers also depends on total demand, because consumers lose wealth when prices rise whether that wealth stays in the country or goes abroad.

In addition to the total amount of oil

used, a second important factor is that oil is an international problem. The demand that soaks up excess OPEC capacity is created by all importers, and the severity of a disruption depends on how all countries manage available supplies and stocks.

Thus, the level of U.S. imports is only one of several factors that determine our vulnerability. Imports are largely responsible for the income effect: that is, the more oil the United States imports, the more money it sends abroad. U.S. imports are a major part of world oil trade, and thus they indirectly influence oil prices. But this country would be economically vulnerable to oil price shocks even if it imported nothing.

To make the problem even more complex, conventional views about the impact of oil price shocks on economic performance are now being challenged. According to RFF senior fellow Douglas R. Bohi in his recent study of oil price shocks and how they affect economic performance, rigidities in the economy appear to amplify the effects of adjusting to higher or unstable oil prices. If this is so, care should be taken in developing policy responses to energy issues, especially policies that impose additional economic rigidities.

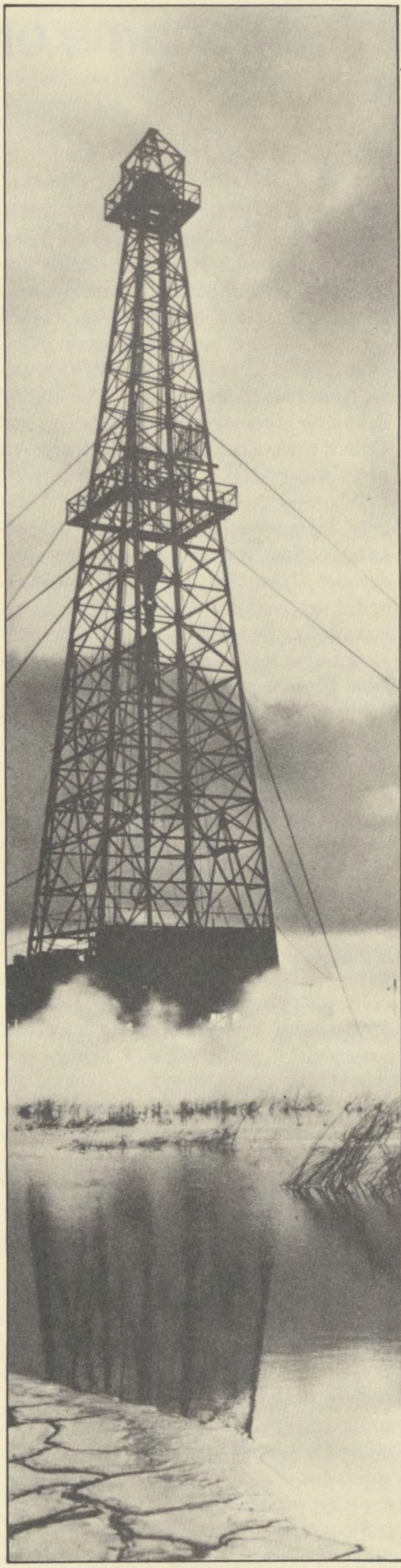
We should worry about U.S. energy security, but we should do so with a broader vision than one that focuses exclusively on the level of oil U.S. imports. With this—and the uncertainties of forecasting—in mind, let us consider several important steps that can be taken to reshape energy policy within the oil sector.

Costs, conservation, and diplomacy

First of all, the cost of new oil production should be reduced both in the United States and elsewhere. Technology has a critical part to play in this process, and it may be appropriate for the government to sponsor research in this area.

The United States should also continue to reduce its reliance on oil. Measures to reduce oil's value in industrial output would minimize adjustment problems. Increased levels of conservation should be sought throughout the economy, but particularly in the transportation sector.

The government can play a useful part in encouraging energy conservation in the transportation sector through the continuation of auto efficiency standards. Pressing forward with research and development of the methanol fuel and electric vehicle options would also provide good insurance.



Courtesy of American Petroleum Institute

Proved U.S. oil reserves of about 30 billion barrels are now producing at less than 9 million barrels per day.

In addition, because oil is an international problem, energy security should be an important and permanent foreign policy objective. Steps to diversify oil production, promote price stability, and head off the growing appetite for oil in developing countries have much merit. The United States would benefit greatly from having a domestic energy policy firmly in place to serve as the starting point for active diplomacy.

Another important policy aim should be an attempt to insulate the domestic economy against the effects of price shocks and potential disruption. The Strategic Petroleum Reserve offers a powerful tool for moderating major price swings; the United States would benefit from an increase in its size.

Risks of market intervention

Beyond these policy objectives that are rooted in the fundamentals of the oil situation, restraint is advisable. Energy is a long-term problem, and quick fixes will do more harm than good. Because the fundamentals change slowly, mistakes are not soon discovered or soon repaired. For instance, though an oil import fee could somewhat reduce imports by depressing demand and possibly temporarily retarding the domestic decline in production, it could also impose serious short-term costs on consumers and industrial users of oil. An import fee would, after all, increase the price of all the oil we use, not just the part that is imported.

More important, an import fee is just the sort of rigidity that could make matters worse in unforeseen ways. Price supports in the 1980s could distort signals to the producing sector just as price controls in the 1970s distorted the response of the consumer sector, with a similarly negative outcome. It would probably be wise to let producer readjustments go forward unattended by excessive market intervention. ■

Robert W. Fri is president and senior fellow of Resources for the Future.

Materials field unified in name only

Hans H. Landsberg

THE MATERIALS COMMUNITY has long been united in its call for a national materials policy, but it has continued to be frustrated in the achievement of that goal despite passage of several major pieces of federal legislation on materials issues in the past fifteen years. The National Critical Materials Act of 1984, for example, seemed to fill the need for high-level government representation of materials interests by establishing the National Critical Materials Council in the Executive Office of the President. But it remains to be seen whether, with its limited staff and budgetary resources, the council will be able to bring about any real change.

From the perspective of the materials community, an effective national policy would need to be rooted in the recognition of materials as an important ingredient in economic development and national security. Such a policy would demand measures to preserve the industry against the inroads of foreign (presumably cheap) competition, encourage cooperative research by government and industry, and help mitigate burdens (such as withdrawals of federal land from mineral development) upon enterprises in the industry.

One major reason for the difficulties in developing cohesive policies in this field is the diversity of the field itself. The term *materials* covers multitudes of substances ranging from wood and metals to high-technology materials such as ceramics and glass fibers. In its most general formulation, often used by materials specialists to obviate lengthy definitional discussions, it includes substances used to make physical things, be they machines, tools, buildings, or fiber-optic cables. Clearly, the policy issues and objectives that relate to materials are equally complex. Furthermore, the field seems to be increasingly fragmented into three major groups: strategic and critical materials, traditional materials (typically produced in large volume), and advanced materials.

Policy focus too narrow

While one can argue endlessly over the definition of the terms *strategic materials* and *critical materials*, they are broadly understood to denote a degree of essentiality during periods of military emergency combined with inadequate availability within the United States. Obviously these characteristics are highly elastic, which explains why the number of materials included in these categories varies so widely, from four to about sixty. (The current definition is contained in the Strategic and Critical Materials Stockpiling Revision Act of 1979.)

Whatever their precise definition, however, these materials have dominated materials policy discussions over the past two decades. This rather narrow focus has resulted in the neglect of many of the issues surrounding materials in the two other major groups, which is all the more regrettable because there *are* ways and means of dealing with the strategic and critical materials according to their special needs.

Whatever its shortcomings—conceptual, technical, administrative—stockpiling still appears to be the best way to meet the demand for these materials. And the smaller the physical volume of a commodity that needs to be accommodated, the more appropriate stockpiling is. For example, to provide a ready-to-use inventory of 10,000 tons of cobalt should not be beyond the ingenuity or the financial resources of a technologically advanced society such as the United States. Nor should it be a forbidding task to widen the range and affordability of substitutes and to provide information to users as they need it.

The composition and characteristics of a stockpile are bound to change—for example, instead of chromium (used in the production of steel alloys) it may be preferable to stock ferrochrome (itself a crude alloy of iron and chromium) to accommodate the decline in domestic processing capacity for chromium. But this should neither strain our inventiveness nor become an argument for discarding stockpiling altogether, as is advocated by those arguing for the maintenance of high-cost domestic production.

Stockpiling of strategic materials has recently come under close scrutiny with the Reagan administration's 1985 proposal to "modernize" the National Defense Stockpile. Under the terms of the proposal, the stockpile goal would be sharply reduced—from $16.3 billion to $6.6 billion—and the inventory of materials would be changed substantially. Without getting into technicalities, the heart of the proposal would be a high-priority stockpile group valued at only $700 million. The balance would be made up of "also-rans." Surprisingly for those familiar with the field, even the top group would not contain such old-timers as platinum, vanadium, and manganese, and it would include only a small quantity of cobalt. The changes represent a drastic shake-up.

The rationale and assumptions underlying this proposal for partial liquidation are not made clear in official statements: the comprehensive interagency study that resulted in the issuance of the President's National Defense Stockpile Policy on July 8, 1985, simply says, "Substantial improvements were made in analytic methods for estimating materials requirements and available supply. These changes, as well as correction of errors and the use of more plausible assumptions, are the primary reasons for the revised stockpile goals."

It is possible, of course, that if the background material supporting the proposal becomes available, the recommended changes may be found to be quite reasonable. In any case, the administration's move may provide a timely occasion to review basic assumptions behind the stockpile concept, such as its applicability in the nuclear age. The debate over the proposal will also permit recommendations such as greater industry involvement in stockpile management to receive more attention. As of early 1987, however, the proposal was still on the shelf due to congressional opposition.

One of the advantages of a thorough debate about and resolution of the issues relating to the stockpile would be that more attention could then be given to the other two segments of the materials field—traditional and advanced materials.

The traditional materials, those "bread-and-butter" items such as steel, copper, lead, zinc, nickel, and tin, have been sorely neglected. That is, little has been done to support the future viability of the industries that produce and process these minerals, to articulate sustainable policies, or to debate any "need" to support them. The consequences of possible decline or even demise of these enterprises in the United States has not been seriously addressed, despite clear-cut evidence that substantial declines have already occurred in both the mining and the processing sectors.

The traditional materials are facing increasing competition from newer materials, both in the area of traditional uses where they still dominate the market and in new applications. On a positive note, however, the industry has begun to look for new ways of processing and manufacturing metal products that could increase its adaptability and cost-competitiveness. For example, faced with competition from advanced materials and with technical impediments to meeting new needs, metals are being increasingly incorporated as part of matrixes—i.e., controlled mixtures of different materials to suit specific uses—rather than used in isolation. It appears, then, that questions of mineral depletion versus adequacy of supplies, which have often been raised, will recede in importance in the years ahead and that competitiveness in the use of traditional materials, to be achieved largely through growing complexity in makeup, will become the focus of attention.

Advanced materials in the limelight

The third segment of the materials field, advanced materials, is growing rapidly and is commonly regarded as the field's frontier area. It has been attracting the cream-of-the-crop of skilled scientists and technologists—as well as a large share of government funding in the materials field, if only because these materials are heavily defense-oriented.

Advanced materials are of widely diverse origins: petrochemicals are derived from hydrocarbons; graphites are also hydrocarbon-associated; materials such as germanium, silicon, zirconium, and gallium are nonfuel minerals that can be used either as such or, more commonly, in so-called composites that draw on two or more advanced materials and one or more of the traditional materials; and alloys such as aluminum-lithium come from the addition of new substitutes (in this case, lithium) to old-line metals.

Applications of advanced materials are wide ranging and offer considerable growth potential, particularly in new technologies and uses—for example, in telecommunications; transportation; power generation, transmission, and distribution; and the electronics field, to whose demanding specifications, in fact, many of these new materials owe their emergence as commercial phenomena. In electronics, applications include sensors, capacitors, chips, and diodes. Processes in which advanced materials are used include but are not limited to coatings, powder-shaping, and rapid solidification. As mentioned, defense needs have been a major source of demand.

Major changes foreseen

Market statistics on advanced materials are not widely available, but those that are convey the strong impression of an impending major shift in emphasis toward their use both in the United States and abroad. The case of ceramics is a good example of the kind of change that might occur.

A frequently quoted estimate puts sales volume in the high-technology ceramics market in the early 1980s at $4.25 billion worldwide. That figure is for finished products including nonceramic parts, but the estimate for the ceramic powder component alone is $250 million, not a negligible level for a material still heavily in the R&D phase. Few believe that a ceramic motor vehicle engine—an achievement that would surely establish ceramics as a powerful new material—will emerge in the 1980s, but the concept has enough merit to make the eventual appearance of ceramic engines seem likely. (Such engines would have superior heat resistance and thus both higher fuel efficiency and longer life.) Thus, some time in the next decade the ceramics market is likely to lose its heavy orientation toward electronic components and cutting tools and to diversify into a great many other uses and devices. If that should happen, it could overtake some of the conventional materials in value of shipments.

It remains to be seen to what extent shifts like this will be limited to a few of the highly industrialized countries (basically, the member countries of the Organisation for Economic Cooperation and Development). This does not mean that the developing countries will relive the materials history of Western Europe, the United States, or Japan. Instead of working their way through a steel–copper–lead–zinc age, they may instead make the leap into the twenty-first century and take advantage of newer materials—above all, the hydrocarbon-based ones such as plastics.

Given these factors, the often-heard assumption of a strong global revival of traditional, mostly large-tonnage materials demand triggered by rising income levels in the developing countries must be viewed with caution. Though some rise in demand is certain to occur, there is strong doubt as to whether it will even begin to match the loss of markets in the industrialized countries of the world, even considering such relatively unknown factors as future levels of demand for traditional materials in the Soviet Union, its satellites, and China.

Projections for probable U.S. consumption of metals in the year 2000 are provided in the U.S. Bureau of Mines' *Mineral Facts and Problems* (1985 edition). The big gainers are three steel-alloying minerals (germanium, columbium, and tungsten) and one (vanadium) of relatively recent prominence in a variety of high-technology applications. Average annual growth rates for these four are projected at 6 to 10 percent between the years 1984 and 2000, whereas large-tonnage metals are projected to grow at rates of 2 to 4 percent per year (aluminum, lead, and nickel at the higher rate; copper and manganese at barely 2 percent). In sum, factors such as those highlighted here make a substantial revival of the conventional metals seem a questionable prospect.

In the energy field, news of improvements in efficiency and resulting decline in consumption is received with enthusiasm. In the materials field this pattern is generally viewed with regret, because it depresses prices and threatens the survival of many mineral enterprises. However, unless there is a major materials market shake-up like the OPEC-triggered oil market disruptions of the 1970s—which is not likely—the decline in materials use intensity (i.e., employment of less material per dollar of gross national product) will continue. The one major exception to this widespread downward trend is the advanced materials—pure, alloyed, or otherwise. Though figures on intensity of use for this group are not readily available, it would be safe to assume that they are rising; all indications point to their substantial expansion at the expense of conventional materials.

Despite mounting evidence that advanced materials may increasingly occupy center stage in the materials field, social science research and even mere interest in this area are as yet limited in the sense that, so far, social science research has not taken much notice of a great number of exciting future technological possibilities and their implications for the U.S. economy. To be sure, statistics are hard to come by, and the technical aspects involved are complex. But unless greater effort is made, the social sciences will remain increasingly in the rear guard, with concern and advice addressed to a shrinking slice of the pie. ■

Hans H. Landsberg is senior fellow emeritus and consultant-in-residence of the Energy and Materials Division at Resources for the Future. This article is adapted, with permission, from his paper "Materials—New Faces and Old," Mineral Processing and Extractive Metallurgy *vol. 3, nos. 1–4 (1987) pp. 117–132. © 1987 by Gordon and Breach Science Publishers Ltd. The author originally presented that paper as the keynote address at the 1986 conference on Changing World Metals Industries, sponsored by the Bureau of Mines of the U.S. Department of the Interior at Columbia University.*

New technologies for chlorine-containing solvents

Philip H. Abelson

More than 280,000 landfills and 340,000 surface impoundments, including both operating and closed facilities, may currently exist in the United States, according to estimates released by the U.S. Congress's Office of Technology Assessment (OTA) in 1985. A significant number of these sites are known to contain appreciable amounts of hazardous materials, including solvents.

Halogenated solvents, which include chlorine-containing chemicals that have been widely used in applications such as dry cleaning, degreasing, aerosols, and as a feedstock in the manufacture of other chemicals, figure prominently among this group of materials. In recent years, increasingly stringent state and federal regulation of solvent production and disposal has markedly decreased the quantity of halogenated solvents that are disposed of at public sites. Therefore, rectifying past mistakes appears to be the major challenge in dealing with these hazardous materials.

Six halogenated solvents—chloroform, carbon tetrachloride, trichloroethylene, tetrachloroethylene, methyl chloroform, and methylene chloride—are among those chemicals most frequently found at waste sites. Environmental concerns began to affect the production, use, and disposal of these solvents during the late 1960s and early 1970s. For example, before about 1975, trichloroethylene (used as a degreaser) was typically removed from industrial premises by a waste hauler and disposed of at a waste site, often a municipal dump. Substantial amounts of oil, grease, and dirt, and often kerosene and other hydrocarbons accompanied the trichloroethylene.

Since that time, new federal regulations have greatly changed customary practices. Waste fluids are now segregated. The dirty hydrocarbons can be burned as fuels and are of economic value for their heat content. In fact, most of the halogenated hydrocarbons now go to recycling plants where they are redistilled and later sold.

During use in dry-cleaning establishments and manufacturing plants, major portions of the solvents evaporate and subsequently are destroyed by reactions with active radicals in the atmosphere. Thus, even during the period predating the advent of environmental concerns, only a relatively minor fraction of the solvent was destined to become a liquid waste.

Once the liquid was brought to the disposal site, additional volatilization often occurred. In fact, the results of extensive studies have led geophysicists to estimate that 95 percent of all carbon tetrachloride and methyl chloroform distributed commercially has gone into the atmosphere. In general, concentrations of the halogenated hydrocarbons in the atmosphere are tiny in comparison with those of such toxic substances as ozone, which causes extensive damage to plants. The use of the atmosphere as a sink and destructive agent for trichloroethylene, tetrachloroethylene, chloroform, and methylene chloride is much to be preferred to the alternative of their incorporation in the ground and subsequent migration to aquifers.

Groundwater contamination

Nevertheless, even the minor fractions of halogenated solvents that have been buried constitute a serious source of pollution in aquifers. Much of this contaminating material comes from three sources—leaking underground tanks, waste sites, and spills.

Under the Superfund program, the federal government has levied funds to clean up hazardous chemicals at selected abandoned sites, including landfills, lagoons, and waste storage sites. In 1985 a total of 845 sites had been placed on the Superfund National Priority List. In addition to these abandoned sites, however, many company-owned locations (also including lagoons and landfills that take in pollutants from leaky underground storage tanks and pipes) are contributing to groundwater contamination.

Although there are no comprehensive statistics on the means by which halogenated solvents have been introduced into soil, anecdotal evidence suggests that about one-third of these solvents originally were contained in drums at landfills, another one-third originated as fluids dumped at landfills, and the remainder entered the soil by means of leaky tanks and plumbing at users' sites.

Underground storage tanks constitute a major source of potential pollution. According to a recent Environmental Protection Agency (EPA) fact book, it has been estimated that there are a million underground tanks, some of which are abandoned, and that 10 percent or more of the total are leaking.

Most of these tanks have held gasoline or other petroleum products, but a substantial number have been devoted to halogenated solvents, some of which have leaked out of the tanks. These solvents tend to migrate downward in the soil, unnoticed and undetected until they appear in groundwater wells. A considerable volume of soil and plumes of water in an aquifer may be contaminated before the leakage becomes evident.

When leaking solvents have reached groundwater, the generally preferred technique for removing them is "air-stripping." In this procedure water is pumped to the top of a tower and is broken up into small droplets. These droplets fall through a rising current of air, allowing the solvent molecules to volatilize and either to escape directly into the atmosphere or else to be captured by an adsorber.

The principal cost of remedying groundwater contamination at any particular location will depend on the volume of groundwater that has been contaminated. The volume that is regarded as being contaminated will depend on the tolerance limit that the regional EPA office sets. One target that has been proposed is one part per billion. In some instances, very large volumes of water will be involved, with corresponding costs for treatment.

Waste site cleanup proceeding slowly

Waste sites usually present a more complex cleanup problem than do leaky underground tanks. Most Superfund sites contain many different chemicals and large volumes of contaminated soil.

Remedial measures have included the removal of drums containing liquid from the surface of some sites, but metal detectors have revealed the presence of other, buried containers. These containers may be corroded and leaking, but only rarely have efforts been made to remove them.

After cursory studies of a targeted site, the usual practice is to build a fence around it. This is sometimes followed by enclosing the area with bentonite slurry walls that are designed to have low permeability and to reduce leakage substantially. The enclosed area is then often capped by a clay layer or a synthetic membrane or both.

Photo by S. C. Delaney, EPA

Drums of contaminating chemicals have been removed from the surface at some Superfund sites, but many leaking drums remain buried.

An additional remedial measure often employed is to locate wells down-gradient from a site and to pump leachate from the wells; the leachate is then processed to remove the contaminants.

Only a fraction of the contaminants at a waste site is usually recovered during initial pumping. Some of the remaining material is treated by being dissolved in immobile fluids, some adsorbs to particles of soil, and some is still contained in corroded drums. Effective treatment of waste chemicals from a particular site could thus require many years of pumping.

At a limited number of sites EPA has paid for a cleanup process that involves excavating soil and moving it to a Superfund disposal site. However, the agency has been criticized for this kind of remediation, which can cost up to $200 per ton. (Some sites contain millions of tons of contaminated soil.) Critics also point out that removal of soil only transfers the problem elsewhere.

A more promising solution for cleaning up waste sites and contaminated groundwater may lie in modifying existing conditions so that naturally occurring microbial activity can be stepped up.

Results of successful large-scale microbial action at municipal dumps, sewage treatment plants, and oil refineries support the growing belief that, ultimately, biodegradation will systematically be applied on a large scale at hazardous waste sites.

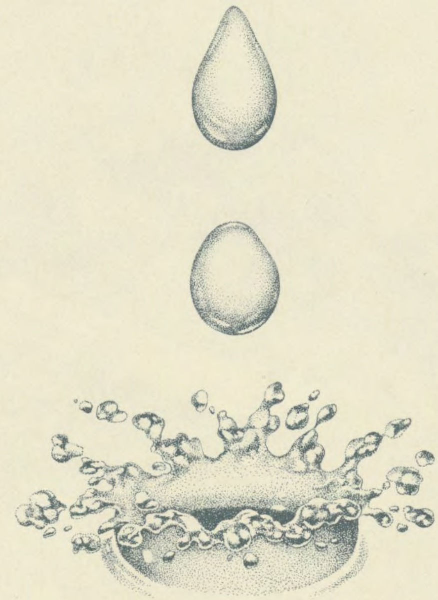
Though it has long been known that anaerobes can be used to dechlorinate chlorine-containing substances, the process has only recently taken on a new significance in light of its potential for remediation work with halogenated solvents. Researchers at a number of institutions have been studying these microorganisms. Experiments at Stanford University have shown that rapid degradation of halogenated solvents can occur under favorable anaerobic conditions. One experiment resulted in nearly quantitative conversion of tetrachloroethylene to vinyl chloride, and a series of experiments with ^{14}C-tagged tetrachloroethylene resulted in variable fractions of the material being converted into carbon dioxide.

Knowledge derived from these and other experiments with anaerobes provides a basis for interpreting some of the observations that have been made on leachates at sites on the Superfund National Priority List. For instance, the *trans*-dichloroethylene that is present at ninety-seven sites could only have been produced by microbial activity, presumably from trichloroethylene.

Based on this and other evidence, there is strong reason to believe that substantial biotransformations of halogenated solvents are already occurring at waste sites. In general, these transformations have proceeded without constructive human intervention. In most cases, there probably have been restraining factors such as a lack of inorganic nutrients or suboptimal pH.

With constructive human intervention, reductive dechlorination by anaerobes at waste sites seems applicable to a large fraction of chlorine-containing chemicals that have more than trivial solubility in water. If anaerobic activity were fostered, at least partial dechlorination of wastes other than solvents would also occur. Partial dechlorination would make the wastes more susceptible to aerobic bacteria and further degradation at a later phase. Ultimately it may be useful to take advantage of new genetic engineering techniques to obtain superior organisms.

The OTA has estimated that hazardous waste cleanup costs could be as high as several hundred billion dollars. Actual costs, which may be less than estimated, will depend on standards yet to be adopted. Present standards (based on animal experiments of increasingly doubtful applicability for humans) are tentative, and requirements for cleanup vary from site to site. In any event, the systematic use of microbes could provide a cost-effective alternative to methods such as spending thirty or more years of pumping leachates and aerating them—a contingency currently considered likely. ■



Philip H. Abelson is scholar-in-residence of the Energy and Materials Division at Resources for the Future. This article is a condensation of his study, "Production, Use, and Disposal of Halogenated Solvents." That study, currently in draft form, includes an inventory of the annual production of solvents dating from 1945 and a more complete description of the microbiological research referred to in this article.

Climate change: a primer Part 2

Norman J. Rosenberg

This is the second part of a two-part article by the director of RFF's new Climate Resources Program. The article—the first part of which appeared in Resources, *Winter 1987—is drawn from the author's RFF discussion paper RR86-04, "A Primer on Climatic Change: Mechanisms, Trends and Projections," the full and annotated text of which is available prepaid at $3.00 (including postage) from the Renewable Resources Division, Resources for the Future, 1616 P Street, N.W., Washington, D.C. 20036.*

ATMOSPHERIC TURBIDITY—any condition of the atmosphere that reduces its transparency to radiation, especially visible radiation—affects our climate. Ordinarily the term *turbidity* is applied to the cloud-free portions of the atmosphere. Pollens, dusts, smoke, water vapor, and all suspended materials affect the atmosphere's turbidity. The term aerosol is used to describe dispersed solid or liquid particles suspended in the air.

Volcanism is the greatest natural contributor to the changing turbidity of the atmosphere, although other natural phenomena such as dust storms and forest and range fires also make significant contributions at times. Slash-and-burn agriculture and other land-clearing and residue-burning operations also load considerable amounts of aerosol into the atmosphere. Plants, too, exude organic aerosols; blue haze over forest areas has been attributed to such emanations.

Through his management or mismanagement of soils and vegetation, man affects the magnitude of atmospheric loading from all these sources except volcanism. In addition, power generation, industrial combustion processes and space heating, and refuse burning load large quantities of soot and other materials into the atmosphere.

Much has been written in recent years about the possibility that increased atmospheric turbidity may be changing climate. Some scientists have related volcanic eruptions to specific climatic events. Experts have also suggested that increasing atmospheric turbidity might have been the cause of the Sahelian droughts in the 1970s.

Evidence now suggests, however, that the earth's atmosphere is *not* becoming more turbid. As measured at the observatory on Mauna Loa mountain in Hawaii, there have been no long-term changes in the amount of small particles suspended in the air sampled over the island. Located in the mid-Pacific at an altitude of 3,350 meters (about 11,000 feet), the air sampled at the observatory represents the condition of the mixed or "average" global atmosphere exceptionally well.

The transmissivity of the atmosphere has been affected from time to time, however, by explosive volcanic events that eject debris into the troposphere and, sometimes, into the stratosphere. (The troposphere is the lowest layer of the atmosphere, extending on the average to about 15 kilometers above the earth; the stratosphere is the layer of the atmosphere extending upward from the top of the troposphere to between 20 and 25 kilometers.) When the stratosphere is relatively free from volcanic intrusions, the transmissivity of the upper atmosphere remains within a relatively limited range. It must also be borne in mind, however, that the turbidity of the atmosphere is frequently increased by aerosols generated by dust storms, the burning of vegetation, and industrial combustion processes. These materials, which tend to settle out of the atmosphere after a few weeks, usually affect radiation balance on a local or regional scale.

The recent episodes of volcanic activity at Mount St. Helens in Washington State and El Chichon in Mexico had quite different effects on the atmosphere. The eruption of the former in 1980 injected immense quantities of relatively large silicate and pumice particles mostly into the troposphere. But some materials were injected into the stratosphere as well. While they remained suspended, these materials certainly could have increased atmospheric reflectivity to space, and they did result in a measurable but transitory reduction of solar radiation receipts at the ground.

By contrast, the El Chichon eruption in 1982 injected great quantities of sulfurous gases into the stratosphere. These were converted to sulfuric acid particles, which can remain suspended for a number of years. Reductions in solar radiation received at ground level were measurable at a number of sites as the volcanic cloud spread over the globe. Residual effects of El Chichon are still measurable.

Trace gases and the "greenhouse effect"

The earth's surfaces, in order to dissipate the energy received from the sun, reradiate in the longwave, or infrared, band from about 3.0 to 80 micrometers. Most of the emission occurs in the wave band from 8 to 14 micrometers, with the wavelength of maximum emission at about 10 micrometers. Water vapor, a strong absorber of infrared radiation, is somewhat transparent in the 8-to-14-micrometer range. This wave band is called the atmospheric window. Methane, nitrous oxide, ozone, carbon dioxide, the chlorofluorocarbons, carbon tetrachloride, and carbon disulfide all have absorption peaks that tend to close the atmospheric window. At this time, probably as a result of man's activities, the concentration of each of these infrared absorptive gases is increasing in the atmosphere.

Methane, a gas produced under anaerobic conditions, has been increasing at the rate of about 1 percent per year for the last decade or so. Current concentration of this gas is about 1.65 parts per million by volume. Ice-core data indicate that the atmospheric concentration of methane may have increased steadily over the last several hundred years. One likely cause is the growth of rice paddy culture around the world. As methane is also a product of both ruminant and nonruminant digestive systems, increasing numbers of animals may account for part of the increase. It has been shown, too, that methane is an important end-product of cellulose digestion by termites. The rapid increase in methane is also a result of the accumulation in the atmosphere of other gaseous species such as carbon monoxide which react with hydroxyl (OH) radicals that would otherwise reduce the methane molecules.

A great increase in the use of nitrogen fertilizers in agriculture, especially since World War II, has been implicated in the average annual 0.2 percent increases of nitrous oxide observed in the atmosphere. Nitrous oxide is released from soil to the atmosphere during the nitrification of ammonium-producing fertilizers under aerobic conditions. However, nitrous oxide is also emitted as the result of denitrification—a process that occurs when soils become water-logged. It has been suggested that the drainage of such soils and alterations in their acidity may have reduced this source of natural nitrogenous emissions to some degree. The combustion of nitrogen-rich fossil fuels may also be contributing to the increase in nitrous oxide.

Until now the trace gas that has received most scientific and public attention is carbon dioxide, an end-product of fossil fuel combustion, cement manufacture, and respiration by living organisms. Its concentration in the atmosphere has increased since at least the beginning of the industrial revolution. Since the late nineteenth century, scientists have speculated that because of its strong absorption of infrared radiation, especially in the atmospheric window, the rising concentration of carbon dioxide must cause a warming of the lower layers of the atmosphere. This phenomenon has been likened to the process that occurs in greenhouses: the glass permits solar radiation to penetrate, but it absorbs infrared radiation emitted by the soil and plants within. Although the analogy is defective, the process of warming in the lower layers of the atmosphere caused by the infrared absorptive behavior of carbon dioxide and the other radiatively active trace gases mentioned above has come to be known as the "greenhouse effect." It is not known for certain what the concentration of carbon dioxide was before the industrial revolution, although the record of sporadic air analyses from 1870 on and samples of air trapped in glacial ice suggest a value of around 280 parts per million.

In 1958, as one of the activities undertaken during the International Geophysical Year, continuous observations of atmospheric carbon dioxide concentration were begun by the Scripps Institute of Oceanography on Mauna Loa (see figure 2). The observations reveal a continuous and possibly accelerating secular increase in the mean annual concentration: in 1958 the concentration was about 316 parts per million; at the end of 1985 it was 345 parts per million. The annual cycle shown in the figure is a response to the seasonal photosynthetic activity in the Northern Hemisphere: during the growing season more carbon dioxide is drawn out of the atmosphere by photosynthesizing plants than is released into it by respiration; in winter the opposite is true. The records of observations of carbon dioxide concentrations at the South Pole, also started in 1958, are less continuous than those from Hawaii, but they closely confirm the findings at Mauna Loa, as do the measurements made at a number of other, more recently established stations around the world. All of these records suggest that the increase in atmospheric carbon dioxide concentration is a global phenomenon. They indicate that in the course of only a quarter-century, carbon dioxide concentration in the atmosphere has increased by nearly 10 percent. And if we consider plausible carbon dioxide concentrations before the industrial revolution, there has been at least a 23 percent increase in carbon dioxide in the atmosphere since then.

Whether the causes of this increase are

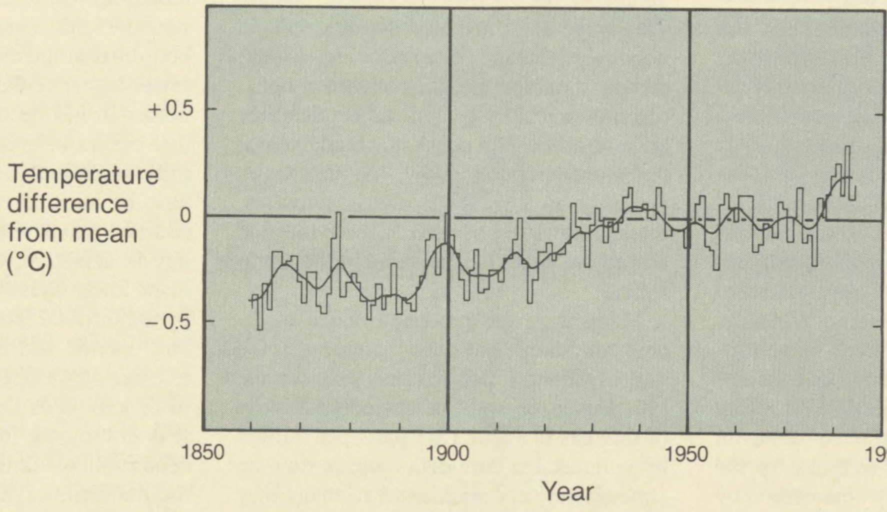


Figure 1 [reprinted, for readers' convenience, from part 1 of "Climate Change: A Primer," *Resources*, Winter 1987, p. 2]. Global annual mean temperature variations since 1861, based on land and marine data. *Source:* Based on figure in P. D. Jones, T. M. L. Wigley, and P. B. Wright, "Global Temperature Variations Between 1961 and 1984," *Nature* vol. 322 (1986) pp. 430–434.

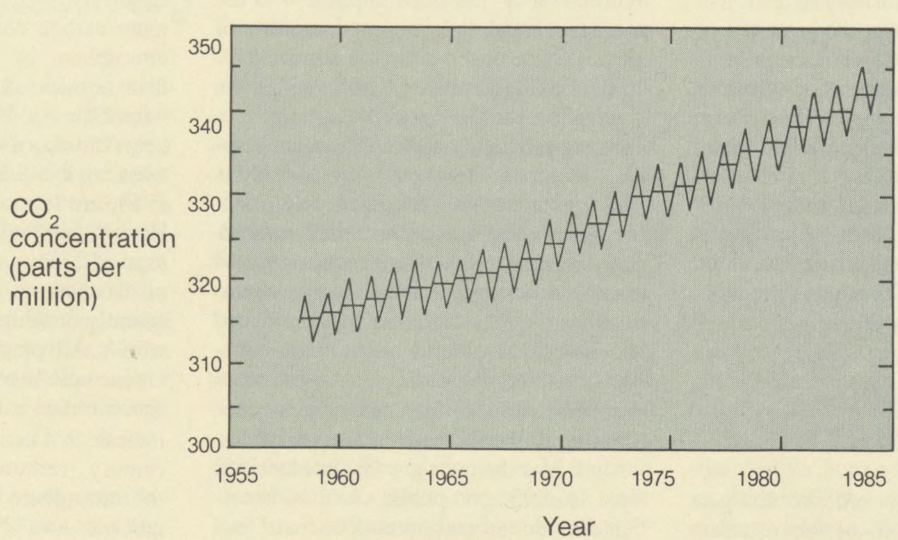


Figure 2. Concentration of atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. The horizontal bars represent annual averages. *Source:* J. R. Trabalka, ed., *Atmospheric Carbon Dioxide and the Global Carbon Cycle*, DOE/ER-0239 (Washington, D.C., U.S. Department of Energy, Office of Energy Research, 1985).

fossil fuel combustion and cement manufacture alone is not certain. More likely, the great changes in land use effected by man—the destruction of forests and their conversion to urban areas, grasslands, and farmlands, and the breaking of sod in natural prairies and plains to permit crop culture—have also been responsible for adding large amounts of carbon dioxide to the atmosphere—carbon dioxide being the end-product when trees are burned and the above-ground litter and soil organic matter are oxidized by microorganisms.

It is uncertain whether land use changes today continue to add significant amounts of carbon dioxide to the atmosphere. Concern has been voiced that conversion of tropical rain forests in Amazonia and elsewhere may lead to additional large increments in atmospheric carbon dioxide. However, the extent of current forest conversion rates is unclear, and the regrowth of forests in the temperate regions may offset these releases to some degree.

Industrial processes are probably the overwhelming cause of the carbon dioxide increase in the atmosphere at this time. Calculations of worldwide fossil fuel usage indicate that the equivalent of at least 3 parts per million of carbon dioxide are injected into the atmosphere yearly. Yet the Mauna Loa record shows that the annual increase over the last ten years has been about 1.36 parts per million. Thus, at least 1.64 parts per million—and, if non-fossil-fuel sources are significant, more—carbon dioxide is unaccounted for.

Some carbon dioxide is recaptured by oceans and on land. Although the matter is disputed, there is some evidence that, despite deforestation in the tropics, reforestation and regrowth of cutover areas may be increasing the area of forested land in the temperate regions. (This conclusion was reached by RFF senior fellows Roger A. Sedjo and Marion Clawson, and reported in their chapter "Global Forests" in *The Resourceful Earth* [Oxford, Blackwell, 1984].) If this is so, the new trees, to support their growth, may actually be extracting large amounts of the excess carbon dioxide from the atmosphere. Other vegetation may also be fixing more carbon dioxide, since photosynthesis increases proportionately in most species with increasing concentration of carbon dioxide in the ambient air.

The role of the biosphere in regulating carbon dioxide concentration in the atmosphere is not yet well understood. In fact, it is uncertain which of the world's major ecosystems are net sources of atmospheric carbon dioxide and which are net "sinks" for it. Whether the world's terrestrial ecosystems as a whole are a net source or a net sink for atmospheric carbon dioxide is also the subject of dispute.

Land use change

Humans have affected the radiation balance of large tracts of earth through changes in land use that lead to changes in the reflection of solar radiation. For example, new snow may reflect 90 percent or more; sandy desert may reflect 50 percent; dark dry soil, 15 percent; the same soil when wet, 8 percent; an alfalfa field, 24 percent; a coniferous forest, 20 percent; calm ocean, 7 percent; wavy ocean, 14 percent; a silt-laden river, 12 percent. Changes in land use also cause changes in surface temperature. The latter affects the emission of longwave radiation to the atmosphere and space.

Most often we think of land use change as due to man's activities. The condition of land surfaces may change as the result of natural processes as well. Soil erosion and species succession alter the character of the surface; these processes may be initiated by geological events, by evolutionary pressures, and, of course, by climatic change. The extent to which these

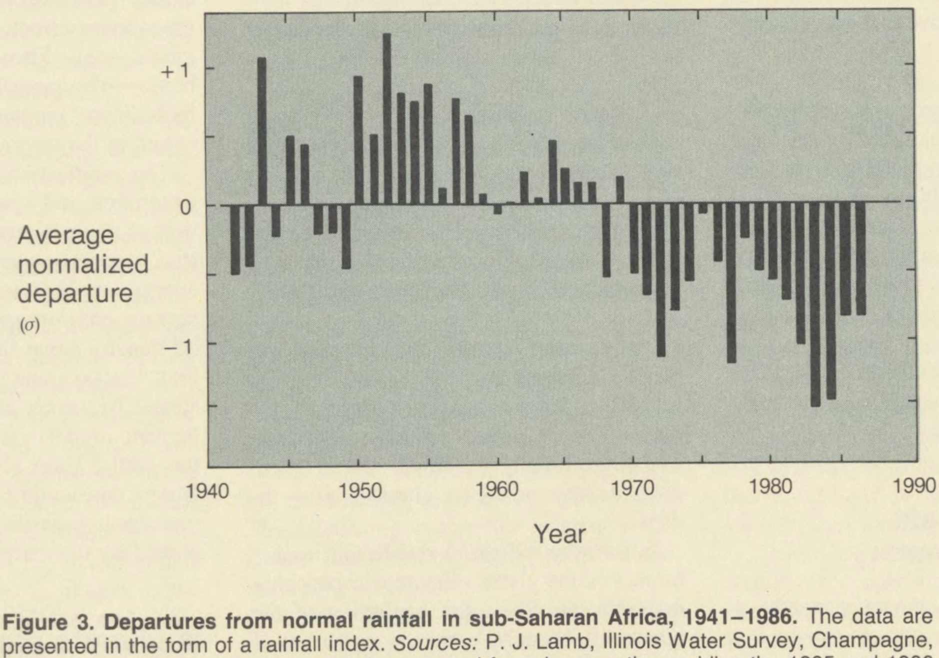


Figure 3. Departures from normal rainfall in sub-Saharan Africa, 1941–1986. The data are presented in the form of a rainfall index. *Sources:* P. J. Lamb, Illinois Water Survey, Champagne, Ill., is responsible for developing the data set and for subsequently providing the 1985 and 1986 data shown here. The figure is adapted, with permission, from R. A. Kerr, "Fifteen Years of African Drought," *Science* vol. 227 (1985) pp. 1453–1454. © 1985 by the American Association for the Advancement of Science.

conversions may alter local climate can be illustrated with a few examples. Consider the conversion to grassland of a hectare of land in the middle of a forest. Surface reflectivity for solar radiation will increase from, say, 18 to 24 percent; the effect will be a reduction in the net radiation. Trees that are deep-rooted can usually continue to extract water after shallow-rooted grass has exhausted its supply. Transpiration is the primary mechanism that allows leaves to remain cool even as they absorb the shortwave and longwave radiation that impinges on them. Thus, the mean temperature of the forest at noon might be 25° C compared to 35° C for grass under the same weather conditions. This difference in leaf temperature increases outgoing longwave radiation by about 14 percent, further reducing the net radiation over the grass.

The net radiation or available energy is not necessarily partitioned in the same ways in grassland and forest. After the grass has exhausted the water from its shallow root zone, its transpiration rate is sharply reduced. The surface becomes warmer than the air above and transfers heat to it. As the air above the grass becomes warmer, its ability to hold water vapor, an exponential function of the air temperature, increases. Relative humidity falls. The warm dry air over the grass can be carried by the wind into the adjacent forest. There, if soil water is still available to the tree roots, it may supplement the energy from the sun and increase the rate of evapotranspiration above that prevailing in the rest of the forest.

The example given above describes the effects of land conversion at the microscale. The same principles apply when large areas of land undergo alterations in use. When rain-fed agricultural lands are irrigated, when forests are removed, when rangelands are overgrazed and denuded, even when portions of large lakes or seas undergo color changes due to algal blooms, their radiation and energy balances are altered, with consequent effects on the local climate and on the climate of adjacent lands and waters downwind.

Factors in climate change—a summary

Three major causes of climate change have been described thus far: (1) changes in the supply of solar energy, (2) changes in the transmissivity of the atmosphere for both incoming and outgoing radiation, and (3) changes in land use that alter the radiation balance. Other causes include the release of heat (thermal pollution) that warms the lower atmosphere directly; the upward transport of chlorofluoromethanes and nitrous oxide into the stratosphere, where photochemical reaction of their dissociation products probably reduces stratospheric ozone with a consequent increase in ultraviolet irradiation of the surface and its inhabitants; and the release of trace gases such as nitrogen oxides, carbon monoxide, or methane that increase ozone concentration in the troposphere by photochemical reactions. Tropospheric ozone also causes significant atmospheric heating that enhances both solar and greenhouse heating of the lower atmosphere.

Change is an inherent feature of the earth's climate. In the future as in the past,

solar luminosity will fluctuate in ways that are only partly predictable. Cycles in the orbital geometry of the earth–sun system will proceed inexorably. Volcanism will be the primary cause of significant fluctuations in the transparency of the atmosphere to solar radiation. Over these phenomena man has no control.

The earth is currently about 10,000 years into an interglacial cycle. There is no valid reason to assume that the final ice age has been experienced on this planet. Were all other factors to remain constant, a return to more ice-age-like conditions would take thousands of years. However, earth's climate will probably be affected by man's activities much sooner, as it already has been. Can these activities speed or delay inevitable climatic changes or trigger events that otherwise would not have occurred? These are among the most critical questions being studied by climatologists today.

Before the industrial revolution, man's impact on the global climate was probably insignificant. Since the beginning of the nineteenth century, however, vast areas of the earth's surface have been modified. The forests of Europe and eastern North America have largely disappeared, and the grasslands of the central United States and Canada have been converted to crop production. Dams have been built and large lakes created. Swamps have been drained. Some semiarid areas have become deserts, and some deserts have been greened by irrigation. All of these changes have altered the surface reflectivity for solar radiation, water balance, temperature, and roughness of the earth's surfaces. Such alterations of surface conditions alter the climate of the affected areas and of areas downwind. Analyses are not yet available of the net, overall effects of these changes in land use on global climate, although techniques are being developed for evaluating their influence at the regional scale, and complex mathematical models of global climatic processes are now being used for this purpose.

Some changes in land use—the clearing of forests and plowing of grassland sod—have also caused large quantities of carbon dioxide and other gases to be released to the atmosphere. Drainage of swamps has probably reduced the quantities of methane emitted into the atmosphere, while the extension of rice paddy culture has likely had the opposite effect. Heavy use of nitrogen fertilizers is seen as a source of the increasing nitrous oxide content in the atmosphere. Other emittants created by industrial combustion processes and space heating have increased the content of ozone in the lower atmosphere. All of the trace gases—carbon dioxide, methane, nitrous oxide, and ozone—contribute to the greenhouse effect. One other category of gases—the Freons (chlorofluorocarbons)—also contribute to this effect and, in addition, increase the concentration of ozone in the troposphere.

The combustion of fossil fuel for power generation and space heating, the operation of nuclear reactors, and many industrial processes convert large quantities of energy into heat which is released directly into the environment. It has been suggested that by some time late in the twenty-first century heat released to the atmosphere by man's activities might equal 1 percent of the solar energy absorbed by the earth. Even today, however, all the energy consumed by humanity is less than one ten-thousandth of the solar energy absorbed by the earth.

Is climate really changing?

Temperature and precipitation are the parameters of weather that have been measured most widely and for which there are records of longest duration. Of these, the temperature records are the most likely to provide evidence of climatic trends or changes, since a thermometer represents a wider area than does a rain gauge. Precipitation is notoriously variable over short distances, especially in regions where much of the rain falls from scattered cumulus clouds.

Evidence of long-term trends in hemispheric and global mean temperature shows that a general worldwide warming trend has occurred over the past century. The data summarized in figure 1 (*Resources*, Winter 1987, p. 2) provide the strongest evidence yet assembled in support of this view. These data also show that the warmest three years on record have occurred in the 1980s. The global temperature trend is also repeated in records for the United States assembled by the National Climatic Data Center. These records show warming until 1940 followed by cooling until the early 1960s and a return to warming.

Reliable data for global trends in mean precipitation are more difficult to come by. A long-term drought in the Sahel, the region of Africa south of the Sahara, has persisted so long as to suggest that a true climatic change may be occurring there. An analysis of rainfall records for Africa, shown in figure 3, supports the contention of an unusually long run of dry years in the Sahel since the late 1960s and of wetter conditions from 1950 to the onset of the drought. Yet the recent drought is not unprecedented in its severity or duration, and it, too, may not yet be taken as evidence of a true climate change.

The preceding discussion relates to changes in the mean or average climate. However, evidence for a consistent global pattern of change in climatic variability is less clear. Theoretically, a global cooling, by increasing the temperature difference between the equator and the poles, should lead to increased circulation in the polar vortex. Principal pathways of cyclones shift southward with cooling and northward with global warming, and both cooling and warming tend to occur to a greater absolute extent in the polar regions than in the equatorial regions. Waves in the vortex are amplified and weather extremes become more frequent. As has been pointed out by climatologist V. Y. Sergin, more intense atmospheric circulation and shifting of the zone of highest wind intensity southward take place as the temperature gradients become larger (i.e., climatic cooling is occurring); changes in the opposite direction take place with warming.

Cool periods in history appear to be periods of enhanced instability of climate characterized by extremes such as droughts, floods, excessively hot summers, and excessively cold winters. Yet there is no clear evidence for an increase in temperature variability during recent decades and no clear linkage between global temperature and variability. Nor is there clear evidence of significant changes in the variability of precipitation throughout the world. A greater agricultural sensitivity to severe climatic anomalies such as interruptions in monsoonal rainfall in India and sub-Saharan Africa may be misinterpreted as indicating a changing variability in precipitation. A much finer network of rain gauges distributed worldwide and including coverage of the oceans will be needed before reliable statements can be made concerning changing variability in precipitation.

Agriculture—a sensitive indicator

Agriculture is the human enterprise most sensitive to change in general climatic conditions and in climatic variability. Increases in variability of annual yields of major U.S. grain crops since the early 1970s have been documented. Some attribute these trends to an increase in climatic variability, or, possibly, to a return after the early 1970s of a more normal degree of variability following an abnormally quiet period in the 1950s and 1960s.

However, other factors, including the genetic uniformity of seeds and increased mechanization, that permit nearly simultaneous planting of crops over wide regions seem more probable causes in that they increase vulnerability to the detrimental impacts of large-scale weather systems. Additionally, plant breeding and improved agronomy have probably reduced downside variability in cereal yield but may have increased upside swings. Since yields are far greater now than they were thirty or forty years ago, bad years can be expected to cause a wider absolute, but not relative, reduction in crop yields. The increasing variability in crop yields cannot be attributed wholly to increasing variability in climate.

In summary, a long-term trend toward higher temperature beginning about 100 years ago has been observed. While significant changes in rainfall may have occurred or may now be occurring in certain places in the world, there is no evidence that these changes are unprecedented and not part of the normal variation to be expected in regional climatic conditions. Had we a better record of precipitation throughout the world it might be possible to detect some clear trends. However, because of the spatial inadequacy in the distribution of weather and precipitation sensors, no clear-cut global patterns of changing precipitation can be discerned.

As for changing climatic variability, here too the record will not sustain a global generalization. For each region in which an increase in temperature variability has been identified, another with decreasing variability or no change can be found. The available evidence does not confirm the existence of any global trend toward either increasing or decreasing climatic variability.

A study by climatologist T. R. Karl concludes that ample evidence suggests that many areas in North America have had statistically and practically significant changes in mean temperature for certain months, seasons, and on an annual basis; but it is more difficult to show statistically significant change in the precipitation climate apparently because of the greater natural variation in precipitation over time and space. Furthermore, the lack of a demonstrated statistical significance in precipitation variability does not mean that these changes are less important than those in temperature—since in North America (and many other regions in the world) water may be of greater importance than temperature.

What's coming next?

What can climatology tell us about the coming decades? The climates of the past offer insights as to what might happen in the future. Additionally, mathematical models that permit realistic simulation of processes that occur in the atmosphere and in its interactions with land, ocean, and cryosphere (snow and land and sea ice) are now becoming available. Although not yet perfect, the Global Climatic Models (GCMs) are considered the best for predicting climate in the near future. A review of their findings is worthwhile.

GCMs have been used to predict the impact of a continued increase in atmospheric carbon dioxide concentrations. Results of a number of GCMs are in close agreement in predicting a change in global average surface temperature of 1.2° C to 1.3° C resulting from a doubling of carbon dioxide concentration if feedback processes (changing cloudiness and oceanic capture or release of heat) are not considered. When these feedback processes are considered, however, the models predict that there will be greenhouse warming of the global average surface air temperature of about 3.5° C to 4.2° C and an increase in the global average precipitation rate of about 7 to 11 percent. The models agree closely with respect to global average surface temperature but much less well in their projections of the regional patterns of such changes.

Equilibrium changes in surface air temperature are predicted to be greatest in the high latitudes near the snow and ice boundaries. Reductions in the extent of snow and ice, however, mean that the predicted zonal warming will be greatest in the winter half of the year and least in the summer half in the high latitudes.

The models also predict greatest changes in the distribution of precipitation in the belt between 30° N and 30° S. Increased precipitation is predicted in this zone, with decreases in the adjacent zones at least during parts of the year. A number of the GCMs predict that the grain belts of Northern Hemisphere continents will become drier especially in the spring and summer. The various models disagree more in their predictions of precipitation change than in their predictions of temperature change.

What do the next decades hold? Obviously there can be no unequivocal answer. There is a broad consensus among climatologists and other involved scientists that, if no unexpected changes in solar luminosity occur and if volcanoes are not extraordinarily active, the greenhouse effect caused by carbon dioxide and other radiatively active trace gases will become indisputably detectable in the next decades. The world will be a warmer place than we have known, and precipitation patterns will be different in most regions than they are today. Changing temperature and precipitation, in combination, will profoundly affect production agriculture, forestry, and water resources throughout the world. ■

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Inside RFF
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New risk center to address environmental concerns

Public concern about environmental threats to health and the difficult choices that arise in trying to regulate them are among the issues to be examined by a research center recently established at Resources for the Future.

The Center for Risk Management will carry out research and sponsor conferences and workshops to help improve public policies concerning environmental risks. Threats arising from toxic substances, hazardous wastes, pesticides, air and water pollutants, and stratospheric ozone depletion will be the focus of the Center's initial activities.

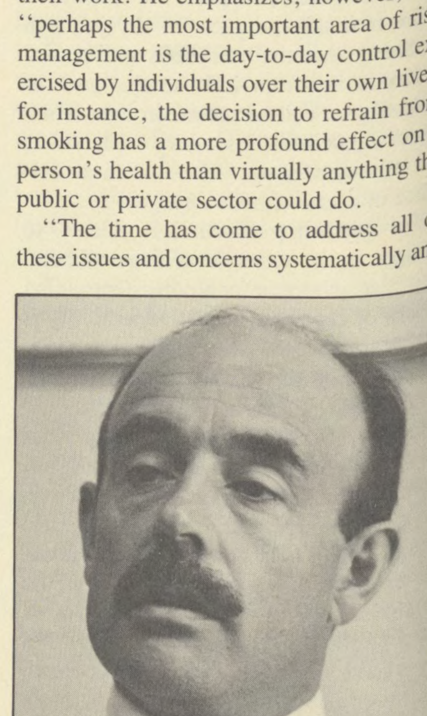
"The public is subjected to a constant stream of information—and misinformation—about all sorts of environmental threats to health," says Center director Paul R. Portney. "Because the issues are so complex, there is a real danger that people will either become overly alarmed or else completely ignore important information."

Portney leaves his post as head of RFF's Quality of the Environment Division to assume directorship of the new Center. He formerly served as the senior staff economist with the White House Council on Environmental Quality and was a visiting professor at the Graduate School of Public Policy at the University of California at Berkeley. He joined RFF in 1972.

In explaining the role of the Center, Portney points to the welter of conflicting issues and interests involved in matters of risk management. Business interests, for example, are particularly concerned about the costs of environmental regulations; they also are questioning whether these regulations are focused on the most serious problems. Consumers and policymakers alike are confused by the multiplicity of issues in this field. Moreover, he continues, some segments of society believe that they are bearing a disproportionate share of environmental risk while others argue that they are bearing the brunt of costs to mitigate these risks. In the meantime, more and more funds are being allocated to cope with existing regulations while new regulations are being considered.

Matters are further complicated because "environmental risks are currently 'managed' in a variety of ways," explains Portney. The Environmental Protection Agency issues regulations that implement federal legislation, but private corporations and state and local governments also make risk decisions in the course of carrying out their work. He emphasizes, however, that "perhaps the most important area of risk management is the day-to-day control exercised by individuals over their own lives: for instance, the decision to refrain from smoking has a more profound effect on a person's health than virtually anything the public or private sector could do.

"The time has come to address all of these issues and concerns systematically and



Paul R. Portney

objectively," says Portney. "The Center for Risk Management was established to play a central role in this process."

Balanced perspective

A broad range of skills and interests will be reflected at the Center. Resident staff and visiting scholars and practitioners will be selected for their expertise in areas such as engineering, law, biostatistics, business, communication, the life sciences, and the social sciences. In keeping with RFF tradition, the Center will also sponsor research at other nonprofit institutions and at universities.

Initial funding for the Center comes from a variety of sources, with approximately equal contributions from the Environmental Protection Agency, private corporations, and private foundations.

A small advisory council will provide guidance on operational and policy matters. Members of the council appointed to date are William D. Ruckelshaus, former administrator of the Environmental Protection Agency; Robert M. White, former administrator of the National Oceanic and Atmospheric Administration and currently president of the National Academy of Engineering; William K. Reilly, president of the World Wildlife Fund/Conservation Foundation; Howard Raiffa, professor of statistics and decision sciences at the Harvard School of Business; Richard D. Lamm, former governor of Colorado; Roger O. McClellan, president of the Inhalation Toxicology Research Institute and Lovelace Biomedical and Environmental Research Institute; and David M. Roderick, chairman of the board and chief executive officer of USX Corporation. Ruckelshaus and White are members of the RFF board of directors.

Center activities

Although research in risk management will be the mainstay of the Center's work during its first several years, it will also examine how risk information is communicated. "Ineffective communication about environmental problems and policies can be more detrimental than no communication," Portney points out. "Virtually all of the information the public receives is filtered through the lens of a TV camera or the screen of a reporter's word processor. It is important to study how this information is reported and how it is perceived."

The Center also plans to carry out studies on current risk assessment procedures and ensuing policy decisions, an area that Portney describes as particularly complex. Though scientific evidence forms the basis for risk assessments, this evidence must be weighed alongside legal, technological, economic, and ethical considerations before a strategy for action can be formulated. "By studying how risk is assessed as well as how it is managed and how information on the subject is communicated, we can offer a comprehensive perspective to a wide range of interested groups," Portney says.

Technical papers, books, and other informational material developed at the Center will be made available to legislative and executive policymakers, private and public interest groups, and lay audiences. A variety of events including press briefings, seminars, workshops, and conferences are envisioned.

Portney says the Center will work closely with other groups and individuals involved in similar work. Eventually it could function as a national focal point for activities on controlling environmental threats to health.

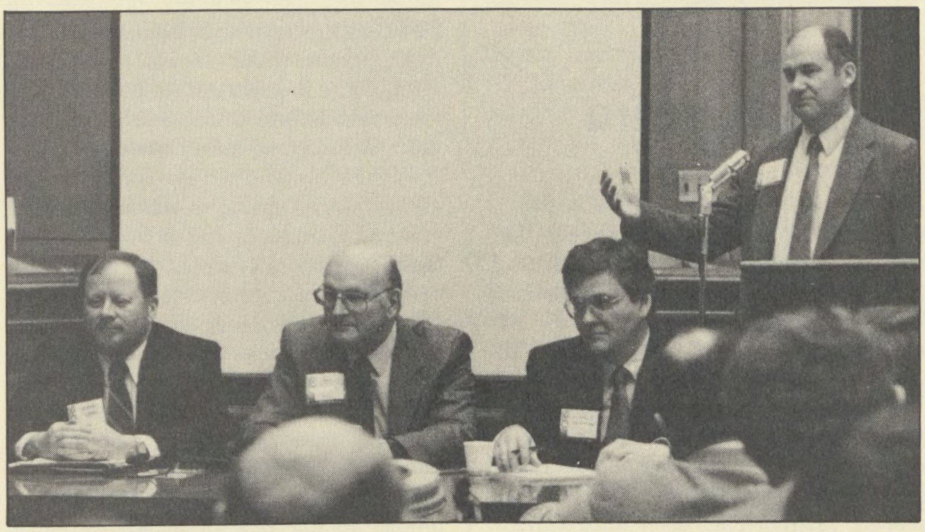
Rossmiller named NCFAP director

George E. Rossmiller has been appointed director of the National Center for Food and Agricultural Policy at Resources for the Future.

Rossmiller joined the Center in 1986 as senior fellow and was responsible for policy analysis and communication in areas related to domestic agricultural policy, macroeconomic policy, and international trade. Before joining RFF he was director of the Planning and Analysis Staff of the Foreign Agricultural Service, U.S. Department of Agriculture (USDA), from 1981. He was assistant administrator for international trade policy of the Foreign Agricultural Service at USDA from 1980 to 1981. From 1978 to 1979 he was agricultural attaché at the U.S. Mission to the Organisation for Economic Cooperation and Development in Paris, France.

Formerly associated with Michigan State University, in 1978 Rossmiller ended his service there as professor of agricultural economics and director of agricultural sector analysis and simulation projects. He received his Ph.D. in agricultural economics from Michigan State University in 1965.

Rossmiller replaces Kenneth R. Farrell, who was the first director of the Center. Farrell has become vice president of agriculture and natural resources at the University of California at Berkeley.



George E. Rossmiller (*second from left*), new director of the National Center for Food and Agricultural Policy (NCFAP) at RFF, participates in a discussion of proposals to revise the 1985 farm bill at a congressional briefing. Held in Washington, D.C., on February 20, 1987, the briefing was sponsored by NCFAP and by the Food and Agricultural Policy Research Institute (FAPRI) of the Universities of Missouri and Iowa State. Also pictured are (*left to right*): Barry Carr, Congressional Research Service; Stanley Johnson, FAPRI; and Rudolph G. Penner, former director of the Congressional Budget Office.

Kopp appointed division director

Senior fellow Raymond J. Kopp has been appointed director of the Quality of the Environment Division at RFF. He succeeds Paul R. Portney, who has become director of the recently established Center for Risk Management (see "New Risk Center," p. 14).

Kopp received his Ph.D. in economics from the State University of New York at Binghamton and specializes in applied microeconomics and econometrics. His recent research has focused on the social costs and benefits of environmental regulations. With the exception of the year he spent as visiting assistant professor at the University of North Carolina, Chapel Hill, Kopp has been with RFF since 1977.

Kneese receives award

Allen V. Kneese, senior fellow in RFF's Quality of the Environment Division, has received a Distinguished Service Award from the Association of Environmental and Resource Economists (AERE). It is one of the first two such awards given by AERE.

Recognizing Kneese's professional service and research contributions in the field of resource and environmental economics, the text of the award says, "He launched modern environmental economics with his own research as well as in his activities directing Resources for the Future's Environmental Quality Program." The citation goes on to say that Kneese's contributions "have influenced nearly all areas of environmental policymaking."

Congressional briefing focuses on energy and related issues

Public policy issues in the oil, coal, and nuclear power industries as well as related environmental dilemmas formed the basis for presentations at an RFF-sponsored congressional briefing held on February 6, 1987.

"We have selected topics which are likely to form a central part of energy discussions over the next several years," commented RFF President Robert W. Fri in his opening remarks to senior members of congressional and committee staffs. "As an organization which carries out research in a number of energy areas, we feel that we have something to contribute to these discussions."

Oil markets and energy security

The issue of oil market behavior as it relates to energy security was explored by Douglas R. Bohi, senior fellow at RFF. Bohi argued that the exact effects of energy price shocks on the domestic economy are not clearly understood. Doubts about their direct economic impact have been reinforced recently because, despite the drop in prices, there has not been an appreciable surge in GNP, nor has unemployment declined significantly.

Government efforts should focus on counteracting the forces of price instability rather than concentrating primarily on OPEC and its activities, Bohi argued. Because forces within the oil market are changing, it is important for policymakers to remain informed on these changes in order to formulate timely strategies.

RFF fellow Michael A. Toman looked at changed oil market conditions as they relate to energy security policy. He contended that policy should be more concerned with reducing the costs of potential oil price jumps on the overall economy than with the costs of dependence on foreign oil.

The U.S. Strategic Petroleum Reserve should continue to be filled at a substantial rate, said Toman, and policies should be directed toward flexible use. Current conditions do not call for a tariff or other restrictions on oil imports. At most, some targeted restrictions—for example, a rise in the gasoline tax—may be advisable. Measures like expanded leasing of federal lands add little to energy security, he said.

International cooperation is essential to energy security, especially since the best U.S. policies could be negated by conflicting responses on the part of other oil-importing countries. To achieve such cooperation requires scrapping most of the crisis-management program of the International Energy Agency, Toman said, and putting in its place an effective program of stock use *and* demand restraints that can clearly moderate market disturbances.

Environmental issues

North American acid rain problems and policy issues were the focus of a presentation by RFF fellow Winston Harrington. Acid rain has been blamed for extensive damage to freshwater lakes and, more recently, forests, Harrington said. Forest damage is less widespread in the United States than in other parts of the world, but it is definitely occurring in selected high elevations in the eastern United States.

The relationship between emissions of nitrogen dioxide and sulfur dioxide and the occurrence of acid rain is not completely understood, he said. Studies have shown that while emission of these pollutants in North America increased only 20 percent in the last two decades, the acidity of rainfall has more than doubled.

Lack of scientific consensus on the role of acid rain in lake and forest damage, as well as uncertainty over the appropriate means for reducing rainfall acidity, has contributed to the current lack of clear public policy on the issue, said Harrington. The conventional view of blaming acid rain primarily on sulfur dioxide emissions is still prevalent in policy debates, even though the problem is now known by scientists to be much more complex.

Pierre R. Crosson, senior fellow at RFF, discussed ozone depletion and climate change and brought a global perspective to the issue of how emissions affect the atmosphere. Experts now generally agree that no significant reduction in the total ozone layer will occur over the next few decades if present emissions continue at present rates, noted Crosson. However, this consensus is fragile because the processes of ozone formation and depletion still are not completely understood.

There is a more robust consensus that global warming will occur, and the first clear signs may be visible in a decade or so. As Crosson explained, this consensus is based on evidence that emissions of methane and other trace gases besides carbon dioxide tend to trap heat at the earth's surface and produce a greenhouse effect. Though expectations of a rise in global average temperature are widely held, atmospheric scientists still are unable to agree on the implications of this temperature increase for regional climates—which presents a serious obstacle to formulating policies for dealing with climate change.

Policy thinking to date has had two major thrusts, Crosson pointed out. In the United States, the major emphasis has been on steps that should be taken to limit the emission of offending gases to the atmosphere. This approach runs into major problems because it depends on securing international agreements, which may be difficult to obtain due to different national interests and perceptions of the problem.

Considering these difficulties, he said, serious attention should be given to the second policy thrust—adapting to the changes that will occur. By reducing scientific uncertainties, research in both the natural and social sciences can play an important role in clarifying the problems and options that policies must consider. Research will not eliminate international differences about how to respond to global climate change, but it can help, said Crosson.

Coal industry trends

RFF senior fellow emeritus Hans H. Landsberg examined U.S. coal industry trends, problems, and policy issues. He called attention to the steady growth in coal's relative contribution to the nation's energy supply. This increase has been achieved largely as a result of greater coal production west of the Mississippi, consisting primarily of surface mining which has a high productivity.

On the other hand, Landsberg said, progress in converting to coal from other sources of fuel in existing facilities has been much slower than anticipated in the 1970s, and the choice of coal in new industrial facilities has been equally limited. The only area in which coal use has steadily forged ahead is the electric utility sector, where oil has been progressively eliminated.

Altogether, utilities now account for 85 percent of domestic coal consumption. Falling oil prices, however, constitute a threat to coal's position, since the price differential between residual oil and coal has dramatically narrowed. Coal policy issues are highly political and must be viewed as a national issue aside from energy supply and demand considerations.

Philip H. Abelson, RFF scholar-in-residence, described technological progress in the use of coal. He said clean use of coal for many purposes is being demonstrated through technologies such as combustion in fluidized beds, gasification, and the use of synthetic gases in combined-cycle turbines. These successes have been supplemented by new developments designed to provide clean fuel for transportation.

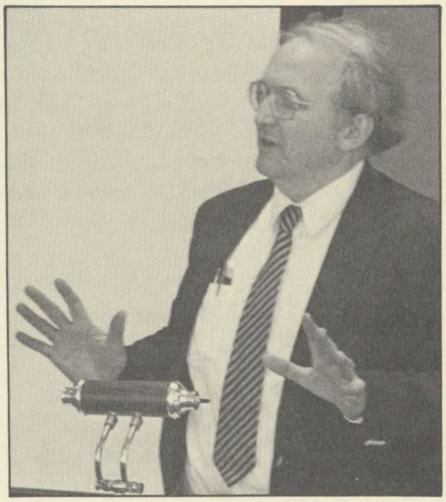
Ultimately, Abelson argued, most gasoline and diesel oil will have to be obtained from coal. Efforts to increase the scope of activities in this and other areas are needed in order to avoid excessive dependence on imported oil.

Nuclear power and wastes

RFF vice president and senior fellow John F. Ahearne looked at problems within the U.S. nuclear industry, including traditionally high costs, less-than-adequate concern about management and operational practices, continued low demand for electricity, and negative public attitudes.

Legislative action to standardize the industry might admittedly offer benefits such as lower construction costs, easier inspection and review procedures, better-trained operators, and, theoretically, greater potential for improved design. However, he pointed out, details such as reaching agreement on which design should be used as the standard could well pose major stumbling blocks.

Other potential measures such as licensing and decisions about Price-Anderson legislation (which establishes a damage compensation fund) require careful study before proposals are put forward, Ahearne said. He endorsed legislation that would reorganize the Nuclear Regulatory Commission to make it a single-administrator agency. Emergency planning should include state and local officials as well as utility officials and the federal government, he added.



RFF Vice President John F. Ahearne discusses problems within the U.S. nuclear industry at a recent congressional briefing on energy and related issues.

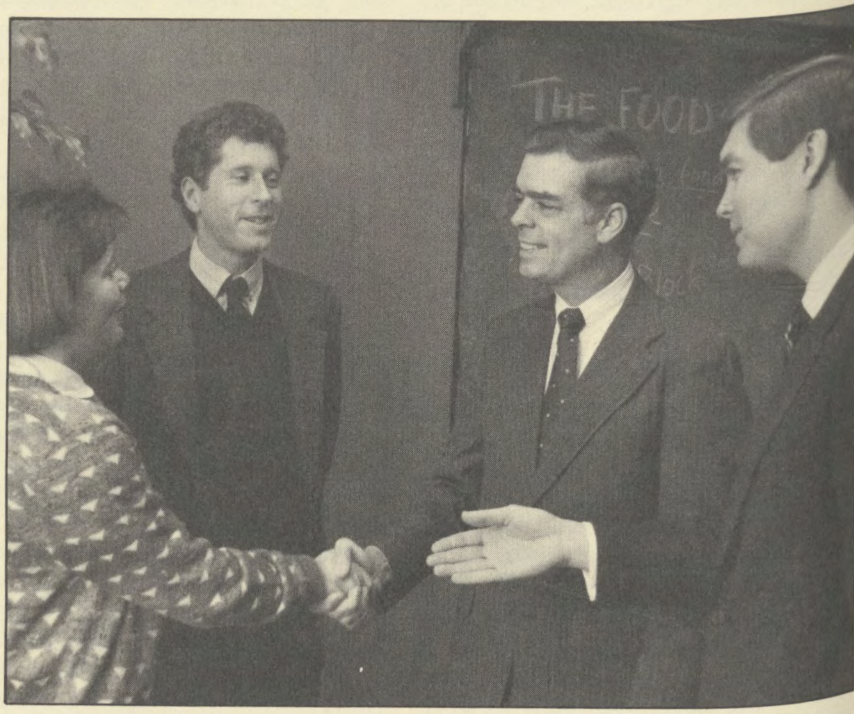
Science writer Luther J. Carter wound up the briefing with a discussion of issues surrounding the siting of a high-level waste repository.

Carter said that current siting policies suffer from several major flaws. First, sites that present major land use and environmental conflicts are not excluded. Second, the site screening process is proving to be an "impossibly difficult procedural and political marathon." Finally, without a promise of major rewards, host state officials will find neither the incentive nor the political room to cooperate.

According to Carter, an effective strategy for repository siting would include designation by Congress of a single primary candidate site that is technically promising and relatively free of conflicts; more emphasis on artificial barriers as part of the overall repository containment system to compensate for uncertainty with respect to geologic barriers; substantial rewards for the host state; and more open and extensive technical peer review, with host state participation.

If the United States solves its waste isolation problem, its success should encourage progress in other countries toward national and international solutions to their own waste problems, said Carter.

Former Secretary of Agriculture featured at Leadership Development event



John R. Block (*second from right*), former U.S. Secretary of Agriculture and president of the National American Wholesale Grocers' Association, discusses food policy issues at a recent 1987 Leadership Development Program seminar. With him are (*left to right*) leadership fellows Nancy C. Muller from the Prudential Insurance Company of America and David T. Kaplan from the U.S. Agricultural Research Service and program director John J. Kornacki.

The Leadership Development Program is sponsored by the National Center for Food and Agricultural Policy at Resources for the Future. Sixteen fellows selected from applicants nationwide convene in Washington, D.C., for four weeks to participate in food and farm policy seminars, workshops, briefings, and special events. They meet with senior policy leaders and analysts in the public and private sectors, including staff members of congressional committees, officials from the World Bank and the Office of the U.S. Trade Representative, and foreign attachés. Fellows prepare reports on policy issues especially relevant to their work.

Discussion papers

RFF discussion papers are available at modest cost to interested members of the research and policy communities. The papers convey the early results of research for the purpose of comment and evaluation. Prices include postage and handling. The following discussion papers have recently been released:

Quality of the Environment Division

- "Establishment-Level Data for Econometric, Engineering, and Policy Analysis: Phase 1," *by Michael Hazilla and Raymond J. Kopp*. QE87-03 ($2.25)
- "Air Pollution and Acute Health Effects: New Evidence," *by Alan J. Krupnick, Winston Harrington, and Bart Ostro*. QE87-04 ($2.25)
- "Benefit Estimation and Environmental Policy: Setting the NAAQS for Photochemical Oxidants," *by Alan J. Krupnick,* QE87-05 ($2.25)
- "Evaluating the Validity of Contingent Valuation Studies," *by Robert Cameron Mitchell and Richard T. Carson*. QE87-06 ($2.25)

Renewable Resources Division

- "Agricultural Trade Model Comparison: A Look at Agricultural Markets in the Year 2000 With and Without Trade Liberalization," *by Rachel Nugent Sarko*. RR87-01 ($5.00)
- "Measuring the Components of Aggregate Productivity Growth in U.S. Agriculture," *by Susan M. Capalbo*. RR87-02 ($3.00)

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RFF reprints present work that RFF staff members have contributed to journals, books, and other publications produced elsewhere. Selected among other criteria for their quality and the limited circulation of the original publication, they are offered at no charge for single copies, at fifty cents for each additional copy. The following reprint has recently been released:

Reprint 230. *Property Rights, Protest, and the Siting of Hazardous Waste Facilities*, by Robert Cameron Mitchell and Richard T. Carson.

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RFF is seeking copies of a few of its early publications for its archives. Items of which it is especially in need are:

Books

Statistics on Outdoor Recreation, Marion Clawson, 1958, 165 pp., paper

Three Water Balance Maps of Eastern North America, C. W. Thornthwaite, John B. Mather, and Douglas B. Carter, 1958, 56 pp., paper

Exploration for Nonferrous Metals: An Economic Analysis, Lee E. Preston, 1960, 212 pp., paper

Historical Statistics of Minerals in the United States, Sam H. Schurr, 1960, 48 pp., paper

Sequence and Timing in River Basin Development, John V. Krutilla, 1960, 40 pp., paper

A National Program of Research in Housing and Urban Development: The Major Requirements and a Suggested Approach, Harvey S. Perloff, ed., 1961, 40 pp., paper

Three Studies in Mineral Economics, Orris C. Herfindahl, 1961, 64 pp., paper

Land Economics Research, Joseph Ackerman, Marion Clawson, and Marshall Harris, eds., 1962, 296 pp., paper

Power and Decision Making in Megalopolis, with Special Reference to Environmental Quality Problems, Delbert C. Miller, James L. Barfoot, Jr., and Paul D. Planchon, 1970, 87 pp., paper

Annual Report

Annual Report, 1953

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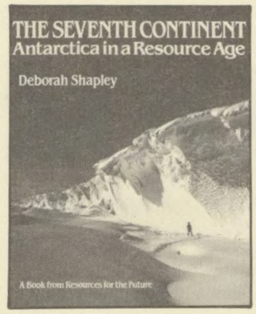

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