9 The Power and Limitations of Science and Technology

If we are going to live so intimately with these chemicals—eating and drinking them and taking them into the very marrow of our bones—we had better know something about their nature and their power.
—Rachel Carson

Science can only give us tools in a box. But of what value are these miraculous tools until we have mastered their cultural and human use?
—Frank Lloyd Wright

Lasers Light Up the Groundwater

In 1984 the housing developments of Henderson, Nevada, just south of Las Vegas were slowly but surely spreading into the vast desert that only a few years earlier had been considered uninhabitable. Green lawns which were sprinkled every day by water from nearby Lake Mead belied the notion that these rock-hard barren areas could not be conquered. Thus, a trip to the "desert" to witness high technology in action took a group of us from the EPA only a few dozen yards from a new row of homes surrounded with cars, pickup trucks, and children's bicycles.

The desert site was less than two miles from the large chemical complex in Henderson which traced its origins to the need for munitions and other industrial supplies to support a wartime economy during the

1940s. Soon thereafter the industrial plants began experiencing the pains of obsolescence. Nevertheless, in 1984 the antiquated facilities continued to provide much of the employment base of the local economy.

Of particular interest, benzene and a variety of other chemicals leaking from large storage containers at the complex had reached the aquifer below us. The residents of the new homes were somewhat concerned about this invasion of the territory underlying their property. However, they had accepted the assurances of the local health authorities that gradual contamination of the aquifer posed no near-term threat.

After rationalizing the situation facing these residents as an inevitable consequence of economic prosperity, my EPA colleagues and I turned to the task at hand. This polluted aquifer which was less than 30 feet below the surface provided a very convenient experimental area for testing the capabilities of new monitoring technology in detecting groundwater contaminants and in measuring levels of contamination.

The visit began with a tour of a large mobile laboratory parked at the edge of the desert. Inside was a dazzling array of laser generators and optical analyzers. A laser light at an appropriate frequency was beamed through a thin tubular fiber encased in a telephone cable. This cable had been inserted into a hole drilled through the desert ground and into the aquifer. The length of such cables can be 30 feet or 3000 feet long since the laser light does not degrade with distance.

The laser beam "sensed" the reactions between chemicals dissolved in the groundwater and a small chemically coated device at the end of the cable called an optrode. The reactions caused a fluorescence or glow of reflected light with the characteristics of the fluorescence dependent on the specific chemical interactions. This reflected light then traveled back up the fiber in the cable. When analyzed in the trailer, the light revealed the presence of polluting chemicals. The light from the returning fluoresced signal was easily separated from the original excitation light sent down the same fiber since it had a shorter wavelength. The key was the optrode which was designed to react with specific chemical pollutants. Different optrodes were used depending on the chemicals likely to be present in the groundwater.

At the time, fiber cables were beginning to take hold as the backbone of the nation's telephone system, and laser-transmission technology had been demonstrated many times over. Fluorosensing of chemicals had also been explored in many facilities, and the determination of chemical signatures from reflected laser signals was an established procedure in military laboratories investigating ways to combat chemical warfare. Still, in the environmental field chemical analysis in well-established laboratories had become the accepted approach for determining pollution levels. The concept of measuring pollutants using reflected light met with considerable skepticism from scientists who were comfortable with the tried-and-true methods of classical chemistry.

The scientists conducting the fiber-optic experiments were from the Lawrence Livermore National Laboratory in California which is best known for its capability to design and test nuclear weapons. They were very excited that they could use technology originally developed for analyzing the results of weapons tests to assess groundwater contamination problems. They beamed with pride as the signals came into the mobile laboratory as expected. They as well as the EPA specialists who were present were very pleased that these measurements were consistent with previous measurements made by the EPA in the same monitoring wells using the traditional method of removing water samples and sending them to a chemical laboratory for analysis.

At the same time, the scientists from California acknowledged the high costs of the experiments which seemed prohibitive in comparison with simply dropping a sampling device down the hole to grab a water sample. While the highly funded nuclear testing programs carried out at the Livermore Laboratory could easily support mobile laboratories that cost hundreds of thousands of dollars, the EPA needed technologies that could be used by tens of thousands of small towns with small budgets and by financially constrained laboratories throughout the country.

Was this just the beginning of a scientific breakthrough in exploring subsurface pollution? The Livermore scientists noted that traditional sampling was plagued with problems. Large holes were needed for the conventional sampling devices. Traditional sampling disturbed the water, and volatile chemical pollutants could escape into the air before the samples reached the surface. Sampling gear became easily contaminated as it was lowered and raised in monitoring wells. The delays in waiting for laboratory results for days or weeks were often very inconvenient.

Fiber-optic technology could avoid all of these problems, according to the scientists. The telephone cable could be inserted into a very small hole and left in place for many months. Measurements could be made instantaneously. Costs would surely fall as the technology became widespread.

Within 12 months, the potential of this technology began to emerge. The scientists from the Livermore Laboratory met me in San Francisco in early 1985 where they briefed the EPA Regional Administrator on the progress of the experiments. They brought along 35-millimeter slides which showed their field operations, but they left the mobile laboratory at home. Instead, they arrived in San Francisco with their new "laboratory." All of their equipment had been miniaturized, and a small suitcase now replaced the mobile van. A light bulb and filters had been substituted for the laser generator, and highly compact electronic devices were used for the analyses. The equipment was battery powered. The cost of the suitcase was $2500, but it was one of a kind. Mass production certainly would reduce the cost further.

In the years that followed, this environmental application of fiber-optic technology has continued to develop, and its application remains of great interest to many environmental agencies. However, as with any new technology, considerable time is needed to refine both the equipment and the procedures for using the new devices. The accuracy and reliability of the equipment must be demonstrated many times in the field so that the data it obtains will stand up to close scrutiny, even under rigorous cross-examination in courtroom settings. In some applications such as repetitive screening for leakages around underground storage tanks for a few well-known chemicals, the value of this technology seems obvious. However, in other situations such as providing definitive evidence on the presence of all possible chemicals in groundwater near a chemical waste site, detailed laboratory analyses of water samples will retain their importance.

Fiber-optic technology is just one example of the many new technologies that can reduce the costs and improve the timeliness of assessments of subsurface environmental contamination. Now let us turn to an example of an older technology with great potential for assessing environmental problems on the surface of the Earth and in the atmosphere.

Finding Pollutants from Airplanes and Satellites

For more than a dozen years aerial photographs have been very important in the national effort to search out abandoned waste sites and poorly managed sites and then to assess the environmental damage near those sites. Photographs provide concrete evidence of irresponsible behavior by chemical dumpers and by operators of waste disposal sites who try to avoid disposal regulations. Such photography is usually obtained from low-flying aircraft although high-altitude photography and even satellite photography have also been very helpful in assessing the destructive impacts of man's chemical litter.

During the 1980s other types of remote sensing technology from aircraft played an important role in our environmental assessment programs. For air pollution, laser systems called "lidars" have been extensively deployed in aircraft, especially over southern California, to study pollution plumes of particulate matter. They complement ground-based air-monitoring instruments which are not able to provide rapid measurements over very large areas. Airborne measurements are critical to understanding the long-range transport of air pollutants. They can reveal the structure of urban haze as well as more definable plumes. They are helpful in linking traces of particulates and other air pollutants with specific pollutant sources. Also, the measurements can be used in mathematical models of problems plaguing large metropolitan areas.

Extensive research efforts have also concentrated on providing airborne laser systems which not only track particulate air plumes but in addition can detect the presence of invisible polluting gases, particularly ozone and sulfur dioxide. Measuring the presence of such gases will help improve our understanding of the extent and causes of pollution problems which are often independent of the problems caused by aerosols of particulates. However, the technical difficulties are formidable. Even though the volumes of pollutant gases which are discharged into the atmosphere can be very large, the gases disperse rapidly. At any given time the concentrations at a specific location are small and difficult to detect. Also, many different gases are of interest to scientists, but a laser sensor is usually tuned to detect only one or two different types of chemical molecules at a time. Perhaps in the future they will be able to detect larger numbers of pollutants simultaneously. Nevertheless, this technology already offers important capabilities.

As we turn to water pollution, we see that laser systems have again proved their worth. Airborne sensors can detect elevated or depressed levels of chlorophyll *a* which is associated with growth of algae in lakes and rivers. Many algal profiles of water boundaries have been determined using these systems. High levels of algae cause foul-smelling water and generally unpleasant aquatic conditions while abnormally low populations of algae may indicate the invasion of substances which are toxic to algal growth and possibly to humans as well. Also, as previously noted, algae can be an indicator of the presence of nutrients needed to sustain fishery resources.

Airborne laser systems also measure the presence of dissolved organic carbon in surface waters which is frequently linked with either man-made or natural polluting substances. Although such substances are seldom highly toxic in low concentrations, they often act as carriers for toxic pollutants. Dissolved organic carbon in raw sources of drinking water raises special concerns since during the chlorination process traces of organic compounds might be converted into carcinogenic chemicals.

Overshadowing laser systems for investigating pollution on the ground or in aquatic systems, however, has been the rapid spread of multispectral sensing technology. This technique discerns abnormalities on the surface of the Earth by measuring reflections of the sun's light in different wave bands. Two decades ago, the U.S. space program dramatically demonstrated this technology. Since that time, both satellite and aircraft multispectral sensing have become popular components of environmental programs. For example, the EPA has used systems mounted in aircraft to determine the biological conditions of Flathead River, Montana; to assess the influences of warm and cold springs in Mono Lake, California; to analyze septic system failures in Windemere, Minnesota; to locate underground coal mine fires in Monarch, Wyoming; and to classify vegetation in Big Bend National Park, Texas. The EPA and other organizations have used satellite systems to trace ocean currents, to delineate ecological destruction from shoreline erosion, to identify areas of forest blight, and to reveal downstream impacts of runoff of toxic metals from mining areas.

However, in 1984 scientists at the EPA's Las Vegas laboratory found resistance in trying to introduce this modern technology into an environmental program which had already been conceived along traditional lines. The EPA headquarters in Washington had called upon the laboratory to direct the sampling of a large number of lakes, using helicopters and mobile laboratories, in areas of the Midwest, New England, and the Southeast which were believed to be particularly vulnerable to acid rain. The Agency's primary interest was finding out the extent of the acidity of the lakes. Measurements of other chemical properties of the lakes in addition to acidity would contribute to understanding *why* the lakes had or had not become acidic.

About 200,000 lakes are located in these vulnerable regions. The EPA selected 2000 as a reasonable number for sampling within the cost constraint of about $15 million for the program. For sampling purposes, the statisticians classified the lakes according to their geographical locations, their altitudes, and their sizes. However, laboratory scientists were concerned whether such a small sample would truly be representative of all the lakes since in many ways each lake is unique. Statistical extrapolations from 2000 to 200,000 lakes would be uncertain at best.

Therefore, the laboratory proposed as a complement to the planned sampling of 2000 lakes the use of multispectral sensing data that could be obtained from satellites which were already in orbit. This information would permit examination of the conditions of many more lakes where the helicopters would not land. For those lakes where the helicopters would land, correlations of monitoring data from the classical chemical measurements and from multispectral sensing would enable scientists to "calibrate" the sensor data. They could then infer from the satellite imagery some of the conditions of the lakes which were beyond the range of the helicopters.

Unfortunately, many skeptics within the EPA were not prepared to support this approach even on a limited experimental basis. They argued that there were no ways to measure the acidity of the lakes directly from sensor data since the proven sensor "signatures" of lake conditions (e.g., turbidity, clarity, algae) are not directly related to acidity. However, tests under other programs had shown a high statistical correlation (80%) between the actual acidity and inferences of acidity from analyzing combinations of other less certain signatures that could be measured directly from satellites. Also, the laboratory argued, the multispectral analyses were not intended to displace the conventional statistical extrapolations from the direct water sampling. Rather, they would help determine the uncertainties in the extrapolations from the acidity conditions in the sampled to the conditions in the unsampled lakes.

Finally, the most persuasive argument, so we thought, was that the sensing and analyses were relatively cheap (a few hundred thousand dollars) since the satellites were already in orbit. Also, the program would provide the EPA with invaluable experience for future investigations of lake conditions as this technology continued to advance. Nevertheless, the EPA simply was not ready to enter the modern age of remote sensing, and the Agency did not agree to provide funds for the use of multispectral scanning. The assessments were to rely only on the direct sampling of the 2000 lakes. Since that time, fortunately, many organizations including the EPA have finally embraced this type of satellite sensing as an important tool in assessing the conditions of lakes.

Indeed, during the past several years global remote sensing systems have been heralded throughout the world as the backbone of the international effort to assess the environmental state of the planet, including impacts of acid rain. Every international plan for protecting the global ecology calls for expanded systems of satellites and aircraft to assess regularly the state of the stratosphere, the atmosphere, and land and water surfaces. The presence of greenhouse gases, the condition of the ozone layer, and the denudation of forest resources are of special concern. Scientific studies of air–sea interactions as measured by satellite systems are also improving our understanding of the capacity of the oceans to absorb carbon dioxide.

The list of potential environmental applications of remote sensing systems is very long. Some applications such as photographs of waste sites relate directly to assessing the impact of chemicals on ecological resources. Other applications such as measuring changes in vegetation and land use can provide indirect indications of the effects of chemicals on the ecology. In numerous ways, remote sensing not only saves time and money, as compared to other data collection techniques, but it also provides data that cannot be collected in any other manner.

The Achilles' heel of remote sensing has always been the limited capabilities for fully using the collected data. More powerful and more friendly computers are a critical part of the answer. Unfortunately, only a small portion of the potential users of ecological information are computer literate, and in many developing nations which are vitally interested in environmental conditions of the planet, computer skills are at a particularly low level. A program to promote remote sensing skills needs to be undertaken without delay at home and abroad. Also, there is no better topic than global ecological change as a focal point for advancing general computer literacy.

Technology and the Greenhouse Gases

While scientists seek improved capabilities to assess environmental problems, engineers are looking for approaches that will reduce the amount of man-made chemicals reaching the environment. As previously discussed, the by-products of fossil fuel combustion, which are major contributors to the greenhouse effect, pose a particular type of hazard.

A large number of technological approaches to reducing the adverse impacts of energy systems on the environment, and particularly curtailing the emissions of greenhouse gases, are in various stages of development and use. Some of these technologies can provide new opportunities for conservation practices by the consumers of energy and thereby reduce energy demand. Others can stimulate the introduction of substitute manufacturing processes or products with reduced requirements for energy. Developing improved efficiencies in the generation and distribution of electricity is also an important technical objective for conserving energy. Fuel switching to increase reliance on less-polluting energy sources depends on technological successes in developing cheaper and reliable alternatives. Finally, new techniques can be used to improve pollution control systems within energy-producing plants. A few of these technological opportunities are discussed below.

Conservation Practices by the Users of Energy. Many techniques are available for designing thermally efficient residential and commercial buildings. They begin with the basic architecture of the buildings. Also, new types of construction and insulating materials, improved window designs and air circulation systems, and even "smart houses" with electronically controlled heating and lighting systems are becoming more important. Very minor engineering modifications of existing heating systems can often improve energy efficiency both in building complexes with central heating and in structures which have their own heating systems. Finally, the energy savings associated with the advent of the heat pump as a heating and cooling device in many homes and commercial buildings have stimulated keen interest in recent years.

Similarly within industrial settings, improvements in energy efficiency depend on a variety of approaches, and frequently relatively minor engineering adjustments of the current manufacturing processes can have significant payoff. Adjusting operating procedures to take advantage of lower-cost electricity during off-peak hours sometimes makes good business sense while saving energy for the geographical area. Some industrial processes, such as metallurgy, are highly energy intensive. Even small-percentage energy savings through more careful control of the temperatures and timing of the manufacturing processes can meaningfully contribute to less pollution.

Improved Efficiency in Electricity Generation and Distribution. Fluidized-bed combustion and integrated gasification–combined-cycle technologies have been shown to provide great advantages in capturing heat that would be otherwise lost from coal-fired power plants. With fluidized-bed combustion, large fans keep powdered coal suspended in midair so it burns cleaner with less energy lost. In integrated gasification plants, coal is turned into a gas, removing sulfur in the process. The gas is then used to run two turbines, one powered by the hot combustion gases and the other by steam.

In recent years natural gas technology has developed rapidly. Combined-cycle systems are analogous to coal gasification systems, relying on both a natural gas-fueled combustion turbine and a heat recovery steam generator and steam turbine. Also, gas can be used in combination with coal: gas–coal co-firing involves the introduction of natural gas into the primary furnace combustion zone of a pulverized coal boiler. This process has the benefit of reducing emissions of nitrous oxides and sulfur dioxide while improving overall system efficiency.

Let us turn to hydropower. While environmental objections frequently thwart the building of new dams, adding and refurbishing turbines at existing sites can often increase output and efficiency at relatively low costs.

Related to improved electrical efficiency is the rapid spread of "co-generation" systems. These systems are built around power plants which generate electricity. While electricity is being generated, either the very hot water or the steam which is produced during the electrical generation cycle is sent through pipes into local residential areas or even into large metropolitan districts as the basis of their heating systems. In some experimental systems, heated natural gas is used both in the power plants and in the heating systems.

Fuel Switching. During combustion, natural gas emits 30% less carbon dioxide than does petroleum and 50% less than coal for equivalent energy production. Therefore, natural gas offers a very attractive near-term fuel alternative in those parts of the world where gas is no more expensive than oil or coal. In some areas where distribution systems are in place, greater reliance on natural gas can take place quickly. In others, the capital costs of distribution systems will undoubtedly inhibit the introduction of new natural gas power plants. In the long run, limitations on the amounts of natural gas which are available will force the use of much of the gas for activities of higher value than electrical generation. For example, natural gas is an important raw material for production of industrial chemicals. Thus, the use of gas for generating electricity will be increasingly confined to localized areas with large supplies.

With regard to renewable sources other than hydropower—such as solar, wind, biomass, and geothermal—the uncertain economics, the need to demonstrate the capability of plants to operate reliably for 25 to 30 years, and limitations on appropriate geographic locations for these technologies will likely constrain their use in the next 50 years. Of course, biomass plants such as those relying on manure in California and on wood chips, tree trimmings, and construction materials on Staten Island should be encouraged even though they will not be large energy contributors. Further research on the use of methanol and other alternate fuels for motor vehicles is important even though the energy content of one gallon of these substitutes is much less than the energy content of one gallon of gasoline. The blending of alternate fuels and gasoline is a particularly attractive approach. Also of special interest is the steady and significant progress in photovaltaic technologies, both in efficiency and in cost. All of these technologies can become minor but nevertheless important contributors to the energy mix during the next century.

Finally, as we have seen, nuclear fission has the potential of being a major energy contributor in the decades ahead. Current designs of inherently safe reactors which shut down in emergency situations through the laws of physics rather than through reliance on human intervention are gaining increasing support from governments and the public. Meanwhile, improvement of maintenance and operating procedures for the current generation of nuclear reactors is urgently needed around the world to prevent accidents that could further jeopardize the future of nuclear power.

Improved Environmental Control of Energy By-products. Several types of pollution-reduction devices have been installed in power plants for many years, and others are under development. Catalytic devices route waste gases through chemical compounds which convert some pollutants to less harmful substances. Many plants have demonstrated that emissions of nitrous oxides, for example, can be reduced by 80–90%. Wet lime or spray dry flue gases can be effective for desulfurization of wastes from coal. Still, additional research is needed to develop even more effective controls for emissions of carbon dioxide.

With regard to mobile sources, most of us are familiar with removal of nitrous oxides emitted by motor vehicles using catalytic technology. In California, as noted, attention is now directed to warning devices which alert the driver when the catalytic controls are not working properly. Meanwhile, the tightening of emission standards is forcing further refinement of catalytic converters not only in the United States but also in many other countries.

Less Energy-Intensive Products. Fuel efficiency of motor vehicles has been a long-standing concern in the United States and other countries. Steady progress is being made to reduce energy requirements of the vehicle fleet. Lighter-weight materials which do not sacrifice safety and improved combustion systems continue to be key aspects of this effort.

A second example of large potential energy savings is the current effort in many countries to reduce their reliance on agricultural pesticides and fertilizers that require high usage of energy during their production. Not only is the consumption of fuels high, but production processes require relatively clean fuels (e.g., petroleum and gas). These fuels are then not available for other uses. Biotechnology and improved tilling practices, which are discussed below, are among the rapidly advancing techniques which hold promise for reducing the need for agricultural chemicals and the attendant drain on relatively clean energy sources.

Farmers Seek Environmental Acceptance

Continuing with the agricultural theme, the Texas Commissioner of Agriculture recently gave the following gloomy assessment of the state of American agriculture:

> In recent years, we've begun to run up an agricultural deficit. Skyrocketing production costs have outstripped farm income. Once thriving farm families sometimes cannot put enough food on the table for their own needs. Increasing concentration in food production and processing operations is reducing the options available to consumers, raising prices, and threatening food safety. Our topsoil is being lost at rates comparable to those of the Dust Bowl of the 1930s: parts of Iowa are losing two bushels of soil for every bushel of corn produced. Our water supplies are becoming contaminated with pesticides, and public health officials are issuing new warnings on the risks of exposure to pesticides for agricultural workers. All the while, pests are growing more resistant to our poisons.
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> The great decline in American family agriculture is the direct result of a system that benefits the corporate farm at the expense of the family farm; that too often stresses cultivation of a single crop to the detriment of diversified agriculture; that is geared for high volume, low price exporters and megacorporate processors rather than for actual demand and local processing; that breeds dependence on expensive synthetic chemicals rather than the replenishment of natural resources.
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> It is the result of a system that locks farmers into debilitating pesticide and fertilizer cycles that deplete the real value of American farms. The land itself becomes addicted to chemical fertilizer, becoming less productive and losing its value. Farmers find themselves spending more in order to put more chemicals into the land each year while getting ever-diminishing returns.[1]

Echoing these concerns, a 1989 report of the National Academy of Sciences concluded that "alternative agriculture systems are economically feasible but are discouraged under federal commodity programs which have a very short-term focus. Alternative systems can sustain production more effectively over the long term. They can minimize harmful environmental side effects that adversely affect people and ecosystems off the farm. Alternative agriculture does not reject conventional practices but more deliberately takes advantage of naturally occurring beneficial relationships—relationships between pests and predators and between nitrogen cycles and plant growth. "Successful alternative farmers do what all good managers do—they apply management skills and information to reduce costs, improve efficiency, and maintain production levels," stresses the Academy report.[2]

According to the National Academy of Sciences, federal agricultural policies work at cross-purposes to the nation's environmental policies and discourage environmentally compatible farming systems which could, for example, rely more heavily on crop rotations and soil conservation while reducing applications of pesticides and fertilizers. The report concluded that even in the absence of federal support, alternative agriculture can be productive and profitable. There are many well-managed alternative farms which use fewer agricultural chemicals—practices that do not decrease but in many cases increase per-acre crop yield and productivity of livestock. The evidence assembled by the academy is persuasive that wider adoption of alternative systems would result both in economic benefits for farmers and in environmental gains for the nation.

In addition to urging modifications in federal subsidy policies which encourage planting of single "program" crops to attain the highest possible immediate yields, the report of the Academy called for expanded research in this area. Improved scientific understanding can broaden the types of proven approaches to agriculture. The academy notes that among the best known alternative farming methods that deserve much greater emphasis are:

- Crop rotations that mitigate weed, disease, insect, and other pest problems; that increase available soil nitrogen and reduce the need for purchased fertilizers; and that help reduce soil erosion.
- Integrated pest management which can cut the use of pesticides by greater reliance on other techniques such as using biological agents to control pests, introducing pest-resistant crop vari-

eties, and "scouting" to assess when pest problems are so severe that pesticides are the only alternative.

- Animal disease prevention through health maintenance rather than through the routine use of preventive antibiotics which can over time influence the quality of animal agriculture and can find their way into the environment.
- Genetic improvement of crops to resist insects and diseases and to use nutrients more effectively.[2]

This current questioning of conventional agricultural practices brings into focus several personal experiences which should have signaled flaws in the nation's approach to agriculture.

When as a young boy I first visited my uncle's farm in Illinois, I was thrilled to fly in his private plane. We had an aerial view of hundreds of square miles of cornfields where he and his neighbors applied modern science and technology to achieve record yields. His management approach included slicing the runway for the plane through the middle of his richest cornfield and also not wasting time in trying to reclaim marginal lands at the edge of his property. The runway as well as the marginal lands became part of the soil bank program. He received a lucrative subsidy for not planting corn in what appeared to be the most fertile part of his property which had been reserved for the runway while he used large amounts of chemicals to increase production to the limit on other parts. This type of subsidy which promoted the use of private airplanes and destroyed any incentive for rehabilitating marginal lands simply didn't make sense to me.

Fifteen years later as a student studying the use of water from the Colorado River, I was amazed to see how the southern California desert, with topsoil of only a few inches, had been brought to life through the wonders of irrigation. But state agricultural officials dismissed the buildup of salt along the banks of the irrigation ditches, the polluted state of the water discharged off the farms, and the declining levels of the rivers and lakes that fed the irrigation system. The folly of this emphasis on production at any price, even in the middle of the desert, is now being exposed as more and more Americans move into these desert regions, depleting limited water supplies and fouling the desert environment.

Twenty years later while visiting the University of Nebraska in

Lincoln, I was very impressed to learn how university professors drawing on American science and engineering knowledge had dramatically increased crop production not only in the United States but also in Latin America and other distant regions. However, they themselves were questioning the soundness of their approaches. They were particularly concerned that the underground aquifers throughout the state of Nebraska, including aquifers under their own property, were rapidly deteriorating as pesticides and fertilizers drained from the fields into the ground water. From all indications in some areas the pollution levels had exceeded the levels of reversibility.

For many decades American agriculture has had no rival. Scientists, extension agents, and farmers throughout the nation have shown the world how modern science can bring bountiful harvests to feed an entire population with enough left over to feed other countries as well. Indeed, supermarkets are a cornerstone of American affluence. Now our scientists, our agricultural community, and the nation are challenged to maintain the harvest while changing those farming trends which are threatening the environment.

The Promise of Biotechnology

Biotechnology based on recombinant DNA is an important scientific breakthrough that should help mitigate some of the adverse side effects of farming practices on the environment. Experiments have demonstrated the feasibility of genetic engineering of crops to increase their internal resistance to pests, to weather, or to herbicidal chemicals designed to kill weeds that threaten the crops. At the same time, the newly induced traits of these plants enable them to produce better and higher crop yields. For example, genetically modified bacteria allow strawberries to withstand frost; molecular manipulations protect cereal crops from insects; and a specially modified gene produces firmer tomatoes.[3]

The traditional methods of selective breeding of hybrid crops which can withstand adverse environmental conditions while producing high yields require many crop generations before the genes with desirable characteristics are established as part of the permanent genetic makeup of the plants. Even after years of trials there can be no guarantees that the crossbreeding will be successful. Biotechnology truncates the development cycle. Another important benefit is that only the specific genetic traits that are desired will be incorporated into the plants. Genetic engineering has a degree of precision that cannot be achieved with breeding. In addition, DNA technology allows foreign genes to be introduced into plants whereas crossbreeding relies only on genes that are already present in the species used in the experiments.

Biotechnology has applications with important environmental benefits in fields other than agriculture. For worldwide energy, converting biomass to raw chemicals through biotechnology may in some instances be a feasible alternative to petroleum as a raw material for industry. Petroleum is of course a finite resource, and the extraction and refining of crude oil is surrounded with potential environmental problems. In contrast, renewable sources of biomass stand underutilized—starch and cellulose from corn and grain, forest products, and even some municipal wastes. In concept, biotechnology processes using DNA technology can enhance the enzymatic actions of microorganisms which break down biomass into forms that can be converted into industrial chemicals. The technology is not yet in hand, but in the future this approach may contribute toward reducing our dependency on oil.

With regard to pollution control, biotechnology may be able to mimic certain natural processes that feed on toxic chemicals. For decades wastewater treatment plants have used microorganisms to help eliminate solid particles. Genetically altered strains of microorganisms offer the promise of enhancing these processes, and perhaps they will eventually be able to degrade hazardous wastes into harmless chemicals. As one example, laboratory experiments have shown that a common rot fungus is able to degrade PCBs and DDT. Investigations are under way to determine if such a fungus, bioengineered to enhance its degradation capabilities, could be spread over a hazardous waste landfill to destroy toxic chemicals.

Microbes are commonly used to leach metals from mining ores and wastes, particularly in the copper industry. Again DNA technology may be able to produce more efficient microorganisms which would flourish in the acidic conditions of mines. In the petroleum field, experiments are being conducted to determine whether microorganisms or microbially produced substances could enhance the recovery of oil that cannot be easily extracted by conventional methods. As an example, bioengineering has produced a fatty substance that reduces the viscosity of crude oil, thus allowing thick oil to be pumped from the ground.

Beginning in the mid-1970s many scientists became concerned that a "superbug" produced by biotechnology might escape into the environment, reproduce in an uncontrolled manner, and create havoc. To prevent such a possibility, federal agencies have promulgated regulatory guidelines. Also, many individual research institutions have established scientific advisory committees to monitor the use of genetically engineered organisms in the environment.

Scientists continue to caution against the release of genetically altered microorganisms. They cite examples of disastrous effects that resulted from the introduction of new species into the environment. Dutch elm disease, gypsy moths, and starlings were all introduced into new ecosystems. With no natural predators, these organisms upset the ecological balance and reproduced in epidemic proportions. Could genetically engineered microorganisms, like nonnative species, have adverse effects of unknown proportions as they reproduce and multiply without the possibility of recall? Or is ecology simply being distorted and portrayed as a subversive science which threatens to thwart the advances of modern technologies?

The National Academy of Sciences pointed out in a 1989 report that the techniques used to genetically engineer organisms are not intrinsically dangerous. The knowledge gained from centuries of plant breeding and decades of modifications of microorganisms, combined with a good understanding of potential release sites, is often sufficient to permit evaluation of the danger of introducing a genetically modified organism into the environment.[4]

The academy notes that the potential for "weediness" has been cited as a major environmental risk posed by introduction of genetically modified plants. Weediness means the ability of a crop to go out of control and to become a weed species itself or, alternatively, to hybridize with wild plants to produce weedier progeny. However, the academy pointed out that the likelihood of enhanced weediness is low for genetically modified, highly domesticated crop plants. The academy also observed that microorganisms are more prone to spontaneous mutations than are plants or animals, but these risks can be evaluated scientifically. One way to confine introduced microorganisms to target environments is to introduce "suicide genes" into the organisms—such as temperature-sensitive genes which ensure that the organisms cannot survive outside the target environment.

Products of biotechnology are gradually becoming ready for the marketplace. The U.S. Department of Agriculture and the EPA have granted about 100 permits for field testing of genetically modified organisms. During the next decade we can expect to see a variety of applications of this technology which holds considerable promise for displacing other approaches that engender many environmental problems.

Technological Opportunities and Social Engineering

The foregoing examples of scientific and technological opportunities to assess and abate the spread of chemicals in the environment begin to explain why many scientists are optimistic that worrisome trends in air and water pollution can be reversed. Hundreds of other recent innovations are also of great interest in the searches for "environmentally soft" industrial processes and products and for technologies which can help identify existing environmental problems and predict future ones. Many current research and development efforts are pointed in these two directions.

Industrial, agricultural, and other commercial interests are intensifying their efforts to find production technologies that will generate fewer hazardous by-products and still remain economical. Our government can encourage these efforts by setting standards that must be met, such as requiring the use of the best available technology that minimizes toxic wastes in manufacturing facilities and calling for the best management practices in the countryside that reduce agricultural runoff. The government can levy taxes on gasoline consumption and on chemical waste streams, and it can provide financial incentives in the form of subsidies or tax deductions for environmentally sound practices in the home and in business. The government can also ensure customer awareness of the characteristics of products with environmental implications, such as gasoline consumption traits of new cars which are conspicuously posted by every car dealer and the hazards of chemical shipments which are indicated on warning labels.

Still, the primary burden for softening the nation's technological base must rest with the private sector. Our technological base is enormous and has become fully integrated with the nation's workforce and the nation's financial institutions. Change will not come easily, but it must come.

With regard to research to improve the country's capabilities for assessing environmental problems, the federal government has traditionally taken the lead. The research budgets of government agencies reflect this responsibility for investigating and developing new and improved assessment technologies and techniques. While industry of course has always been expected to be alert to the problems it may be causing, too often liability suits have been needed to capture the attention of industry even to apply well-known assessment and mitigation approaches. Similarly, in the agricultural sector, commercial interests frequently have preferred not to investigate the obvious side effects of increasingly intensive farming methods.

Historically, a few large companies have long supported significant research programs in the fields of environmental assessment and control. In recent years, the number of companies financing such activities has increased dramatically. As many companies are forced to pay the bills for cleaning up environmental problems, they usually prefer to rely in the first place on their own scientific staffs for advice rather than simply being directed by the government as to how they should move forward with remediation efforts. These staffs in turn become internal company lobbyists for more aggressive environmental programs. Also, many engineering service companies see ever more lucrative governmental contracts for environmental cleanups on the horizon, particularly within the Superfund program; and they are rapidly expanding their technical wherewithal to compete for these contracts.

A flash point for heated debates in Washington over the adequacy of research and development activities to address environmental problems is the size of the EPA's research budget. In 1980 the budget was about $350 million. Ten years later it remained at that level despite the growing array of environmental problems, the dramatic increase in the overall operating budget of the Agency, the ever-expanding commitments of the Agency to provide technical support for the states, and inflation. Many of the scientific uncertainties that confronted the EPA in 1980 loom larger than ever in 1990. We know little about the neurotoxic effects of chemicals. The resiliency of ecological systems to rebound to their original states after being temporarily stressed by chemicals is now little more than a theory. Extrapolating effects of chemicals on laboratory animals to effects on humans continues to baffle scientists from many disciplines. The feasibility of detoxifying concentrated wastes and residues by spraying them with selected chemicals has yet to be demonstrated outside the laboratory.

One hopeful sign in Washington is the strong budgetary support that is now being directed to understanding global warming. The federal research program calls for seven agencies to devote $1 billion in 1991 to supporting research in seven categories. They are climate and hydrological systems, biogeochemical dynamics, ecological systems and dynamics, the history of the Earth's climates and environments, human interactions with global systems, solid earth processes, and solar influences. When these efforts are combined with similar research undertakings in other countries, the government is well on the way in its scientific commitment to clarify the uncertainties of one of the most ominous problems confronting all nations.

In short, both the environmental regulatory agencies and the research agencies of government influence technological developments throughout the nation. However, these agencies are not well equipped for the task. Neither they nor anyone else comprehends the profound changes that will reverberate throughout society as conventional concepts of the economic viability of commercial endeavors are modified in response to environmental concerns.

For the past two decades our nation has been engaged not only in environmental engineering but also in social engineering. We are attempting to change the very basis of our life-styles. The changes demanded of our population thus far have been modest in comparison to what lies ahead if America is to continue to enjoy a tolerable environment.

During these 20 years, the president has had a Council on Environmental Quality which has been bogged down in the minutiae of regulatory details which are the bread and butter of the regulatory agencies. In 1990 it took a step toward executive leadership in its publication of recent environmental trends. However, a far broader vision is needed, a vision that goes beyond pollution to life-styles. What better task could there be for an organization at the highest level of government than to provide a perspective of the future of a nation in responding to environmental stresses of unprecedented magnitude? Such a perspective would provide invaluable guidance in how best to target resources for research, including research on social as well as physical processes, as the nation girds for the long haul.

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