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Chapter Author: John R. Pierce

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Part I

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Chapter One

Engineering and the Natural Environment

John R. Pierce

Our concern with engineering and the natural environment stems from human life and from the power of technology. If there were no people, the earth would pass from birth to death without human concern. Species would arise and become extinct, continents would drift through the oceans, tropical ages would alternate with ice ages, but there would be no concern about better or worse. Or, if rational people were destitute of a powerful technology, they might speculate about past, present and future, but one would be little able to influence them. One could farm, wisely or unwisely, until the soil was exhausted. One could in some ways protect oneself and one's possessions from inclement weather. If all else failed, one could perish or migrate.

Humanity does exist, and does have a powerful technology. In some degree we are able to influence our environment. Our concerns about ourselves and our world are more than that of seeking religious or philosophical reasons or values. They are concerns about what we have done and what we may do. In considering engineering and our environment, it seems to me reasonable to discuss three general topics. The first is, What is the actual power of technology and how do we measure that power? The second is, What *is* the natural environment? The third is, What can we do and what should we do?

THE POWER OF TECHNOLOGY

The Apollo program, which took men to the moon and back, was clearly a triumph of engineering. Twenty-five years earlier, no one but Wernher von Braun and a few science-fiction writers regarded a flight to the moon as feasible, yet men went to the moon and returned. This proved to be a very difficult and complex undertaking. The more informed one was, the more surprising it seemed that everything worked. Yet the people and the equipment, the space vehicles as well as the many persons concerned, played their complex parts. Six landings were made on the moon, and the only fatalities in the program were on earth, preceding the moon landings.

It is of interest that the Apollo program cost $25.4 billion, and that the total distance covered was 18.1 billion nautical miles. For a crew of three, the man-miles traveled are three times as large. The cost of Apollo travel per man statute mile is about $400. Not many people can afford to pay $400 a mile to travel. I think that Apollo has little significance for everyday human activities.

Apollo is a grand monument to contemporary engineering skill, as the pyramids are a monument to the skills of the Egyptians, and the cathedrals of Europe and the temple Angkor Wat are monuments to the skills of other peoples. Monuments represent only a part of humanity's skilled effort, and usually a small part. Historically, except in favored regions of easy life, people have worked hard just to feed and clothe themselves and to protect themselves from the elements. As a part of this practical work, humanity has accomplished things rivaling the monuments that have been raised.

The Indians of the Salt River Valley of Arizona irrigated 250,000 acres with 1,000 miles of canals and ditches. About 3000 B.C., the Egyptians built a 49-foot-high masonry dam on the Nile at Kosheish to provide water for Memphis. The Tu-kian Dam, built in China about 200 B.C., irrigated 500,000 acres of land and provided water for the 700-mile-long Imperial Canal, built in 589-618 A.D. The Minneriya Tank, a reservoir built in Ceylon in 900 A.D., has surface dimensions of 6 miles by 2 miles. New York City may be a monument to the past, but it was financed and built for housing and commerce. Engineering feats in the pursuit of everyday, practical ends are as astonishing as, and far more extensive than, the monuments we have raised.

Technology today is so extensive and various that one might despair of describing it, let alone giving a measure of its power. Yet a rational measure of the power of today's technology is indeed possible. In order to arrive at such a measure it is best to look at the ends of technology and how well they have been accomplished, rather than at the internal nature of the technology itself. Technology is particularly well adapted to increasing our ability to provide material goods and services. In the early days of our country, most people were farmers. It was hard for people to feed and clothe themselves adequately. Housing and the production of goods took much of the rest of their efforts. People began productive activities early in life, and physical productivity was limited by failure of strength rather than an arbitrary retirement age. Technology has changed all that. All of the population—men, women, children too young to work, those who have retired—all must eat. Today, in the United States, about 1.5 percent of the total population is engaged in agriculture. This 1.5 percent of our population grows a great deal of food for the rest of the world, as well as enough for their fellow citizens.

About 15 percent of the U.S. population provides us with *all* physical goods and services. These include food, minerals, houses and buildings, all manufactured goods, and transportation, communication, electricity, gas and water. The fraction of the population that produces goods and physical services has declined steadily. It was 21 percent in 1950, rather than 15 percent, as it is today. So in 1977 less than a sixth of the population provides, and provides lavishly, all the physical things that they and the rest of the population have come to depend on. We may wonder what all the other people do. Nearly half are deemed to be too young or too old to work. About half of the population is female, but about half of the women with children work, and that fraction is increasing. Further, the very technology that has made it possible for less than a sixth of our people to supply the physical needs of all is a very specialized technology. Few producers sell their products directly to consumers. Hence, a great many people are engaged in distribution and marketing and in advertising. Others work in government agencies, or in schools or in hospitals, or are lawyers busy helping us to sue and to be sued. Some are unemployed. The point is that 15 percent of the U.S. population can now supply the physical needs of the entire population of our nation. This, it seems to me, is a true and valid measure of the power of today's technology. And it is a quantitative measure.

The implications of this power of technology are another story. Our technology of production has made possible an increase in the total national expenditure in health care from about $10 billion in 1950 to about $150 billion in 1977. That this increase in expenditure appears to have affected our health very little is irrelevant to the argument made here. The argument is that a small fraction of our population can supply our physical needs, and the rest are available to do something else, or to do nothing. We should also note in passing that if some country could find a way to employ 45 percent of its population in producing physical goods and services, that nation could have as much per person as we do even if the productivity of each worker was only a third as great as ours.

In terms of producing what people need, or at least what Americans want, our technology is very powerful indeed. Are there other measures of its power? What about measuring it against the power of nature? Measured in this way, common examples show us that our technology is puny indeed. A hydrogen bomb is puny compared with a major volcanic eruption or an earthquake. Some are concerned lest our activities *may* influence the climate. Nature has repeatedly produced ice ages, and even more drastic alterations of the climate. Continents drift while our technology changes the face of the earth scarcely at all. Quantitative measurements also confirm that humanity is puny compared with nature. The energy of sunlight that falls on our country each year is a hundred thousand times as great as our total energy consumption.

We can imagine that humanity may truly alter the face of the earth. During the first atomic test, Oppenheimer feared that the intense heat might ignite the atmosphere, causing the oxygen and nitrogen to burn. Early in the atomic era, people feared that cobalt bombs might destroy all life. Perhaps we *should* fear. People bent on destruction might, wittingly or unwittingly, change our planet in a major way. It hasn't happened, and it might be very difficult to make it happen. Still, we should keep the possibililty in mind.

We can conclude, however, that technology is weak compared with other natural forces, but that it is powerful in altering human life. It is important, however, that we understand a condition. If our technology is to have a major effect on our lives, our lives and our world must change drastically. It is a wonder of technology that 1.5 percent of our country's population can produce food for us all, and a good deal more. It would be ridiculous to imagine that technology could simply have reduced each farmer's labor without changing the nature of farming and without moving people from farms to factories. The increased productivity of agriculture depends on science and technology of plants, fertilizers and machines that could not exist in a primarily agricultural society. Even the computer plays an important role in farming. Agriculture has advanced because the whole world has changed. The changes in agriculture would have been impossible without other changes.

In trying to understand how technology is linked to social change, we can trace particular technological changes, but we must realize that the changing aspects of our world interact in ways so complicated that we can scarcely understand them. Transportation was once largely via seas and rivers, and great cities were thus situated on harbors and rivers. In the early nineteenth century, canals became powerful extensions of rivers and opened access to locations far from natural water-ways. By the end of the last century, canals were largely displaced by railroads, which opened up even more remote regions to commerce and settlement.

It is easy to see that these changing modes of transportation had a profound effect on life in this country. We may overlook the fact that they brought with them other changes. In the day of canals, the ownership of canals and barges was separate. This pattern of ownership and operation was tried in the early days of railroads, even before steam locomotives. It proved impractical. Railroad companies came to own both trains and tracks. With the advent of the airplane, some thought there would be widespread personal ownership of airplanes. There is, but not in the sense of widespread personal ownership of automobiles. Not only are new technologies different, but their implications for social patterns are different.

More than canals, railroads and interurban rail opened up new land for business and residence. Indeed, the value of the land opened up was a chief source of funds and profit for those who built railroads and interurban rail. That the appreciation of land values because of rail is a thing of the past may well explain a part of rail's financial problems. California once had 1,200 miles of interurban rail, and interurban rail in the East was even more extensive. In those days, residences and work locations were within walking distance of trolley lines. People could reach work from lakeside summer resorts by interurban. With the spreading of the automobile, people moved beyond walking distance of anything. The whole pattern of settlement changed.

The automobile plays an important part in our lives because our life has so altered that we have become dependent on the automobile. The telephone plays such an important part in our lives because our lives have so altered that we have become dependent on the telephone. What of the fraternal organizations of the days of my father? The very sort of communities in which they thrived are gone, or are so altered by television and easy travel that people seek companionship and distraction in other ways. They seek help from the government, not from lodges.

The power of technology is dependent on its power to change our world. Those who call on technology to ameliorate present conditions are misled about technology's power and effect. Early in this century a person might have asked for a scientific solution to the pressing problem of keeping the streets clear of horse dung. That problem has vanished. Today we are fighting the emissions of gasoline-powered vehicles. It is a secret from only the blindest or most inattentive that the problem of pollution through burning gasoline cannot persist for many decades. We will run out of oil. We must indeed use technology to cope with present problems, but present problems are problems left over from the past. Unless we prevent change, which would be very difficult, the world of tomorrow and the problems of tomorrow will be very different from the world of today and the problems of today.

That technology can be very powerful in people's lives is demonstrated by the ways in which it has changed people's lives. It has made it possible for 15 percent of the population to provide all our material goods and services. This power of technology can be exercised only by changes in our world—in our environment, if you will. With such change, our work, our concerns and our behavior have changed. The power of technology is not a power manifested in our machines only; it is a power manifested in our lives, and in our concept of our world and ourselves.

Yet, when we compare the power of technology with the power of other forces, we find it weak indeed. The history of the earth before people existed exhibits changes in geology, climate and species that make any general changes wrought by humanity insignificant. The changes that we have worked seem so large to us because our technology has changed profoundly those things that we deem important.

WHAT IS THE NATURAL ENVIRONMENT?

The Book of Genesis recounts the creation of the heavens, the earth, the sea and the dry land; of plants, fishes, birds and beasts; and of man all in a week of creation. God gave man dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth. And of the earth, God told man to subdue it. We need not argue whether the Bible is the word of God or whether it proceeds from the human heart. For many years, Western cultures have accepted nature as it is described in Genesis, a nature of which we are a part and are yet somehow above, a nature which we must subdue in deriving support. Our natural environment includes the stars and the planets, and air and the sea, the land and the plants and animals that dwell in the sea and on land. It is very hard to argue that humanity and its works are not a part of nature.

We flatter ourselves that we have greater and more far-reaching powers than other animals. No other animal has placed things on the surface of the moon or Mars, or has caused satellites to orbit the earth. No other animal has built works so complex as ours, and few other forms of life have spread over so many regions of the globe. We have even worked the extinction of species. The smallpox virus is all but extinct, and this has been a deliberate effort at extinction. The passenger pigeon is gone; that was inadvertent. Other species are endangered. But the number of species that we have extinguished is miniscule compared with those that have perished without our intervention. Where are the many species of dinosaurs, and what destroyed them? It was certainly not humanity.

We are not the only force, or the only life, that causes changes in the environment. But we are the only creature with a conception of change, and with a fear and distrust of change. We continually hearken back to the golden age, the Arcadian myth, the good old times. In the very process of changing our environment, we become distrustful and wish, somehow, that things were still as they were before. Yet it is the nature of humanity, which is a part of nature, to change its environment. Perhaps there is a happiness that does not involve such change—the happiness of our first parents in the Garden of Eden before their curiosity was aroused—the happiness alleged of South Sea islands before contact with the West. In "The Water Babies," Charles Kingsley describes people who lie under the flapdoodle trees, waiting for the fruit to fall into their mouths, and for tigers to eat them.

Most of the environment untouched by humankind is hostile. It is successively cold, hot and damp. It is infested by insects and other annoyances. It will support a very sparse population by hunting and gathering. The life of the hunter can be fun, but game can be scarce or exhausted locally. Commonly, the lives of the hunters and the gatherers involve seasonal journeys, and hardships against which they have no protection.

The environments in which civilized people live can be called natural only if we regard ourselves and our works as a part of nature. Once on a flight over Iowa I took a picture in which the most conspicuous features were the roads, a mile apart east and west and north and south, that bounded the sections. The sections were subdivided into rectuangular fields, and no stream cut diagonally across any. On each quarter section there were a farm house and buildings, or the sites of them, for when the land was first divided, a farm was a quarter section. Around the houses, a few trees grew, planted by the farmers, perhaps on Arbor Day.

The environment that surrounds me today has been drastically altered. Once it was what I, coming from the lush fields of Iowa, would have called desert, though native Californians would have called it chaparral country. Today trees and plants from all parts of the world grow around me, because water has been brought from rivers hundreds of miles away. The houses are fronted by green lawns in imitation of those of the East and Midwest, which in turn, I suppose, derived from the grazed meadows of England. Los Angeles County is a museum of rare nature drawn from all parts of the globe. But is this natural? Would it be natural if we turned the water off? It wouldn't be pleasing to us; we would describe it as a waste, a wreck. To us, the evidence of our intervention would still be apparent. I doubt, however, if the raccoons and coyotes who frequent our Pasadena garden have thoughts on the subject, one way or the other.

We have a vacation place in northwest Massachusetts, in the old township of Buckland. There we fight an unremitting battle to keep the woods from swallowing the house and view. Our meadow is mown once a year; otherwise it would become woods. Down the slope between us and the Mohawk Trail and Deerfield River we spray to keep the trees and bushes from growing. The hillside has been taken over by several varieties of fern, with a scattering of mountain laurel and a few swamp pinks. To us this has a beauty different from the woods, and but for us it would not be the way it is, nor would the meadow.

Still, the woods and the things that grow therein—mushrooms, trillium, indian pipes, and all the things I cannot name—are a delight. We walk through the woods along abandoned roads, between the stone walls that once bounded fields. Nature takes over quickly in Massachusetts. Today the small farmers who once supported themselves from the land could not grow enough to pay taxes. The small dairy farmers are gone; they could not afford to meet today's sanitary regulations. Their farms have returned to nature. The endless stone walls testify to our struggle against adverse forces. Here that struggle with value is almost over, as it is not in the more hospitable fields of Iowa or in the man-made oasis of Los Angeles County.

We have considerable power to modify land by cultivation and irrigation. We have not been able to modify substantially the climate or weather, but we have been able to shelter ourselves from the elements and to light and heat our habitations; today we can even cool them. We can bridge rivers and build roads across treacherous soil. We can travel on these comfortably in heat and cold, and (usually) keep them open in blizzards. I do not think that we have conquered the seas or the air, but we travel them despite their furies.

When we drive across the country on the federal highway system we see that our determined hold on our enviroment spans a huge continent. Towns are recognizably similar from sea to sea. The lives that people live are, despite great diversity, recognizably similar. The technology that has enabled us to live comfortably in the face of the adversity of our environment is similar, coast to coast. But when we pass long miles of untouched grandeur, or of untouched nothing—at least, nothing to us—we realize how little we hold. From the air this is even more apparent. Highways wind through mountains or go straight across barren wastes. A few miles from the highways there is nothing of man's. Even in the declared megalopolitan Northeast Corridor between Boston and Washington there are hundreds of miles of uninhabited pine barrens.

Our reshaping of the land on which humanity lives is extensive in that we live in almost all parts of all continents, but much land remains untouched. We can ruin the environment for ourselves in trying to cope with it, but the effects have been surprisingly local and often transitory. The Greek Islands, or some of them, were once wooded; goats and repeated rapine have rendered them bare and inhospitable. Some say that the classical Mayan civilization failed because their primitive slash-and-burn agriculture failed. Whether or not this is so, the jungle has hidden the Mayan temples. The land below the cliff dwelling of Keet Seel was farmed when that dwelling was inhabited. The fields are now gullied and washed away, perhaps because of that very farming. But Keet Seel and the other cliff dwellings housed few people and are far between.

Sometimes humanity's adverse effect on the environment is more widespread. The Aswan High Dam has changed conditions in the Nile delta. Lake Erie and some American river systems have been seriously polluted. Use and reuse of Colorado River water has raised the salt content where that river enters Mexico. Both hunting and overgrazing have adversely (for people and animals) affected large areas in Africa. Yet it is fair to say that large as humanity's effect on the environment has seemed to us, in a broader context it has been chiefly local and transitory. It is certainly so compared with those changes in the environment that have characterized geological history.

But changes that we can and do work in our environment are essential to our lives. We can live in any numbers and in any comfort only in an environment that we have substantially modified through building, cultivation, and, often, irrigation. Whether or not this modified environment is natural or not must depend on whether or not we regard ourselves as a part of nature. Who worries about this question? We do, of course.

Whether or not we are concerned about the world *natural* in connection with our environment, we are concerned about whether or not that environment is congenial. Sometimes we wish to go to places relatively untouched by humankind. Mostly, we want to live in comfortable and convenient surroundings. Here almost all people express very real concerns. Some of these concerns are about features of the environment that affect health or welfare very directly. Some of the concerns are about preference—preference for the sea, or for skiing, or golf, or crowds and public entertainment, or comparative isolation, or for handsome surroundings and an absence of billboards and garish signs.

Among features of our environment that can affect our health and welfare very directly are danger from intense smog; danger of earthquakes; danger of flooding, especially in low-lying land protected by levees; danger of landslides; danger of fire, especially near some mountain areas; danger of tidal waves; danger from volcanic eruptions; danger of loss of water or fuel, such as natural gas; danger from auto traffic, especially to children; danger of violence from other people; and lack of reasonably priced housing.

Among matters of preference, one of the strongest contrasts in preference is city versus small-town or country living. Other matters of preference are clean air versus excessive soot and dirt, and handsome surroundings versus billboards, junky stores and run-down houses. Access (which means good roads and not-too-great distances) to sea, lakes, mountains, skiing, fishing and other sports is very important to some.

Today, many profess a deep love of nature. Love of nature can mean many things. Hunting and gardens have played a part in the good life in many ages. Forests and parks are important in hunting because huntable game live there. Poachers and development are the enemies of game, as are the hunters, who want the game preserved for them. Gardens have often been as formal and highly developed as palaces.

In Western culture, the love of nature in a primitive state is said to have begun with Rousseau. Certainly, Western romantic landscape painting follows him. In China and Japan, landscape painting was associated with a love of nature that preceded Rousseau by many centuries. In Japan, for over a millenium, nature—and the seasons and the changes accompanying them—have been a subject of poetry, and the observation of nature has been an important part of esthetic experience. This has led to the preservation and embellishment of natural sites. The scenery around Nikko is beautiful, but so are the temples and shrines. As the Japanese consider seals and calligraphy an embellishment of pictures, so they consider temples an embellishment of landscapes.

The Japanese love of nature has led to some of the most artful gardens in the world. Falls, lakes, mountains and woods are reproduced in miniature, as parts of palace grounds or temple complexes. Is a Japanese garden, because it expresses a love of nature, a natural environment? Only if one sees oneself as a part of nature. The survival of a Japanese garden depends on people's care, on wrapping the trees to protect them, on spreading mats over the moss to shield it from sun in summer or from cold in winter, on continually plucking out weeds, on ceaseless replanting, pruning and improving. Yet the Japanese garden does express a close observation of and real love for nature.

Whatever our attitude toward nature may be, it is clear that an environment unaffected by humans and the nature of humans cannot support many people, and even they would not be very comfortable. If people are to live in any comfort and to have the leisure for reflection and invention, they must modify a part of their environment as best they can. It is desirable that such modifications produce an environment that is healthful for people and for what else of nature they value. This need not include smallpox, malaria and mosquitoes. The environment should suit our taste, but the same taste is by no means common to all people. It seems desirable that some areas be preserved with little modification, both for those who like nature uninfluenced by people, as a sort of museum, and as a hedge against the future. However, preserving nature as it would be if uninfluenced by people is not easy. Thousands of acres of government land near Hanford, Washington, have been substantially modified simply by protection from and extinguishing of fires. The brush has thrived at the expense of the grasses.

Unless we consider humanity as a part of nature, the natural environment is something of an illusion. We must, and do, affect our environment. And yet our effect is far smaller than that of other forces.

WHAT CAN WE DO AND WHAT SHOULD WE DO?

What we can do depends on the power of technology and on our enterprise and malleability. What we feel we should do must depend on what we can do, but it depends also on our attitude toward humanity and surrounding environment.

What do we mean when we say that we can do a thing? We may mean that it has been done before and that the technology, materials, energy and skills to do it again are still available. Thus, a house, a dam, a new model of automobile can be ordered up, so to speak. We may, however, mean that the individual technologies needed have advanced far enough so that we believe there will be no insuperable obstacle in pushing them farther to accomplish some new thing. This was the case with President Kennedy's program to send a man to the moon and return him safely before the end of the decade. Nothing—not propulsion, guidance, life support, or re-entry—had been done on the scale or with the reliability required in order to accomplish the mission. But, to those most familiar with the technologies needed, it seemed that a straightforward effort could push the technologies far enough to accomplish the goal. This we were able to do, while the Russians failed.

Thus, when we say that we can do a thing, we mean either that we know we can, or that we believe that we can push technology far enough to accomplish the task. This second sort of ability to do a thing calls for more money and more time than the first. But, having in hand known technologies gives us some confidence that money and effort can push them farther.

Sometimes we *feel* that by gathering new knowledge and devising new technologies we will ultimately be able to do a thing. When this is the state of our knowledge, we cannot set a timetable, and high ability of the people who undertake the task is far more important than the total amount of money spent. Indeed, in this sort of endeavor it is not clear whether spending more money will speed progress toward the goal or slow it. I have used building a new house, or dam, or a new model of automobile as examples of things we *really* know we can do, granted the money. I have used the Apollo program as an example of something that we had good reason to believe we could do, granted a lot of money, because all the technologies needed had succeeded in a smaller and less demanding way. Deriving useful amounts of power economically by fusion is an example of something that informed people feel can be done by gathering new knowledge and devising new technologies. Money and effort cannot deliver fusion on a timetable. The central part of the technology needed has not yet succeeded on *any* scale. All we can do is to support the very best people in a degree that seems reasonable to them. In our present state of ignorance, spending a great deal more money or working on ancillary problems when we don't know what form fusion will take if it does succeed would be inexcusable folly.

In the field of energy, of which fusion may one day be a part, we *know* we can build safe, economical fission power plants. This has been done. We have every reason to believe that we can build safe, economical breeder reactors. In fact, breeders have been operated. We can only hope that fusion by *some means* may *some day* provide safe, economical power. But that is not something we can assert. We will know only when much more progress has been made. We don't know when that will be.

Because large amounts of money have sometimes produced startling results, some people have been misled into believing that money will buy anything. Indeed, ours has become the age of Mammon and Mammon worship. Money bought the atom bomb because the fundamental scientific knowledge and the beginnings of the required technology proved to be available. Making the atom bomb was, however, a chancy business, and we were lucky that there were no unforeseen and irremediable obstacles. Apollo was a better bet because the fundamental technologies had been demonstrated. When work on fusion was first started, some believed that a large enough effort would push things through. They were wrong.

In seeking fusion power, all sorts of problems turned up. Mammon worship was proved wrong; no amount of money would buy fusion in a hurry. Indeed, the big machines that people constructed in ignorance retarded progress—until people were brave enough to abandon them and seek knowledge patiently. Nonetheless, Mammon worshipers refuse to learn. They believe that enough money really will buy *anything*. Human weakness being what it is, Mammon worshipers can always find someone to spend money. Sometimes those who spend the money are deceived and corrupted by it and become Mammon worshipers themselves. Sometimes they try to do something they regard as good with a part of the money. Sometimes they merely enjoy spending the money.

Distinguishing among the things that it is clear we can do, the things that it seems likely that we can do, and the things that we have some reason to believe that we can do some day is not easy. Experts can be wrong. People who are not experts may be right, because chance may favor them. But nothing but luck favors the ignorant. Yet, knowing what we can do must be an important part of any consideration of engineering and the natural environment. It must take precedence over considerations of what we should do. If it does not, we may be tempted to undertake to do things that we cannot do, or to place great reliance on things we may (or may not) be able to do at some unknown time in the future. If we do not understand our real abilities, we will mislead ourselves and other people.

But consideration of what we should do, among the things that we can do, must be an essential part of any decent program or proposed program. Indeed, a long discussion of what we can do would be empty and misleading without some consideration of what we should do. Unhappily, *should* means very different things to different people because values differ fundamentally. Some regard all seemingly avoidable deaths as equally bad and wasteful. Others believe that some avoidable deaths, such as those resulting from political or legal action, are of great importance, and that others, such as those resulting from drunk drivers or inherent in the use of oil and coal as fuels, are of far less importance. Some believe that individuals should have a very wide choice of action, as long as this does not result in risk to others. Others believe that if a person can be protected, one should be protected, regardless of the constraint one may feel or the inability to gauge and take risks that may result. Some feel that the good life is knowable, and that all should lead it. Others believe that, while we may be able to judge some lives as bad, good lives can be as different as good books, and as hard to judge. Thus, while I feel that *should* as well as *can* must be a part of any discussion of technology and the environment, I cannot arrive at any clear *should*.

Neither can we very much alter the terrain we inhabit. We cannot exalt valleys or make mountains and hills low, except on a miniscule scale. Making the rough places plane is confined largely to highways and fields. In farming, we must cope with slopes by terracing, contour plowing, or perhaps better, by no-tillage farming. We can to some degree protect against floods and provide irrigation with dams, but these sometimes fail with disastrous results. Levees are even more prone to failure. To endeavor to make an uninhabitable or dangerous region habitable or safe, by means other than irrigation, may be asking for trouble. People who live behind levees or in other regions known to be subject to floods incur a very real risk. So do those who live in earthquake-prone regions. But at least buildings can be designed to withstand most earthquakes. Our compassion makes it incumbent upon us to try to relieve the sufferings of victims of natural disasters. If, however, the disasters recur, we must realize that we are paying out of general funds for the consequences of choices made by particular individuals.

The natural environment has features that we cannot alter for the better on a large scale. But we can move to other places. It is both common and natural for individuals to seek safer or more agreeable environments. Anyone who has pushed a spade into Iowa soil may well wonder why people ever tried to farm in Massachusetts. There are social reasons why people and businesses move from the Northeast to the South and Southwest, but there are reasons of climate and comfort also, and individual reasons of less expensive construction and less cost and expenditure of energy in heating. Wherever people exist, they should use their science and technology wisely in making life in the environment healthier, more productive and more agreeable. Sometimes, however, it is easier and wiser simply to move.

But in no environment can people live what we regard as a civilized life without housing, heating and sometimes cooling, transportation, and communication. All of these take materials and energy. Today we feel a good deal of concern about possible shortages of materials and energy, and we have recently seen the disastrous consequences of a shortage of natural gas. It seems that a shortage of materials would be more likely than a shortage of energy. After all, trees grow naturally and we can burn them. The sun shines down, the winds blow. It is, however, a shortage of energy that we suffer from. As various materials have become scarcer and more costly, we have found substitutes, often with superior qualities. Synthetic fibres are in many ways better than natural fibres. For many purposes, plastics are better than wood or metal. There are even plastic automobile bodies and composites stronger than steel. Glasses and ceramics have proved to be marvelously versatile substances. Indeed, it seems likely that transparent fibres will ultimately replace copper wires and tubes in communication. Some metals, such as aluminum and magnesium, are distributed very widely. Granted enough energy, we are scarcely likely ever to exhaust the supply.

It is energy that we are short of. And our rapid depletion of the world's oil reserves raises a specter of a very real materials shortage. For, through the petrochemical industry, oil is a source of all sorts of valuable products, including plastics and synthetic fibres. Because oil is such an exhaustible and seemingly irreplaceable resource (except perhaps, for the substitution of coal), some feel that it is far too valuable to burn. But, burn it we do. Although our reserves of coal are very large, we may well ask, Is not coal also too valuable to burn? Should we not reserve it largely for the material needs of generations to come, or for the production of synthetic hydrocarbons that can provide portable energy where we must have it?

The need for energy raises very real materials problems we should take into account. The production of energy raises other problems as well—of economy, of safety, of environmental damage and of storage and distribution. Oil is easily stored and easily distributed, by pipe, truck, rail or ship. Gas is less easily stored in quantity, but distribution by pipeline is so easy that production can be linked to use. Coal is less easily distributed than oil or gas, but it can be stored.

Hydroelectric energy can be distributed only as electricity, but it can be stored. Indeed, in pumped hydroelectric, water is actually pumped to a higher level so as to store energy for future use. Alas, there aren't many suitable locations in the United States. Nuclear energy is easily and copiously stored in the fuel elements of reactors. Like hydroelectric energy, nuclear energy must (for civilian purposes) be distributed as electricity. Except for pumped hydroelectric, large-scale storage of energy is very costly and requires large amounts of materials. Flywheels and superconducting electromagnets have been suggested, but improved storage batteries seem the nearest solution. We don't have them. We should work toward such batteries in a reasonable way.

The production, storage and distribution of hydrogen through pipes has been suggested as an alternative to the production, storage and distribution of electricity. Hydrogen is very light, and it is not easy to store large amounts of it. Hydrogen is an extremely dangerous gas. Unlike most other flammable gases, very small amounts of hydrogen mixed with air form an explosive mixture. Perhaps some day we will have a hydrogen economy. But at the moment a good many people would say that electricity will remain the common medium for energy exchange and that better means for storing electric energy will be developed. Ultimated we *may* have effective electric vehicles fueled from the electric system. Or vehicles may run on products derived from coal or vegetation.

More than anything else, the problems of energy production may have something in common in both developing and developed economies. Large-scale power production is more efficient of energy and materials than small-scale production. Electricity is a very convenient common medium of exchange of energy. Loads shared among many users are steadier than the energy demands of individual users, and this also makes for efficiency. Small power tools are a boon in any economy, and electric power tools are cheap, durable and effective. Electricity fits in well with decentralization, because expensive primary power plants need not be located everywhere. Thus, large-scale production of electricity may be a good feature for all nations and all social organizations. Or it may not.

Perhaps technology will provide cheap solar or wind power sources—cheap in the initial cost per kilowatt—which can be used for many purposes without storage. Perhaps technology will provide cheap means for storing energy—cheap in terms of initial cost. So far technology has provided neither. Or perhaps technology will provide small, cheap *and* efficient power sources that burn or use fossil fuels. Technology has not done so. Perhaps technology will. Until we have new or better technologies, it appears that solar energy will be best used for heating water, or for heating or cooling homes, and that it will be less wasteful to burn fossil fuels in large rather than in small power-generating stations.

In providing the power that will be needed in the near future in high-technology countries, and in some others as well, the alternatives (other than hydroelectric power) are coal and nuclear energy. We have had a good deal of experience with both. Of the two, the actual, demonstrable death rate per kilowatt hour, including mining, transportation and production, is clearly higher for coal. So is the disturbance to the environment, both in mining, transportation and operation. The waste-disposal problem in coal plants is formidable. In trying to cope with it, the Japanese find themselves saddled with large and uneconomic stocks of gympsum and ammonium sulfate.

There may be long-range reasons for preferring coal to nuclear energy. If we adopt coal, we should honestly face the cumulative loss of life, the environmental damage and the cutting into large but limited stocks of a very valuable material. People do make sacrifices, of life and of well-being, in a good cause. But if people are to make sacrifices, they should understand the goal of the sacrifice.

While materials and energy can be exhaustible resources, communication appears to be inexhaustible in amount and variety. In developing countries, communication is an essential means both for holding a society together and for changing it. The needs for communication can be met by rather simple means. Radio broadcast and transistor radios are cheap and very effective. Communication satellites have linked cities in all parts of the world to one another at a moderate cost. A few telephone lines or microwave or satellite circuits between principal points can provide essential two-way communication in a developing society. The society does not need nor can it afford a telephone in every house.

In a highly developed technological economy, communication appears to offer an alternative to much business travel, as well as a means for linking geographically distributed parts of large enterprises, private or public. In *The Telecommunications-Transportation Tradeoff*, Jack M. Nilles and his colleagues conclude that in a selected service industry, relocation from one to eighteen centers in Los Angeles County could reduce that one-way commuting distance from 10.7 miles to 3.9 miles. They conclude that the change would be cost-effective for the company. Hiring would be easier; it would no longer be necessary to pay premium salaries and to give fringe benefits to get employees to work in the downtown area, and the termination rate would be lower.

The automobile and adequate roads and freeways have had a wonderfully liberating effect. People have gained great freedom to seek economical and pleasant housing. They have gained freedom to go to the beach, to the mountains, or where you will. What seems unreasonable is that people should have to commute long distances to crowded areas where businesses have chosen to remain. Such commuting is wasteful of energy, and it is not enjoyable. But if work is decentralized in order to reduce the energy demands and discomfort of commuting, what will the future of the city be in a society of automobiles, roads and communication? Are cities to remain dangerous traps for poor people who cannot find rewarding jobs and yet cannot, or will not, or are induced not, to leave? Whatever the problems of the city may be, it is disheartening and it appears to defy solution. Either people know no remedy, or there is no remedy that anyone can apply or is willing to apply.

This seemingly intractable problem of the city exists in developing as well as in high-technology societies. In each we see jobless poor trapped in cities. In the high-technology societies, automobiles, good roads and an increased use of communication appear to allow a dispersal of work as well as of residence, with less unnecessary travel, less pollution and less energy consumption. In the developing societies, the problem is to make life on the land productive and more agreeable than a jobless existence in a huge city. An economical, small source of energy would help. One would hope that communication could be made to help rather than to hinder. The challenge is great, but the solution is not clear.

In contrasting the needs of a developing society with those of a high-technology society, it has been rightly pointed out that the developing society cannot afford a high capital investment per job. Except for the introduction of industries by outside companies, this points to simple mechanization and a modest use of scarce materials, including oil and fertilizers. I have pointed out earlier that if a country could so organize itself that 45 percent of its population was employed in the production of food and manufactured goods, in mining, in building and in supplying energy and communication, that country could have as much as we have even if the productivity was only a third as great per person. That country could have half as much physical goods and services as we have even if its labor was only a sixth as productive as ours.

Getting so large a fraction of the population to produce food and physical goods and services is probably impractical. It would mean that the young and old would have to work. Perhaps they would like to. It would mean that idle poor could not be allowed to accumulate in cities. It would mean a bureaucracy and an army of modest size. It would mean that school teachers, doctors and nurses and lawyers would constitute a small fraction of the population.

SOME WORDS IN CONCLUSION

The power of our technology is great in human terms but small in terms of our total environment. Apollo, the pyramids and other monuments are enduring reminders of that power. To my mind, the most striking measure of the power of our technology is the fact that about 15 percent of the U.S. population provides food, goods and material services for the nation, and that this percentage has been falling steadily. Yet volcanoes, earthquakes, changes in climate and geological epochs show us how small our power is.

In the minds of many people, humanity is a part of nature, though a rather special part. What we do cannot be unnatural; it can only be unpleasant. To whom? To ourselves. The power of technology can be realized through drastic changes in the way we live and work. Whatever the natural environment may be, the unaltered earth will not support many people very well. A look at Iowa or Southern California shows what we can do to a small part of a country's surface, and the look is not unpleasant. But for every acre we have changed, many acres of our land remain untouched.

Most of the forces and aspects of nature we cannot change; we can only protect ourselves against them. If we are realistic, we will try to do what we can do, not what we cannot do. If we are wise, we will do what will make us well and productive and, we hope, happy or at least cheerful. If we are to be realistic, if we are to have a chance to be wise, we must, as nearly as possible, see things as they are. We must neither overestimate nor underestimate our powers. We must take due account of the present, the near future and the far future. And we must take into account the needs and desires of people other than ourselves.

REFERENCES

A good deal of what I have written comes from the life I have led. I am not an expert figure-looker-upper. I have relied on a few sources for numbers and fewer for ideas. I have found helpful: *The Encyclopedia Britannica; The World Book, 1977; Statistical Abstracts;* James O'Toole (University of Southern California Center for Future Research), *Energy and Social Change* (Cambridge: MIT Press, 1976); Jack M. Nilles, F. Roy Carlson, Jr., Paul Gray, and Gerhard J. Hanneman, *The Telecommunications-Transportation Tradeoff* (New York: Wiley, 1976); Readings from the Scientific American, *Scientific Technology and Social Change* (San Francisco: W.H. Freeman and Company, 1974).

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Chapter Two

Discussion of "Engineering and the Natural Environment," by J.R. Pierce

Harvey J. McMains

It is indeed a pleasure to have been asked to comment on Dr. Pierce's paper. It gives us much to think about and it is worth several readings. First, he reminds us that any concern with engineering and the natural environment stems from humanity's basic nature and from the power of our evolved technology. Dr. Pierce then states a most important fact: there exists a powerful technology, and because it exists we can, to some degree, influence our environment. This fact makes it possible for us to think and plan for all humanity's future. Next, Dr. Pierce divides his paper into three general subject areas: (1) The actual power of technology and the measure of that power; (2) what the natural environment is; and (3) what can we do and what should we do?

The measure of the power of technology that Pierce picks is the percentage of the population that provides us with all physical goods and services, including communications, electricity, gas, and water. He states that the percent of population is approximately 15 percent today, and that it was 21 percent in 1950. Whether this is the best measure is hardly worth debating. The important thing is that this has been a national focus for technological thought and innovation. Will it continue? Should it continue? Before we answer these questions, we need to study and research this trend in terms of its human consequences. Dr. Howard R. Bowen, in his introduction to the report of the National Commission on Technology, Automation, and Economic Progress, 1964, said, "Technology is not a vessel into which people are to be poured and to which they must be molded. It is something to be adapted to the needs of man and to the furtherance of human ends, including the enrichment of personality and environment." It does not seem quite right to me that our technology should be slowly eroding humanity's right to be a part of the production process for the physical goods and services it needs without our knowing that that is the way humanity wants it. It may not be important, but what if it is and we never bother to learn this until it is too late? We should keep in mind what Dr. Pierce reminds us: "Our technology changes profoundly those things that we deem important."

What is the natural environment? It is just about everything that exists on earth, including humans and what they do or do not do. People are, as Pierce points out, a part of the natural environment. Further, humans are creatures with a conception of change and the ability to plan for change even though they distrust and fear it. Without this ability, the world would be a rather dismal place considering the number of humans on the earth at this time, not to mention the number that will inhabit the earth a hundred years from now. Whatever is now on earth that will change, will happen either as a consequence of the power of nature or by humanity. It is worth noting that people are capable of recording facts and making analyses. They can determine what has happened and is happening and, with less certainty, what may happen. For example, how much of which materials are being used for the manufacture of certain products and services and how long will they last? They also think of alternative ways of doing things, including material substitution-people can determine who is doing what, and to some degree how well. They are able to dream beyond their capabilities or expectations and have a pretty good record of causing these dreams to come true.

A word of caution—as technology has continued to improve, it has become more complex. This has made it harder to determine what can be done and who should do it—if for no other reason than there is simply much more of it. Pierce suggests that the best we can do is pick good people and give them the resources they think they can use and hope they can do what they think may be possible. But somehow we must do better than this. We need to determine our priorities and which of these priorities offer the most, considering the risk of success. National planning and goal-setting in the past has not been done well, but maybe that is because we don't believe it is possible—and thus haven't ever given it a chance. People who could, may not be interested, because it does not advance their cause in science. The challenge is to make planning a point of focus for the capability for the best minds. Dr. Pierce asks the question, "What can we do and what should we do?" While it is true that we can really only do what we can do—what *are* the things we *can* do? Which are the important ones and what are they worth in these uncertain times?

Energy is probably the number one current problem for a country as industrialized as the United States. We presently use oil and gas as our principal source of energy and it is in short supply, but there are other sources of energy. Of those currently most promising, which are the best bets with existing technology, and how should we develop them? What should be the government role? What should be industry's role? And perhaps more importantly, what should be the role of the individual citizen? The private citizen needs to be informed with the facts as they exist. This is not a task to be taken lightly.

Planning has been left out of Dr. Pierce's paper, and yet it seems to me it is an important part of engineering and the natural environment. Planning and its implementation must be as creative as any applied technology—past or present. What is needed is to determine where we are, where we want to go, and establish the goals and objectives for our existing enterprise system to take us where we want to go. This sounds, of course, like a platitude, but determining the issues and setting about to solve them is what has been done so well by our enterprise system. Creative ingenuity is what has made our marketplace so effective. At the present time, too much of our talent is consumed by technology for technology's sake or in finding out what has been done wrong or what is being done wrong. We need to marshal a fair share of the superior talent to carry out the planning mission. We need the best talent available for determining, for example, what alternative sources of energy offer the best potential for development, what they will cost, and when and how they can be phased into our way of life. Effective planning should be a major goal of engineering and technology.

Technology has on balance surely been a great blessing to all of humanity, despite the fact that some of its benefits have been offset by costs. I would not propose slowing it down by diverting some of its talents to planning if I didn't think this would result in directing it more nearly to human concern and need and in the final analysis give us more of what is needed. We can no longer afford to squander our technical resources without good guidance. The questions engineering and technology should focus on in this critical period of natural resource evaluation and reevaluation is *what, when, who*, and *how*. Planning should guide the focus for effort, and not the means. The future need not be one of limits, but can be one of wise alternatives with an even higher quality of life.

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Chapter Three

Discussion of "Engineering and the Natural Environment," by J.R. Pierce

Benjamin C. Dysart III

Eugene Odum (12) pointed out recently that "ecology" and"economics" come from the same Greek root, ecology translating as "the study of the house" and economics as "the management of the house." I believe that all of you share with me a strong desire to see our nation's, and our region's, substantial natural resources and environmental amenities handled in a manner that is both "manageable and managed" (6). I believe that is the task before us as natural resources engineers.

I am pleased to be able to discuss John Pierce's paper. It was refreshing, expansive, and stimulating, attributes all too frequently absent from typical "engineering" discourses. But refreshing and imaginative thinking alone will not suffice, I suppose, if we are to be responsive to the charter established for this symposium. Considering the challenges to society, and to our engineering profession in particular, we have little need to dwell on the more pedestrian aspects of technology, and less for bromides.

I find little in Pierce's paper with which to take strong exception. I will, however, from my very different background and vantage point, provide some alternative views and perspectives on some of his key assumptions, contentions, and conclusions.

Pierce begins by establishing some basic points of departure:

a. *Humanity* exists.
b. *Humanity* has a powerful technology.
c. *Humanity* can influence *its environment.*
d. *Humanity*'s concerns about *itself* and *its world* center on what it has done and what it may do.

To me, there seems to be a preoccupation with humanity, our environment, our world, and so on, before establishing, or speculating upon, what might be the appropriate or proper role for humanity. Then, Pierce might have even gone on to consider, at the outset, the responsibilities of engineering and engineers vis-à-vis all else but humanity.

Pierce elected to address three broad topics or questions:

a. What is the actual power of our technology, and can it be measured?
b. Just what is "the natural environment" anyway?
c. What can we do with our technology, and what should we do with it?

My discussion and comments will be organized under these same three major headings for convenience. My discussion will vary from the equivalent of footnotes to Pierce's paper to alternate or added arguments and conclusions.

THE POWER OF TECHNOLOGY

Pierce answered his questions about the power of technology. I wish to make some added points.

The Man-to-the-Moon Syndrome

When the matter of technology arises, our effort to land men on the moon and safely return them to earth usually follows closely. Pierce put this undertaking into perspective very well. Though a "triumph of high technology," Pierce feels that Apollo had "little significance for everyday human activities." There were the obvious beneficial spinoffs from the effort; but there was, at least in my mind, a substantial negative spinoff as well so far as natural resources management is concerned.

Since the touchdown of our first manned craft on the moon, many have felt that technology could therefore triumph over any and all mere earthbound problems. Many of the same firms that helped put men on the moon switched, or tried to switch, to environmental and natural resources work as America's space trip slowed down rapidly.

Too many, including not only the technology people but many in the general public, felt that the awesome technology that put men on the moon, and brought us "Tang," could surely clean up our rivers, unsnarl our transportation mess, improve health care, and so on. But regular people and their natural resources are, some learned, not totally amenable to control and optimization like a stainless steel, solid-

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Another spinoff from Apollo, as I see it, was the idea that, if the nation throws enough dollars and technology at problems, they can be overwhelmed. (Pierce also speaks to this point later in his paper.) That has been tried with environmental and energy problems with mixed success.

In natural resources engineering, we also do a lot of "people engineering"; and we have to maintain a healthy respect for the differences between people and "things natural," as Leopold (8) would say, on the one hand, and objects, things, and problems that are completely described by and obey the immutable laws of thermodynamics and the like, on the other hand. The former are at least as complex as the latter, and our efforts as engineers are preordained to failure should we forget this.

The Practical as Great Monuments

I concur that our engineering feats pursuing practical ends are truly astonishing and rival the monuments humans have raised, and are raising today. Pierce alludes to the importance and magnitude of irrigation works in ancient times, as well as today in his home state of California. Since my principal interests are water resources and energy, I am also well acquainted with the great inland navigation, irrigation, flood control, and hydroelectric projects across our nation that have done, and will continue to do, so much for the nation's economic vitality. The U.S. Army Corps of Engineers and the Interior Department's Bureau of Reclamation have designed and erected many of the type of practical and astonishing works that indeed rival other human monuments per se.

Providing Material Goods

Pierce maintains that the power of our technology can be measured by the fact that only 15 percent of our people "supply the physical needs of the entire population." He points out further that our technology is well adapted to providing "material goods and services." "Our technology is very powerful indeed," Pierce states "in terms of producing what people need, or at least what Americans want."

The emphasis of this measurement and quantification of the power of human technology is clearly on the physical, the material. I would have little quarrel with this (since I have spent some years out in industry helping keep the wheels turning, producing physical goods) were I satisfied that we engineers in, or someone else, were giving appropriate attention to aspects in addition to the physical, the material, simply giving Americans what they "want."

I agree completely that being able to give our citizens the material things they want is truly indicative of a powerful technology. But are we, as engineers and in concert with others, discharging or sufficiently aware of our responsibilities to help define what our people—society in general—need? What is in their best long-run interest, and in the best long-run interest of our nation and our international posture?

Mine is not just a concern that we include the spiritual and esoteric in addition to the material in our plans and works. The attitude that may or could cause practitioners of our powerful technology to focus on the physical and the material goods has indeed massive implications for our natural resources and their wise use.

There is a growing interest in attempting to quantify, in some meaningful manner, the quality of the environment and the quality of life, both for comparison purposes and to describe trends. An example is the annual EQ Index (for environmental quality) compiled for eight years now by the National Wildlife Federation (11). It deals with the entire United States and rates resources separately—for example, water, wildlife, and minerals.

Ann Crittenden (5) recently reported the development of a physical quality of life index (PQLI) for nations. It is based on three factors: literacy, life expectancy, and infant mortality. (By the way, the United States scored 96 out of 100.)

It is to be hoped that we engineers are concerned about the total quality of life for the public, in addition to the fact that a shrinking percentage, now only 15 percent, is producing all our physical needs. We must be aware of the implications of our technology for the other 85 percent. And, when all the dimensions of the quality of life are considered, are the 85 percent, and the 15 percent, really better off because of our technology? I hope so.

Tomorrow's Different Problems

Pierce pointed out that, like pollution problems of the animal-power era early in this century, emissions from gasoline-powered vehicles, too, would vanish in the near future, if for no other reason than simply because we are running out of oil. I agree, for the most part, with Pierce that we must use technology to cope with current problems and that "present problems are problems left over from the past." He goes on to say that tomorrow and its problems will be "very different from the world of today and the problems of today."

With respect to energy, Charles Hitch (7) seemed to support, at least in part, this notion of great change for the future. Hitch stated that "we can expect that all kinds of unpredictable dynamic developments will occur during the next 25 years, let alone the next 1000." His editorial concluded with this sentence: "Our single clear criterion for the future is flexibility."

I am somewhat concerned, not so much with what Pierce is saying, but with what he could be construed as saying. One would be ignoring one's responsibilities if one were to interpret Pierce's message as: (a) problems that seem critical at some time fade into obscurity before too many years; and (b) since tomorrow's world and problems—and therefore the challenges to natural resources engineers—will be very different from today's, we will just take care of them then because we cannot anticipate them.

I do not believe that is what was meant at all. I believe the message is for us to cope successfully with natural resources and environmental problems on a current basis, so they will not become a heritage of dross to future generations. Since some natural resources and pollutant problems that are coming to the fore today are many orders of magnitude more complex, and persistent, than "horse dung" (nuclear wastes and persistent carcinogenic agents, for instance), the increasingly greater challenge to us to do a good job and stay ahead of the power curve is obvious.

Not too many years ago Kenneth Boulding (2) proposed, then rejected, this scenario:

> . . . The problems of the future can be left to the future. . . . The needs of the then present will determine the solutions of the then present, and there is no use giving ourselves ulcers by worrying about problems that we really do not have to solve.

In rejecting this attitude, Boulding argued convincingly that "tomorrow is not only very close, but in many respects it is already here."

It should be clear that we, as natural resources engineers, must do a better job of anticipating and predicting the impacts of our technology, the direct and the subtle effects, and feed this back into our decisionmaking processes. The most obvious and widespread opportunity to do this is the process of preparing meaningful environmental impact statements (EIS). As EIS frequently says much about the industry or the agency that prepares it. As stated well by the President's Council on Environmental Quality (4):

> The EIS itself is intended to be, and often is, the tip of an iceberg, the visible evidence of an underlying planning and decisionmaking process that is usually unnoticed by the public.

CEQ promotes, as I do, the "up-side" of environmental impact analysis (4): "Properly conceived and written, the EIS is an extremely useful management tool."

Humanity's Relatively Weak Technology

No one could possibly contest Pierce's contention that, in contrast to the power of nature, "our technology is puny indeed." He cites technology's biggest force, the hydrogen bomb, and compares it with a great earthquake or massive volcanic eruption. Human technology (in this case, a thermonuclear bomb) would indeed seem to release much less energy, inflict less direct physical damage, kill fewer persons at the time, and soon. But what about the longer-term effects? Are we, in reality, likely to be faced with a bomb and an earthquake, one-on-one? I submit that there are products of technology that, if utilized to their full capabilities, would have more impact, probably a longer-lasting impact, and certainly more trauma, than the forces of nature cited.

And, of course, there is another aspect of the comparison between the hydrogen bomb and, say, an earthquake. We could control our technology, whereas nature's hazards are beyond our control. Actually, though, we can probably design for, or otherwise minimize our risk from or exposure to, some natural hazards more readily than technological hazards. We can build earthquake-resistant structures, avoid certain types of development in flood-plains, for instance. But Pierce's conclusion that, though our technology is "weak compared with other natural forces, . . . it is powerful in altering human life," is inescapable.

Changes Made by Technology: Are They Significant?

Pierce contends that the changes on the face of the earth that occurred before the advent of human beings render changes made by humanity "insignificant" by comparison. I agree, and would hasten to say that, for example, if glaciers should ever come through this immediate area, both human improvements and abuses to the land would surely pale into relative insignificance. But we as natural resources engineers or whatnot are, I believe, as powerless to deal with continental drift as we are to do anything about the changes to the earth before the era of humans. Our only concern should be with the present and the future, dealing with that which is within our control, within our control as individual citizens, within our control as competent and responsible professionals, or within the collective control of humanity and its institutions.

Our planning horizon, even when it is long, is infinitesimal compared to geologic time. But I believe we can and do make changes to "truly alter the face of the earth." Though I am sure they will not last forever, the changes to the face of the earth in the strip-mined areas of Appalachia will go beyond our usual planning horizons. And the "changes wrought by humanity" around Copper Hill, Tennessee are, in my opinion, extensive and, it would seem, rather persistent.

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determine his or her own criteria as to just what constitutes a "major" human-induced change), and "it might be very difficult to make it happen." Quoting further: "Still, we should keep the possibility in mind." Again, I believe I know what Pierce is saying, and generally agree. If, however, someone were to misinterpret his message as: (a) this old world has taken a lot of licks and has not changed much; (b) it might be really difficult to cause a major change; (c) it could just possibly happen though; but (d) as a caveat, just to be on the safe side, watch out.

I believe such an interpretation could promote, or continue, natural resources brinkmanship. Somehow, we engineers have the idea that the processes we deal with are reversible. At least we hope so. If the environmental or natural resources analogy to "fatigue cracks" start to develop, we back off the load. Maybe we then slap on the equivalent of some super epoxy and see if we can go up to an even higher stress, before a new cracking point is reached. As Pierce says, in a way, no one has tested a world, or a "major" part of it, to failure yet. I hope, as the myriad pressures—old and new—being placed on our natural resources build up, we can and will "keep the possibility in mind" that, though nature is obviously resilient or in some cases malleable, failure is possible.

Although, as natural resources engineers, we have mastered much, we must maintain a healthy respect for failure, for discontinuities, especially as we sail into uncharted waters and encounter strange winds. This is to be expected, though, as we approach more closely the edge.

As my final comment on the power of our technology, I call to your attention another perceptive quote from Pierce, that "our technology changes profoundly those things that we deem important." So, in addition to the desired or wanted direct beneficial effects, the indirect, and perhaps the unanticipated, adverse effects will eventually be internalized. As Eugene Odum (12) said recently, "It is the secondary impacts that will get you if you do not consider the whole."

Of course, our technology also "changes profoundly" many things not "deemed important" by many, perhaps most, people. These may be some of the many small "cogs" and "wheels" that Leopold (8) spoke of. They may be important, even essential, but are not recognized as such. Today the responsible and perceptive natural resources engineer is going to recognize the true value of more "things" and "cogs" than his less well-informed, or perhaps even obsolete, peer.

WHAT IS THE NATURAL ENVIRONMENT?

Pierce effectively raised the vital, and normally overlooked, question: Just what is the "natural environment"? I do not believe he answered the philosophical question to my satisfaction. Nor, I freely admit, can I. But I shall add my perspectives in discussing several of Pierce's points.

Western Man and Genesis

In approaching the question of just what the "natural environment" is, or to deal with man-nature relationships, in general, perhaps the notion of Western man that he was given license to subdue nature, and all her parts, is a good place to start.

In policymaking circles today, people want to know where you are coming from. Perhaps we, as natural resources engineers and influential American citizens, should ask the same question. Roderick Nash (10) quotes from a pioneer settler's guidebook of 1849: "I vanquished this wilderness and made the chaos pregnant with order and civilization, alone I did it." John Wesley Powell and Gifford Pinchot were two prime movers in the development of this nation's land and water resources policy in the late nineteenth and early twentieth centuries. W. J. McGee, according to Nash (10) "a disciple of Powell and colleague of Pinchot," expressed an important attitude that prevailed near the turn of the century. Quoting Nash (10):

> The "Conquest of Water," W. J. McGee grandly declared, was as crucial to human progress as the "Conquest over Fire, Knife, Spring, and Wheel" and, indeed, "the single step remaining to be taken before Man becomes master over Nature."

And today our powers are, as pointed out by Pierce, "greater and more far-reaching" than those of "other animals." He points out that "no other animal has placed things on the surface of the moon or Mars, or has caused satellites to orbit the earth. No other animal has built works so complex as ours. . . ."

The conclusion is, I suppose, that our "technology" is superior to that of all the other species. I agree, but would add this thought: we are the only species that, in addition to being "intelligent" enough to do it, really cares whether things are put on Mars or not, or whether satellites orbit the earth or not. Such endeavors are of benefit to us.

As to whether water resources development projects, for example, are proportionately more "complex" than a beaver community's extensive water management program, I cannot say for sure. The latter's "technology" would appear to be entirely adequate to achieve the community's diverse needs. This "technology" of the beavers may have evolved over the centuries to the point where we might do well to study it, and emulate their example of optimizing resource utilization, their giving due regard to all the important and relevant constraints as well as the objective function, and their maintaining system stability in harmony with other systems.

Humanity as a Part of Nature

Pierce seems to argue that humanity and its works must be considered as a part of nature, instead of apart or aloof from nature. If his reasoning for this is to lead us to take what now exists and try to do the best job of managing it from here on out, I will not argue with him. It is frequently counterproductive to argue whether some section of a river or tract of land is (or is not) in a "natural" condition, and therefore suitable (or unsuitable) for preservation or some use. Too many parts of "nature" defy our attempts to ascertain their degrees of "naturalness," but responsible management decisions must be made.

In some notable instances, changes wrought by people give some areas greatly enhanced utility as "natural" areas, or at least areas possessing greatly increased values to humanity and other species. For example, many contend that the pools created to facilitate commercial navigation in the upper Mississippi River basin have produced a substantial net increase so far as fish and wildlife habitat is concerned.

Instead of dwelling on "nature," and whether man and his works are or are not a part thereof, I believe it would be much more useful to think in holistic terms of the total ecosystem. There can surely be no debate as to whether a person is or is not a part of an ecosystem, be it local, regional, national, or global.

Local and Transitory Changes

Pierce's position is most clearly articulated on the nature of humanity's effect on the environment. This effect, according to Pierce, "had been chiefly local and transitory . . . certainly so compared with those changes in the environment that have characterized geological history." For what it may add to this discussion, I quote Carl Sagan (13) on this topic:

> Science and, particularly, technology have not been pursued with sufficient attention to their ultimate humane objectives. For example, it has gradually dawned on us that human activities can have an adverse effect not only on the local but also on the global environment.

Sagan's views are echoed by Boulding (2), who stated that "fouling of the nest which has been typical of man's activity in the past on a local scale now seems to be extending to the whole world society." Ian McHarg (9) argues that major and long-lasting change to the landscape has taken place as a result of our activity. For instance, of the induced fire of the aboriginal hunter, McHarg says:

> Of the prairies there is hardly any trace and little more of the great beasts that once dominated them.

As previously stated, I believe there is room to differ as to how "local and transitory" some of humanity's effects have been. I must point out, though, that changes in the environment over geologic time allow for orderly adaptation or evolution of humans and all other life forms. Changes that take place according to the dictates of human institutions and enterprises, within our relatively short planning horizons compared to geologic time, may not allow for such evolution.

Pierce seems to point up a conflict in our view of change. First, "Most of the environment untouched by humankind is hostile" and, further, "it is the nature of humanity . . . to change its environment." But also, "In the very process of changing our environment, we become distrustful and wish, somehow, that things were still as they had been before"; and further, "we are the only creature . . . with a fear and distrust of change."

Pierce points out correctly that the human is not the only life form that effects change in the environment. Though other animals create some measure of change, and some even use tools, humans are the only ones that create new technologies. Other animals, other life, seem to desire principally to get along with their environment, that is, stay at equilibrium (dynamic as it may be in the short term) with other forces in the ecosystem. Humans seem to be the only ones that can, with the help of their technology, effect widespread environmental change, on themselves and all other species, in a planned way. They are the only ones that attempt to gain control of the ecosystem and modify the "natural" equilibria, attempt to drive the total ecosystem to a different final state, attempt to proceed there at a different rate. What are considered exogenous inputs to other species are, it would seem, but more knobs for people ("a part of nature," man the compulsive changer, man who fears change) to turn.

The fact that the great number of species that became extinct over geologic time prior to humanity dwarf the number since would seem to have little significance for the natural resources engineer of today. The fact that, for all I know, 10,000 species or subspecies or variants of, say, salamanders have gone by the board since time began is not, to me, a sufficiently compelling argument for letting another one or two go by. They may be wrongly viewed by us, perchance, as merely "uneconomic parts," when in reality they are necessary parts of Aldo Leopold's "biotic clock" (8).

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I would reiterate that our responsibility, as professionals and decisionmakers, is to do the best we can with what we have, giving both the present and the future their due, as contrasted with dwelling on changes over geologic time. I cannot differentiate between a "bug" that produces an intestinal disorder and one that could produce a new miracle drug to alleviate suffering worldwide. But I do hope someone who can, or might, is in the loop as species of plants and animals become threatened, then endangered, and finally extinct.

The same applies to valuable lands that are being "consumed"—productive agricultural lands and our prime wetlands, for instance. For some reason I am, at this point, reminded of the engineering executive who told me, not too long ago, "If you've seen one swamp, you've seen 'em all." To some, I suppose, pearls and pea gravel and purple-hull peas look about the same. But it is most unfortunate, in fact it is sad and even dangerous sometimes, when such persons are managing society's and the nation's natural resources.

WHAT CAN WE DO AND WHAT SHOULD WE DO?

Having addressed the questions of: (a) the power of our technology; and (b) just what the natural environment is or is not, Pierce proceeds to look to the future, the action phase. He poses two questions in one: What can we do and what should we do? I find these questions to be at least as difficult as did Pierce, who said he could not arrive at any clear notion of what we "should" do. I can only underscore a few of the several good points he made.

Reality and Expectations

Pierce does us all a great service by emphasizing the importance of knowing just what we, as natural resources engineers or others, can do. As he says: "If we do not understand our real abilities, we will mislead ourselves and other people." Considering our tremendous challenges in the environmental, natural resources, and energy areas, society can ill afford public disillusionment and a loss of credibility in those perceptive professionals who offer hope.

As a nation we could not "whip inflation now" by everyone's wearing a "WIN" button, or declaring that there was in effect a "project independence" for energy did not help get us through the bitter winter of 1977. There are no quick fixes. Any who would promise quick fixes or propose slogans in lieu of hard, realistic, and implementable solutions is merely exacerbating already critical situations—critical not only to our future quality of life but literally critical to our very national survival.

Throwing Money at Problems

Pierce emphasizes most effectively the fallacy of, as he calls it, "Mammon worship": throwing large amounts of money at problems to buy quick, and hopefully even easy, solution to hard problems. Unfortunately, too frequently the problem is that some agency has to obligate so many hundred million dollars by a certain date or lose it, or not have next year's budget increase. As Pierce points out, someone can always be found to spend the money. Too frequently there is, or appears to be, more concern with getting money and getting it spent and the related bookkeeping and endless "housekeeping chores" than with the quality of the product.

Energy Impacts on the Future

Pierce has much to say about energy, as well he should. It is unlikely that any major natural resources decisions in the foreseeable future will be independent of energy considerations. Many, perhaps most, will in fact be determined by energy dimensions.

The accelerating pace of energy-related change in the nation is illustrated by the following by Philip Abelson and Irene Tinker (1):

> What current U.S. technology would be useful to Third World countries for the long term? Much of the U.S. industrial and distribution system was designed to use abundant low-cost energy in the form of oil and natural gas. Now some of this technology is obsolete, and within a decade bulldozers will be knocking down facilities that were designed to use cheap fuels.

We as a nation have had tremendous faith in American science and technology. When something runs out or gets in short supply, a better substitute is always developed. The man on the street knows it is just this way. That may be a big part of our problem. Science and technology has always come through. With regard to energy and some other natural resources challenges looming large on the horizon, the ingenuity of American science and technology, and the will of our people, will in all likelihood be tested as never before.

Thinking of the Big Issues

I agree with Pierce that, whether we are talking about energy or any other really critical national natural resources issue, "high ability of the people who undertake the task is far more important than the total amount of money spent." He further suggests that we "support the very best people in a degree that seems reasonable to them." It is, unfortunately, sometimes difficult to do this in reality in the academic setting. When you identify high-priority research and development (or, for that matter, teaching) activities, then identify faculty (in-house or needs from external sources) capable of accomplishing such efforts in a scholarly manner, then concentrate enough resources there to get really substantial results, what have you got left? Too frequently you have a lot of nonsqueaky wheels also wanting to be greased. And the rusty wheels decry the notion of any priorities, preferring instead advocacy of the least common scholarly denominators, if anything. What excellence built is too often sacrificed to serve the endless needs of mediocrity.

Pierce is correct: there must be some, hopefully enough, individuals somewhere—in government, in the private sector, and in our universities with strong research capabilities—who are thinking and doing something innovative about the great and emerging problems of society and the nation. But it is hard to do this while burrowed down under endless minutiae or figuring out better ways to make left-handed wheelbarrows a little cheaper or out chasing Mammon's hubcaps.

Taylor Branch (3) speaks of "holy grail" agencies in the federal government as well as agencies whose mission is "delivering the mail." The same sort of distinction applies, of course, in industry and the academic community. Obviously, in the typical industrial, government, or university environment, more disciplines and departments and individuals will be figuratively "carrying the mail" than will be off searching for the "holy grail," that is, seeking innovative solutions to the really substantive questions of the time. Fortunately for the nation and its institutions, public and private, not everyone is off seeking the holy grail, else things would grind to a stop.

Perhaps the most difficult task, though, is for someone at a higher organizational level than the researchers—the "very best people" Pierce says need to be properly supported—to identify the areas to be pushed, and take the heat from those in nonpriority areas. These people topside, the upper layers of management, must frequently ask Peter Drucker's (6) basic question: What is our business, and what should it be?

CLOSURE

I wish to close with a final thought from Leopold (8):

> Man, while now captain of the adventuring ship, is hardly the sole object of its quest, and . . . his prior assumptions to this effect arose from the simple necessity of whistling in the dark.

We, as responsible natural resources engineers and decisionmakers, as managers and policymakers, as risk-makers and risk-takers, must become sufficiently aware of the current and, more importantly, the emerging resources challenges of our region and our nation, and what our options are. Better yet, we should take the lead in developing the options.

I believe we will be better able to discharge our responsibilities for having shared our thoughts at this symposium, better able to make the hard, but necessary, tradeoffs involving natural resources, tradeoffs that are intelligent and informed. I hope, also, that we find ourselves having to resort to "whistling in the dark" as infrequently as possible in the future.

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