THE PRICE OF FIRE:
THE APPLICATION OF MODERN TECHNOLOGY
TO THE IMPROVEMENT OF MAN'S ENVIRONMENT

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INTRODUCTION

The ancient Greeks would have understood why we are meeting here today. Their old myths tell of Prometheus, the Titan, who stole fire from the gods and gave it to man, thereby making civilization possible. This greatly displeased Zeus, and in his vindictive wrath he sent the woman Pandora to live among men. With her Pandora brought a large jar containing evil and toil and disease. The lid of the jar was lifted, and the curses within were released to torment men forever after. Fire and civilization finally blighted both man and nature. Through Pandora, men paid "the price of fire."

It is quite apparent that we are paying the price of fire today. The fire of modern industrial technology, in a literal and metaphorical sense, has brought us the blessings of an advanced civilization. It has also brought, as we now realize, the evils of Pandora's jar, in the form of a steady deterioration of our natural environment. Most advanced industrial countries, in other words, have purchased economic growth at the price of environmental quality. It is now obvious that we must reduce that price to its minimum possible value.

Until recently, the primary quantitative goal of sustained economic growth has been implicitly equated with an improvement of the quality of...

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This paper represents a somewhat modified version of a talk delivered by the senior author at the IV International Conference on Science and Society, "Science, Man, and his Environment," Herceg-Novi, Yugoslavia, July 3-10, 1971.
life. In many industrial nations, the demand for economic growth has been met — often with spectacular success. It is in the advanced industrial countries, however, that environmental by-products of this growth are beginning to conflict with the implicit goal of enhancing the quality of life. I am not going to attempt a catalog of those by-products. They are well known to most of us here. I shall be concerned rather with the ways in which technology may be applied to the solution of problems created by technology. Such a formulation may have the ring of paradox — and since some influential voices have recently been challenging this notion, I would like to explain my position.

It is perhaps helpful to remind ourselves — in the interest of historical perspective — of the great social and economic benefits conferred by industrialization, benefits sometimes neglected in discussions of the environmental depredations of technology. Such conditions as acute poverty, epidemic disease, and rigid social systems have been all but eliminated in most of the advanced industrial countries. The Industrial Revolution of the eighteenth century has brought in its wake revolutions in communications, transportation, medicine, food production, shelter, and — in a more abstract realm — social justice. More important, the benefits of these associated revolutions have accrued not only to the wealthy or the propertied classes, but over the entire range of the social spectrum. If anyone doubts this, I invite him to examine the life conditions of the typical pre-industrial European peasant — that is, the vast majority of the population at that time — as portrayed in numerous works of social and economic history. Life at that time, as judged by our standards — was indeed harsh. Epidemic disease, natural disaster, poverty, violence, and distant and largely unresponsive forms of government conspired to impose a kind of passive resignation on the many. The Industrial Revolution irreversibly altered those conditions, to the point where it is difficult for us today to project ourselves back beyond the economic statistics to imagine conditions of life that are already alien and almost incomprehensible.

I mention these benefits of industrialization, so obvious that we tend to take them for granted, because the existence of environmental problems today has generated in some quarters a reaction against the
idea of technology itself. It is perhaps a measure of our isolation from the past that significant numbers of our best educated youth perceive only the evils of technology and none of its benefits. The English author C. P. Snow has termed this revulsion from technology "intellectual Luddism," alluding to the bands of displaced workers, ostensibly led by a Ned Ludd, that roamed English industrial centers destroying the newly introduced machinery during the eighteenth century. The spirit of Ned Ludd stalks among us again today, too frequently animating those who should know better.

In essence, the anti-technology argument is simplicity itself: If the cause of so many of our current concerns is more technology, then the solution lies in less technology. It is perhaps in the pristine simplicity of this argument that we find its appeal. Declare a moratorium on science and technology, and the undesirable by-products of science and technology will vanish. The difficulty is that nearly everything else that we value will vanish too, including the hope of many millions in less developed countries today who see technology as their chief means of emerging from economic stagnation. The utility of technology lies in the fact that it is one of man's principal instruments for shaping the natural world to his will; and if we wish to restore our environment, it must be done through the intelligent application of these instruments.

A more defensible strategy, I think, would seek to curb the unrestrained and indiscriminate proliferation of technology where it impinges on the public interest. With that I think we can all agree, and indeed such measures are the subject of a number of papers at this meeting. But such a strategy is designed mainly to prevent matters from growing worse, and not necessarily to restore the sectors of our environment already damaged. To do that, we must utilize technology in a positive manner. What I would like to discuss today, then, are examples of some of the ways in which technology can be applied to the solution of our environmental problems. Paradoxically, the discovery of a social problem is sometimes stimulated by the discovery of its solution. At least a part of the concern with our environment in recent years may have arisen from the fact that a good deal of the technology for solving these problems is available today.
For purposes of discussion, I will divide environmental technology into two principal areas: monitoring technology and abatement technology. There is no sharp distinction between these, of course, and there is often a good deal of overlap.

**MONITORING TECHNOLOGY**

The uses of monitoring technology are at least twofold. One is to provide the basic empirical data necessary to construct analytical models of environmental regimes. These models will, in turn, help us to predict, and hopefully to control, the effects of alternative courses of action. The other is to allow us to measure the types, sources, and levels of potential and actual environmental damage.

The high-speed, high-capacity computer is one of the most versatile tools of the environmental scientist. It can be used both for the reduction of data associated with monitoring and measuring levels of environmental damage and for the simulation of environmental processes. At The Rand Corporation in California we have been using computers to model such phenomena as the dynamics of climate on a global scale. An understanding of global atmospheric circulation is essential to predicting the possible long-term climatic effects of atmospheric pollution. By deliberately changing the boundary or initial conditions of the numerical simulation, one may explore the climate's response or sensitivity to a variety of conceivable alterations. For example, we can examine the climatological effects of changes in the albedo of large areas of the earth's surface -- changes brought about, say, by changes in vegetation cover. At Rand we have simulated one such condition by assuming the disappearance of the polar icecap.\(^1\) The result was a net atmospheric temperature increase to the point at which the computation was terminated. Since each simulated year consumes 30 minutes of 360/91 time, our runs were relatively short term. In another application, a group at Stanford University, using the same atmospheric circulation model, has recently simulated the global transport of carbon monoxide generated in the industrial regions of Europe and North America.\(^2\)

On a smaller scale, a model of smog processes in the Los Angeles Basin has recently been developed at the University of Wisconsin.\(^3\)
Such models can be used to explore the various components of photochemical smog and the complex relationships among the various chemical, physical, and energy budgets involved. An understanding of these processes can lead to optimal siting of power stations or factories with respect to flow patterns and terrain configuration.

At Rand we are also developing computer simulation models to study the problems associated with water quality in well-mixed estuaries and coastal seas. By numerically integrating sets of equations, we have successfully simulated the movements of tides and dissolved waste constituents in Jamaica Bay, New York.\(^4,5,6\) A typical output of this work is shown in Fig. 1.

At Williams College in Massachusetts, a computer model has been developed to predict changes in shorelines of lakes or seas caused by changes in water level.\(^7\) Such a model would better enable us to plan homes, highways, and other features subject to damage by changing shorelines.

Advanced computer technology also permits the rapid collection and reduction of data from many sensor points. Used in conjunction with environmental simulation models, this technology permits the monitoring of environmental pollution and flow patterns on an experimental basis, thus providing a validation of a model's accuracy. For example, in the Jamaica Bay work we discovered the existence of a clockwise current in the bay set up by tidal action, a phenomenon since confirmed by actual measurements.

A wide variety of instruments and sensors is available for monitoring environmental processes. A potentially inexpensive means of carrying out comprehensive measurement programs is provided by the use of microelectronics. Since the preprocessing circuit logic in these instruments will eventually be simple and compact, they will be able to assume a greater share of the processing role. This will in turn reduce data telemetry requirements, and hence permit a narrower signal bandwidth. The compactness of microelectronic sensors with contiguous processing will also allow us to employ correlation techniques among sensors, and thus open possibilities of spectral comparison, signature analysis of particular chemical species, and so on. An example of a microelectronic
Fig. 1 -- Computed coliform density distributions from sewage plants at intervals of 2 hours and 4 minutes.
image-array TV camera is given in Fig. 2. It is formed by a matrix of 256 × 256 elements. Each element is a complete photosensor and electronic amplifier circuit. The scanning control circuitry is contiguous, and is made of the same materials as the image array. This device incorporates polycrystalline semi-conductor thin-film transistors, made by evaporation in a bell jar. This work is being done at RCA by Dr. Paul Weimer and has been carried out over the years on a modest funding level. The camera, incidentally, is hardly bigger than the transistor set you are now using. In fact we now have reasonably powerful, complete computers of this size.

Many of the previously described detectors and processing techniques have already been developed in connection with space-system instrumentation, and their adaptation to sensing and monitoring environmental conditions should be relatively trivial. One technology of great potential value is the use of high-altitude aircraft and satellite photography to survey, record, and map environmental conditions. The National Aeronautics and Space Administration is currently conducting or planning several environmental monitoring programs using various types of aircraft. In one of these, a multispectral scanning system has been mounted aboard a converted transport aircraft for remote sensing and processing of data related to geology, hydrology, agriculture, and forestry. The system is already demonstrating promising capabilities in flight tests. The scanning system gathers information at 24 wavelength bands between 0.34 and 13 microns. Data are processed and analyzed at the system's ground station, which consists of digital computers and a display console for monitoring imagery. Its ability to simultaneously monitor data from 24 different wavelengths gives the system great flexibility, allowing its application to such diverse functions as identification of mineral resources, monitoring volcanic eruptions and landslides, locating forest fires, determining the vigor of crops, identifying oil films on water, and predicting and assessing flood damage.

The National Oceanic and Atmospheric Administration now determines snow-pack thickness from aircraft through measurement of the attenuation of the earth's natural gamma-ray emission.
Fig. 2 -- Complete 256 × 256 element integrated thin-film sensor deposited upon two glass substrates mounted upon a printed-circuit board for convenient plugging into the camera.
In another project, NASA has recently applied remote-sensing techniques to the study of corn-leaf blight. Sensor-equipped aircraft were flown over fields at altitudes as high as 60,000 feet to monitor the spread of the disease and to determine whether remote sensing can assess the status of the blight and its impact on crop production.

In the field of satellite monitoring, NASA's Earth Resources Technology Satellite is scheduled for launch early next year. Equipped with multispectral sensors, the satellite will allow us to evaluate the kinds of information of utility in surveying and managing resources such as crops, fresh water, minerals, soil and vegetation, and even fish. Its sensors and high-resolution television system are intended to supply a complete resources map of the United States every two weeks. Estimates of the economic benefits accruing from the use of this system run to about thirty-six billion dollars a year, a remarkable return for the fifty million dollars a year it will cost to operate the program.

At Rand we are currently developing several techniques of pseudo-color enhancement for application to photo-interpretation work. These processes are used to transform photographically each density level in a continuous-tone black-and-white image into a different color in the enhanced image. The results are often striking, especially in aerial reconnaissance photographs. Their utility as an aid to environmental monitoring shows considerable promise. This technique is also being applied to the X-ray diagnosis of medical and industrial problems.

Laser technology is also beginning to find applications to environmental monitoring. Returns from multispectral laser beams are being used in direct monitoring of atmospheric phenomena, enabling this kind of device to function as a scanning spectrometer.

Recently developed high-flux charged-particle accelerators make it feasible to produce short-half-life radiochemicals for tracing estuary flow. Such nuclides would die out rapidly, a property that would facilitate temporal measurements and also would prevent the tracers themselves from becoming pollutants.

One of the most challenging and intriguing areas of environmental monitoring is earthquake prediction. The great destructiveness of earthquakes in densely populated urban areas makes it imperative to
find a reliable method of anticipating major tremors. The monitoring of such potential indicators as fault strains, ground tilt, magnetic field disturbances, concentrations of subterranean gasses, and other types of possible precursor activity should provide us with an adequate physical understanding of earthquakes. Such knowledge is not far off from three to five years, in one estimate. Coupled with automatic sensor systems, perhaps deployed in major fault zones, this theoretical knowledge should one day allow us to make reasonably accurate predictions of specific earthquakes. Probably further in the future, but not entirely unlikely, is the possibility of controlling or preventing earth tremors. Exploratory experiments are already under way in California and Colorado to determine the effects of altering subterranean fluid pressure along fault lines, through aquifers, with preliminary results that are encouraging.

In addition to the monitoring of local conditions I have described, there are plans to implement national and even global systems making extensive use of remote sensors, satellite observation, and computer processing. The technology for such systems is largely available now, and the principal difficulties concern such matters as funding, organization, and international cooperation. In the United States, our Government's newly established National Oceanic and Atmospheric Administration has given priority to the creation of a national environmental monitoring, predicting, and warning system. As planned, this system will eventually incorporate VHF-FM radio stations, satellites, computers, and a radar network to provide needed information about environmental conditions and events.

Although progress toward a global monitoring network is slow, preliminary steps are being taken. The General Assembly of the International Biological Program has recently accepted a report from a three-nation committee (the United States, Sweden, and the Union of Soviet Socialist Republics) providing a basic outline for a global environmental monitoring system. The proposed program has now been turned over to the International Council of Scientific Unions Special committee on problems of the environment. It is hoped that the United Nations will eventually be able to undertake the implementation of such a system.
ABATEMENT TECHNOLOGY

The other major area of environmental technology is abatement technology. In this category we find the various technologies that form the "cutting edge," so to speak, of environmental management. It is here that technology is applied to the prevention of environmental deterioration, the reduction of health hazards, the conservation of natural resources, and the aesthetic enhancement of man's environment. Since this topic is so broad, and the available technologies are developing so rapidly, I would like to discuss the various possibilities under a few headings by way of illustration.

Energy Production and Consumption

First let us look at the problems associated with the production and consumption of energy, an area of crucial concern in the advanced industrial countries. The present major source of commercial electrical power in the United States and in most regions of Europe is the burning of fossil fuels. These fuels are also a significant source of atmospheric pollution. Although there are several quite promising alternative sources of electrical energy on the horizon, which I shall discuss shortly, the greatest short-term need is for technologies that can effectively and economically reduce the amount of environmental pollution resulting from fossil-fuel burning.

A major possibility lies in processes for the gasification and liquefaction of coal.\(^{(19,20)}\) The United States Office of Coal Research is currently sponsoring development of two such processes, the Hi Gas and the CO\(_2\) acceptor process, and the United States Bureau of Mines is undertaking research on two alternative processes termed Synthane and OCR H-Coal. All of these appear promising, and one or more may be ready to provide a less-polluting large-scale source of electrical energy by 1980. In essence, the liquefaction or gasification process removes most of the sulfur found in coal or oil. The gas is then burned in a turbine generator system and the hot exhaust gases are used to produce steam for a steam turbine connected to a generator.
In addition to reducing the amount of atmospheric pollutants emitted, these processes would improve efficiency by using the now-wasted heat from gas turbines.

Other possible sources of electrical power often discussed are geothermal and solar energy, although both of these may suffer from economic considerations and constraints of climate and geology that would limit their use to a relatively small scale.

Looking further into the future, two of the most promising long-range, nonpolluting sources of energy are fast-breeder reactors and controlled thermonuclear power.

Electrical power demand is now doubling every seven years in the United States. Is this growth rate commensurate with proper ecological development or is it unnecessarily fostered by commercial power interests? Factors relating to this problem are presently under study at Rand for the National Science Foundation. One way to reduce per-capita needs would be the design of more efficient electrical appliances, particularly through the use of higher-temperature insulations and microelectronics. On the other hand, the development of an electric automobile and the substitution of electricity for fossil fuels in other applications such as the heating of buildings and refrigeration will add to the demands for electrical power. It is estimated that by the year 2000, the United States must add 1,600 kw of electrical generating power to its present capacity of 340 million kw. In view of this pressing demand, the rising costs of alternative fuels, such as coal and oil, in addition to their adverse environmental effects, and the dwindling supplies of high-grade uranium, a feasible fast-breeder program has taken on some urgency. (21)

Although the United States's current fast-breeder reactor program, sponsored by the Atomic Energy Commission, faces both technical and economic difficulties, this technology appears to be moving along reasonably well. Some authorities are in fact convinced that fast-breeder technology may be the only way in which the United States can meet its demand for electrical energy in the 1980s. One of the benefits of fast-breeder reactors is that they produce more fuel than they consume, converting uranium 238, an abundant, low-grade form of nonfissionable
uranium, into a greater quantity of fissionable plutonium. Glenn Seaborg, the former chairman of the Atomic Energy Commission, has stated that the breeder process "will allow us to stretch the world's known uranium supply from one lasting decades to one lasting centuries, even thousands of years."(22)

Further on the horizon, but no less important, is the prospect of obtaining cheap, pollution-free electrical power from controlled thermonuclear fusion. (23,24,25) If found feasible, such a process promises to provide man with a virtually limitless source of energy from the natural supply of deuterium in the world's oceans. Although the problem of harnessing fusion energy has been described as "probably the most difficult technical task that has ever been attempted, bar none," recent advances have been highly encouraging. One potential technique for avoiding some of the technical problems associated with "conventional" approaches to controlled fusion is the use of high-power lasers. (26) Recent experiments have demonstrated the possibility of initiating and controlling energy-releasing fusion reactions by focusing a laser pulse on a dense frozen pellet consisting of deuterium and tritium. In addition to allowing one to dispense with a confining magnetic field, this technology generates very high temperatures by using lenses and mirrors to focus high-powered radiation. If the feasibility of such a process is demonstrated, preliminary cost estimates show that laser-initiated fusion power plants should be economically attractive and competitive with fossil-fuel plants. It appears now that some type of fusion technology is closer in time than was once widely believed, so much so that some American researchers now believe that the feasibility of controlled fusion will be demonstrated before the end of this decade, with pilot fusion plants perhaps producing electricity by 1990.

Transportation

Transportation systems pose well-known environmental problems. A prominent source of harmful environmental and health effects, especially in the urban areas of the United States, is the extensive use of the automobile for private transportation. Indeed the health hazards posed by photochemical smog are of major concern today to urban planners and
transportation specialists -- to say nothing of the urban congestion posed by extensive use of the private automobile. New technology provides a number of possible approaches to this problem, and the transportation system that emerges will most likely combine several technologies.

New techniques for tunneling, for example, offer the prospect of dramatic changes in transportation patterns and distribution of utilities. Among the techniques for inexpensive, high-speed tunneling currently under investigation are lasers, electron accelerators, acoustic methods, chemical breaking or softening of rock, the ultra-high-pressure water drill, reactor-heated tungsten rods, and special shaped-charge methods. Electrically driven underground transportation systems could eliminate much surface freight and passenger traffic, with concomitant reduction of noise, unsightliness, and thermal and chemical effects.

Even the function of long-range aircraft could be supplemented by very fast electromagnetically suspended cars using superconducting current loops and travelling in evacuated tubes. (The technological feasibility of a lower-speed version of such a train, operating between urban centers at speeds of 300 miles an hour, is currently being studied by the Stanford Research Institute in California.)

Rand has been investigating a Very High Speed Transport (VHST) system that will be capable of speeds of thousands of miles an hour. With such a system it should be possible to travel from Los Angeles to New York in less than an hour in a train that is readily interfaced with local transit systems. At these speeds, new factors become important. Lateral accelerations play a dominant role, requiring that the evacuated tunnel have a highly defined guideway. This guide is formed by the electromagnetic fields that support and propel the vehicle. The fields must be carefully controlled to provide exactly the right configuration at each point.

The vehicle would contain superconducting loops that interface with travelling wave fields of the "stator" structure built into the guideway. In this manner the vehicle would essentially "surf" on an electromagnetic wave that is properly phased and oriented to both propel and support the vehicle.

Economic analyses show that more than 90 percent of the cost of the
VHST system will be tied up in the cost of the tunnel -- even with the most sophisticated vehicle and stator structure that can be conceived. Thus the most economical utilization of this hole in the ground is to drive the system as fast as possible. Even at the highest speeds examined (yielding a 21-minute transit time from Los Angeles to New York City) this still holds true. The power cost for this case is less than $2 per passenger trip, illustrating further that the "hole" costs dominate. Amortizing the system over 20 to 30 years could be accomplished with coast-to-coast passenger fares of $30 to $60. The principal barrier to the VHST, however, is the sheer magnitude of such a project, which may discourage its initiation.

Incidentally, since tunnels can be bored under the ocean -- particularly at a mile or less in depth -- there are possible routes that could connect the United States with Europe (via Canada, Greenland, and Iceland).

An additional benefit of such tunneling technology would be the employment of underground superconducting power cables to eliminate much electrical power distribution loss and provide greater flexibility in the location of power-generation stations. (The curtailment of the aesthetic blight of overhead power lines is another obvious side benefit.) Underground superconductors would also allow more efficient siting of power plants to minimize thermal and atmospheric pollution near densely populated areas and to reduce costs of fuel transport. Taking into account various economic, environmental, and technical factors, optimum siting could be determined by computer modeling.

Mutual economic benefits can result if the VHST tunnel complex is used for additional transportation systems, such as a collocated 100-mph steel-wheels-on-rail freight system with gondolas capable of carrying standard freight cars. Interfacing everywhere with existing rail lines, such a system could transport (in one dual coast-to-coast channel) seven million tons of freight a day. Other uses of the tunnel complex include pipelines for oil, water, material slurries, mail, and wastes, and communication links comprising cables, wave guides, and laser channels.
Another transportation technology under investigation -- the electric car -- would preserve the benefits of private transportation but eliminate many adverse environmental effects of the internal combustion engine. The major outstanding technical problem in this area involves developments in electrochemical batteries and fuel cells. At Rand, we have recently reviewed a dramatic breakthrough in power cells by a large industrial firm that may offer a feasible solution to the power problem. (This work is still in the proprietary stage, so that no details can be given.)

External combustion engines using the Stirling cycle may provide advantages over current IC engines in reducing pollution from oxides of nitrogen. Philips Cie. of Eindhoven now have a demonstration bus run by such an engine. The engine is also nearly noiseless and vibrationless, characteristics that promise to help alleviate "sound pollution" problems.

Waste Disposal and Waste Prevention

Another environmental problem on which a great deal of ingenuity is currently being expended is the disposal and utilization of sewage, trash, and waste. This is probably the single environmental problem that has received the most public attention in the United States, partly because the growing pollution of lakes and rivers has had a direct and immediate impact on the recreational activities and health of millions of persons. To give some idea of the scope of the problem, it is estimated that Americans generate 360 million tons of household, commercial, and industrial wastes each year, or more than 10 pounds of solid refuse per head per day, and this amount is increasing. In addition, thousands of millions of gallons of sewage are produced each day. Of the solid wastes, more than 90 percent are sent to land disposal sites, only six percent of which are sanitary landfills (landfill areas around some major cities are rapidly disappearing). Most of the rest is incinerated. Of the 17 trillion gallons of ground and surface water used by industry each year, less than 5 trillion gallons are treated before discharge, the remainder flowing into our rivers and lakes despite increasing efforts to
control these effluents. Waste disposal is unquestionably becoming a problem of horrendous proportions.

Although much remains to be done in this area, technological progress appears to be fairly rapid. One of the most intriguing aspects of this problem is that it encourages us to turn a sow's ear into a silk purse.

There are several principal ways in which we may process or utilize waste: recycling, adaptive processing, and what one of my colleagues at Rand has described as "positive pollution."

The recycling of wastes is a rapidly growing industry. 52 percent of lead consumption in the United States, 45 percent of the copper and brass, 30 percent of the aluminum, and smaller percentages of other materials are now being satisfied from recycled wastes. One company, for example, has plans for a plant that will accept anything from beer cans to tires, shred it into small chunks, separate the materials, and produce marketable granules of glass, steel, aluminum, and shredded paper. (28) The plant will eventually have a capacity of handling 570 tons of refuse a day while turning out 262 tons of reusable materials. Another plant will be able to turn 130,000 tons of refuse a year into 52,000 tons of raw materials worth about 830,000 dollars. Using mostly conventional technology for shredding and incineration, this plant will incorporate a recovery unit newly developed by the Bureau of Mines for separating metals. The final products will be separated into five categories: nonmagnetic glass, magnetic glass, ferrous metals, nonferrous metals, and sand. Another optional unit will reclaim up to 400 tons of fiber a week.

In another process, road-building materials are recycled from ground glass, plastic containers, and rubber tires. This "Glasphalt" is being tested in many parts of the United States, and could cut road-building costs by as much as one-fifth.

Another interesting technology, developed by E. I. du Pont de Nemours and Co., (29) is a polyamide hollow-fiber process for removing salts from brackish water to render it suitable for human or industrial consumption.
These are only a representative sample of the kinds of recycling technology presently under development.

What we have called "adaptive processing" represents another area of waste-disposal technology. As distinguished from recycling, this class of processes transforms otherwise useless waste into specialized materials.

One new company, Ecology, Inc., grinds up trash and "digests" it biologically until all organic matter is reduced to a fine, crumbly compost. This compost is then turned into fertilizer in the usual way, by adding chemicals containing nitrogen, potassium, and phosphorus. This process sacrifices nitrogen -- later added -- by breaking down cellulose in stacked digester trays.

Another interesting process, developed at Louisiana State University and still in the experimental stage, breaks down solid cellulose wastes to convert them to edible protein. Using cellulose-metabolizing bacteria, researchers are presently trying to develop an economical animal feed, and hope to eventually refine the product for humans. Present cost estimates indicate that the material will be cheaper than fish-protein concentrate.

At Virginia Polytechnic Institute and State University, experiments are under way to process fly ash from electrostatic precipitators for use as a soil enricher -- fly ash contains certain trace elements required by plants.

Ecologists are increasingly tending to view sewage as "resources out of place," not waste, and are developing adaptive processes to convert it into useful material. At Pennsylvania State University, pilot projects are being conducted in which treated sewage is sprayed on marginal soils instead of dumped into waterways. Sewage effluent from cities and towns is released into aeration lagoons for biological treatment by bacteria. It will then flow into storage lagoons capable of holding the effluent during the nonirrigation season, from whence it will go to spraying irrigation devices. Corn will be grown on the irrigated fields.

"Positive pollution," as the term suggests, relies on application engineering more than developments of new technologies. To cite a
few examples, it has been found that thermal by-products of industry, such as heated water, can benefit mariculture. In one cooperative endeavor, the Long Island Oyster Farms in New York is utilizing thermal effluent from a fossil-fuel plant to stimulate oyster growth. Weight increases have also been demonstrated for certain types of fish in a number of rivers receiving heated effluents from industry. Utilization of thermal effluents from nuclear power-generation stations in mariculture in the Pacific Northwest has resulted in large-sized rainbow trout that are grown in a very short time in a controlled experiment by the U.S. Bureau of Fisheries. Along the coast of California, sport fishing has been aided by sinking discarded automobiles and streetcars offshore to provide holdfasts for kelp growth and shelters for the fish population. As these artificial reefs disintegrate every three or four years, there is a continuing need for these junk products.

As I have indicated, modern waste-processing technology is a relatively new field of opportunity, and appears to be advancing so rapidly that it is becoming increasingly competitive with older methods of disposal such as incineration. One would hope that eventually the utilization of waste might be optimized by the inter-industry exchange of waste products adaptable to specific recycling processes.

Recycling, however, while a useful expedient, really affects only one end of the problem. A more effective approach to the waste-disposal problem, in the long run, is to find ways to eliminate or reduce input waste.

A present disturbing trend is the tremendous proliferation of paper products. Parkinsonian increases in administrative organization in government, business, and industry are demanding ever-increasing documentation and distribution of copies of such documents. Issues of daily newspapers sometimes exceed 300 pages; a trainload of newsprint comes into the New York area every day, for example. The Xerox machine has made duplication readily available and widespread. The paper packaging of food and other products is increasing exponentially. The result is, of course, not only detrimental to resources such as forests, but also imposes great demands on waste management.
One promising remedy for this situation is to replace paper in communication processes by the use of electronic display. The daily newspaper, for example, can be replaced by use of an adapter attached to the home television set that makes it possible to selectively redisplay any particular frame of a sequence of many frames. At The Rand Corporation, we are presently investigating such a device based upon a simple disk-type video recorder. This same system will also permit multiplexing several television programs over a single channel. This feature offers new approaches in both education and in television for developing countries as well as a mechanism for two-way communication with the TV viewer.

As I have mentioned previously, we are on the brink of a new era of microelectronics. Miniature TV sets are one obvious application of this new capability. Such sets could use flat, array-type displays analogous to the microelectronic image array I have previously described. The "newspaper" attachment described above could incorporate metal-oxide-silicon memories for buffer storage of the video frames. Thus a future device combining TV and a selective-frame capability could be simple and portable, use small penlight batteries, and also be inexpensive, reliable, and rugged. It would cost no more than the present day shirt-pocket transistor receivers, and need only be large enough to afford a reasonable size for a viewing screen.

The implications of such a device are obvious. Similar devices can be employed in industry, commerce, and government for individual viewing of information which can be stored, retrieved, edited, and modified by a computer. Thus much of the snowstorm of paper for communications could be replaced by appropriate microelectronic devices. As a collateral benefit, a particular document could be kept in a completely current state, since modifications or additions could be easily made through communication with the computer. The newspaper version of this scheme could be kept continuously up to date with the latest news as well as the latest advertising specials, etc.

Color is another dimension that can be added to the various devices discussed above. Since we now are using the techniques I have described for communicating with computers, all of these devices may some day be available to users at all levels.
Recent developments in computers permit us to display information in both color and in three dimensions (3-D). Thus an architect can produce a rendering of a new building on a computer and then view it in 3-D. By suitable control of computer output he can also view his rendering from various perspectives. Further, he can readily change its shape, stretch it, or reorder it at will by issuing simple instructions to the computer. The coupling of this latter feature of presently expensive computer displays to the low-cost portable data terminal discussed above is obvious. The 3-D effect can be produced by miniature TV screens for each eye. The entire terminal becomes a pair of "spectacles," with the microelectronics built into the frames.

Similar types of spectacles can also be devised by coupling the image array previously described to the microdisplay array. In this way the user can be equipped with night vision, an ability that could reduce the need for large-scale ambient lighting of the environment at night. (The same pair of spectacles could be used for both the data terminal and the night-vision functions.)

One initial question is how we might convert from present-day mechanisms to this new method of communication. The portable TV-receiver/data-terminal progression is fairly straightforward. Most present-day business typewriters cannot communicate with computers, and the development of reading machines to input textual material to the computer is an expensive and difficult process. We already have prototype devices, costing only a few dollars, that can be attached to an ordinary typewriter to encode its output in a binary form. Once the text is in this form, all of the communication, storage, and editing functions of the computer can be exploited. The written draft of the speech that I've presented here today was edited and typed on a computer. Changes in its structure, such as the insertion or deletion of material, were much easier than by conventional methods.

The applications of the developments described above to communications are multifarious. Microelectronic logic circuitry can aid in compressing textual and other material sent over data links. The links themselves can utilize laser beams in enclosed channels, permitting,
for example, multi-locational conferences that will obviate the need for travel. Visual and other information links can assist doctors in performing remote diagnosis. In conjunction with local paramedical personnel, this application may greatly facilitate medical treatment, particularly in remote or primitive areas.

Another source of waste is food containers. Recent developments in the use of nuclear radiation for the sterilization of food should eventually help here, but there is a further need for biodegradable or perhaps even edible packages.

Going further, it should be possible to greatly improve industrial processes that are now major sources of pollution and waste production. The same sensor and computer technology I have discussed in connection with environmental monitoring can also be employed at the factory or power station to monitor and control production. Equally important is the application of advanced technology, including lasers and microelectronics, not only to control pollutants, but to modify or optimize basic industrial processes themselves. High-capacity computers and modern analytical techniques can also be applied to the redesign or optimization of many industrial processes.

The potential benefits of these technologies are twofold: (1) production cost savings resulting from increased efficiency, and (2) the effective management and disposal of industrial wastes. These techniques may allow the factory of the future to produce at about the same cost while still meeting strict environmental control regulations. Such technology will partly overcome the difficulties raised by Professor Tepina regarding the economic aspects of technology versus environment in the newly developing countries. It might prove feasible for these countries to develop new processes that would be highly competitive with those of the more developed nations, and that at the same time would be designed for minimum impact on the environment.

Computers and computerized design and production will play a significant role in the architectural design and construction of future cities. Already we have methods of directly transferring architectural coordinates into both computer-output blueprints and displays. The
latter output enables the user to visualize configurations on a three-dimensional basis from all possible vantage points, and to change scale or shape at will. Other computer programs optimize layouts of such systems as sprinkler piping. Optimal civic planning is a natural follow-on to this work. Siting for the transportation and communication systems described above can be planned by the iterative fitting and search capability of the computer. The various alternatives in ecological planning must be thoroughly analyzed. It is one thing to solve a transportation problem with a tunnel or a freeway; it is another to take into account its possible aesthetic effects and its impact on socio-economic patterns.

These computer-aided optimization processes can be extended to the analysis of appropriate development strategies for emerging countries, including such factors as scale and organizational structure (for example, the concept of polycentric development).

This cursory survey of environmental technologies can hardly do justice to the scope and variety of developmental work underway. Considering the apparently inexhaustible possibilities of technology, we have barely begun the task of harnessing its vast energies in the service of environmental management. Perhaps the second industrial revolution, in which we now find ourselves, can also foster another revolution in the quality of human life.

CONCLUSION

Before concluding, I would like to add a caveat or two concerning the field of environmental management. First, I am not suggesting that technology represents the only solution to environmental problems. Appropriate legislation will have to provide the incentives for effective action, and much economic analysis and interdisciplinary research remains to be done before we understand in any depth the complex interactions of legal, economic, ecological, and technological factors involved. What is important, and what appears to be emerging today, is the institutionalization of concern for environmental problems, so aptly pointed out by Professor Meadows. My own Government has recently established several large agencies whose primary responsibility lies in the area of environmental management, and the scope of their activities is likely to grow with time.
There are a good many -- often conflicting -- interests and motives involved in effective environmental management, and a quite useful administrative and analytical goal would be a sorting out of environmental objectives and a rational assessment of priorities. Many of the new agencies, however, are unschooled in the process of mounting large R & D programs on the scale demanded by our growing ecological problems, and a certain amount of organizational learning will be necessary.\(^{(35)}\)

The second point I would like to leave with you is that it is important to notice that the problems of environment encompass a good deal more than the effects of man's activities. Climate, weather, natural disasters such as earthquakes, forest fires and floods, animal and plant diseases, and so forth, are all part of man's natural environment, and until recently we were largely powerless either to anticipate or to avert their consequences. With intelligent environmental management, man's ability to manipulate and control these phenomena should grow also.

Technology is indeed a mixed blessing. In Los Angeles, California, we have seen our green spaces transformed into a concrete desert and our air saturated with smog by the advent of freeways and high-speed automobile travel. The Indians of the Amazon Basin are benefiting from communication through the transistor radio and from the new forest marginal road that is opening up the "Yungaz" regions. Along with these benefits, however, they are also experiencing exploitation by individuals and groups that now have greater access to them.

We must therefore understand that every solution is a new problem, and for the foreseeable future we are going to have to run as fast as we can to balance our budget of problems and solutions. There is the ever-present possibility, voiced by Dr. Trapnell of NSF, that we have already passed the point of no return in critical environmental areas. It is difficult for man to perceive exponential processes wherein the acceleration is accelerating. If on the other hand, effective policies and incentives can be devised soon enough to focus technology on these vexing problems, the time scale for finding solutions might also be exponentially foreshortened.
I am confident that technology can be brought to bear upon all of the tasks I've described above, and many more. However, I am far less confident that mankind -- enmeshed in its web of conflicting interests and parochial concerns -- will be able to effectively plan and manage for the future. "Prometheus" in the ancient Greek tongue meant "foresight." In the long run, our ability to extend the blessings of Prometheus's gift of fire will depend on whether we can also appropriate the foresight of the gods and couple it with the more human qualities of persistence and intelligence. It is here that the real challenge lies.
REFERENCES


