The University and Environmental Research

The bandwagon of saving the planet from environmental pollution and from suffocation is well occupied now. Indeed, everyone is on it. Being on it is rather like being against sin, and, as in the case of sin, the universal practice is to point the finger at other people. But in the case of pollution few have so far approached the sinners' bench to confess. The universal enthusiasm for preventing environmental pollution and the equally universal reluctance to admit responsibility for it raise a serious question in my mind as to whether the nature and magnitude of the problem are understood.

The concrete actions necessary to limit man's effects on his environment through his own consumption and behavior will strongly affect us all in what is likely to be —at least initially—a very painful way. For we are all involved—not just the engineers who design the automobiles and the manufacturers who make them and the salesmen who sell them and the oil companies that produce the gas to run them, but the consumers who buy them on the basis of large size, rapid acceleration, and all the other characteristics that increase the contribution to environmental pollution.

Who is responsible for solid wastes? Not only the container manufacturers who produce no-deposit, no return, throw-away containers, which neither decay nor rust. Equally—or more—responsible are the consumers, you and I, who buy the products and throw away the containers without making any effort to separate them so that the reclaimable can be reclaimed.

Another example. Americans consume electric power at the rate of about one kilowatt per person 24 hours a day. We are very proud of that consumption rate; we often describe it as having the equivalent of a large number of mechanical servants working for each of us. However, the power is almost entirely produced from fossil fuel. Its consumption thus contributes substantially to the sulphur dioxide contamination of the atmosphere in many places, and contributes about a quarter of the nitrogen oxides released to the air of the Los Angeles Basin.

To a rather good approximation, the three basic factors that multiply together to give a "figure of demerit" for total adverse impact on the environment are:

(1) Total population.
(2) What we have been accustomed to think of as the average standard of living.
(3) A coefficient corresponding to the degree of attention paid to environmental quality in making industrial, agricultural, or consumer decisions.

Recently we have been concentrating on the third of these, but we must remember that it is the enormous growth of the first two factors which has created the danger. Reducing the coefficient cannot save us if we let the first two remain unbounded variables. Specifically, no cure for environmental problems is possible unless the population of the earth, and of the U.S., stops growing.

For example, the stationary power production in the world is a function of total population and power per person. In thermal terms it amounted to about 3×10^{18} calories in 1967 in the United States, and about 10^{19} in the world. The sun irradiates the earth with about 10^{24} calories per year, and the earth absorbs perhaps half of it, so the ratio of solar energy to locally developed energy is "only" 1/500 of 1 percent. If earth population doubles by the year 2000, and the rest of the world demands electric power consumption per person equal to what the United States now has, the 1/500 will become 1/50 of 1 percent, still leaving what is probably a safe margin.

But by that time the atmospheric CO_2 content will be 25 percent more than it was in 1900, because the principal power source in the 20th century is fossil fuel. If fossil fuel continues as the principal source of energy in the 21st century, the "greenhouse" effect of the CO_2 could cause a substantial atmospheric temperature rise, with unknown but possibly very serious effects. This assumes that a possible contrary effect—reduction of radiation reaching earth by the increase of particulate matter in by Harold Brown

Being on the bandwagon to save the planet from environmental pollution is like being against sin. As in the case of sin, the universal practice is to point the finger at other people.

the upper atmosphere from combustion—does not take place in a magnitude sufficient to reduce the earth's temperature.

Looking at this kind of problem, we must face up to the fact that when we talk about polluters—the guilty ones in connection with the environmental health question —we mean us, all of us. We would do well to remember this as we seek solutions.

It is probably good that everyone is in on the act now. At Caltech, and at many other universities, the problem attracted attention some time ago. I need only mention the name of Professor Arie Haagen-Smit, who, about 20 years ago, undertook to investigate what produces smog in the Los Angeles Basin. You will recall that at the time everyone knew the smog to be entirely the result of backyard trash burning. Haagen-Smit investigated the chemical constituents of eye-irritating smog, examined the complex photochemical reactions among some of the sources, and was able to show that the bulk of the end products could be traced to automobile emissions and some stationary power plants.

But university participation in altering the environment goes back to a still earlier time. In the case of Caltech, for example, it includes the work on bringing the water supply into the Los Angeles Basin and also the design of the electrical transmissions system back in the 1920's. It includes the fundamental aeronautical design which led to the development of the aircraft industry, and to the jet aircraft whose exhausts at present contribute about 10 percent of the particulate matter to the atmospheric pollution. Thus I would certainly be the first to acknowledge that Caltech's technological contributions of the past bear some of the responsibility for the environmental problems which we face.

But we have also for a long time been interested in their solutions. For well over 20 years now Caltech has carried on work in environmental engineering, with faculty members such as Jack McKee, Norman Brooks, and Sheldon Friedlander doing research and training undergraduate and graduate students in problems of environment and ecology, and of waste disposal. In the early 1960's extensive laboratory research facilities in the William M. Keck Laboratory of Environmental Health Engineering were set up to advance this activity, and the Kerckhoff Marine Laboratory at Corona del Mar has been doing work in marine ecology for a long time. Last year, recognizing that the need for protection and control of man's environment had reached the crisis stage, Caltech instituted a specific degree program in environmental engineering science leading to the MS and PhD degrees.

What can the university do about the protection of the environment? The answer will be different for each institution, depending on its size, its specialties, and its particular interests.

All universities are dedicated to scholarship and to teaching. In the case of environmental pollution and control, as for other situations, the university's contribution will be new knowledge and able people. Some also have developmental adjuncts—for example, the Jet Propulsion Laboratory of Caltech. The developmental and systems engineering capability they provide can help deal with problems which have reached crisis proportions. But by and large, the university will not be unique in this particular capability.

What the university at its best may be able to contribute, and which will not be available elsewhere, is a critical look at problems and at proposed solutions. The university, on the other hand, will not be very useful at spending the $3 billion which it is estimated will be spent by the federal government over the next ten years for water purification. And indeed, the universities won't be getting any of that money. That program turns out to be one of matching funds to help support municipal and water district construction costs. It does not contain money for research or for training, though minor amounts may be found for these elsewhere in the federal budget.

Thus, activities of all the universities taken together will be swamped by the total needs—and the total expenditures—on environmental protection and control.

"I would be the first to acknowledge that Caltech's technological contributions of the past bear some of the responsibility for the environmental problems which we face."

This is probably as it should be, because research and training costs are likely to be a tiny fraction of the over-all cost of programs which are concerned with altering, avoiding, or suppressing the undesirable by-products of large-scale manufacture and consumption. Still, it is worth noting that research and teaching costs are small. And even in the league of total funding for university research and training, the size of the activity on the Caltech campus will be small, simply because we are a very small institution.

But despite this, we decided to take a look at some parts of the environmental problem. We wanted to educate ourselves to the current state of knowledge. We wanted to probe more deeply into the situation so as to be able to decide what we ourselves might be able to do. And we picked, as is natural to the inhabitants of the Los Angeles Basin, the smog problem. As a result we believe we understand better the smog problem and some of the things that need to be done. We also are somewhat reassured that some of them apparently are being done.

In going at this problem at Caltech, we had the advantage of having a number of people who were enthusiastic about tackling it. In particular, about three months ago Professor Carver Mead of our engineering and applied science faculty volunteered to enlist other faculty people to spend a fraction of their time, small or large, to take a look. They would examine not only the scientific and technical situation but also, so far as they were able, the economic, social, and political context in which that situation exists. About 25 other people contributed from 10 percent up to almost 100 percent of their time during the past three months. The group included three or four people from the Jet Propulsion Laboratory who were able to make use of the facilities there for computation and design. Many of the participants were professionals who already are deeply in this matter, such as faculty in our chemistry and chemical engineering division who have, over the past couple of years, put together a model for the purpose of forecasting smog production and distribution in the Los Angeles Basin. The study was funded from Caltech's own funds and from the JPL Director's Fund set up by NASA to allow JPL to engage in a small amount of this kind of research.

The group examined the various kinds of atmospheric pollutants and their sources. It looked at the projections of what is likely to happen to each of the pollution components as a function of time in the future. This was done for various assumptions about the controls to be imposed, made possible by technology which is now available or in sight. As I said, the group also looked briefly at the larger context of these technical questions.

Without going into all of the details—the group will be issuing a final report shortly—here are their conclusions and some of the possibilities which they think are feasible as a result of future development.

First, the breakdown of pollutants according to source and the future projections (based on specific assumptions) made by the Air Pollution Control District of Los Angeles County last year in *Profile of Air Pollution Control in Los Angeles County* have been generally confirmed by the Caltech study group. This should not be a surprise to anyone who has followed the work of the APCD or followed the available literature in this field. But I know that APCD was glad to have an independent group confirm their calculations and analyses in this regard, and I think this points out the value of an independent critical group which can be provided from the talents available at a university.

To summarize these results, about 90 percent of the carbon monoxide and high reactivity organic gases (hydrocarbons) in the Basin come from motor vehicles, as do about two-thirds of the nitrogen oxides, and 40 percent of the particulate matter. Forty percent of the sulphur dioxide (which has a rather small emission in Los Angeles compared to most eastern industrial cities) comes from the chemical industry, with smaller fractions coming from motor vehicles, from petroleum evaporation, and from stationary power plants. These latter also contribute about one-quarter of the nitrogen oxides and

"Environmental and ecological studies are more like chess than checkers. You must play two or three moves ahead."

about 10 percent of the particulate matter. Organic solvent usage contributes about 40 percent to low reactivity organic gases, and aircraft about 10 percent to particulate matter.

The reactive hydrocarbons and nitrogen oxides undergo photochemical reaction in the atmosphere in the presence of sunlight and oxygen to produce eye-irritating smog and ozone which, although not the producer of eye irritation, has its own bad effects. Because ozone is produced and moves with eye irritants, it is a good measure of their presence.

Sulphur dioxide emission in the Los Angeles Basin, as a result of the use of low-sulphur fuel, is actually less than it was in 1940. Carbon monoxide increased by a factor of four from 1940 to the mid-1960's, but has now begun to come down again as a result of the recent controls on carbon monoxide emission from motor vehicles. With the present control program it should keep falling, until in 1980 it will be near the 1940 level. Hydrocarbon emission from motor vehicles almost quadrupled from 1940 to the mid-1960's but has now begun to come down again as a result of the control program. With the present control program it projects to reach the 1940 level again in about 1980, despite the estimate of increasing auto use in Los Angeles. Nitrogen oxides rose by about a factor of five from the end of World War II to the mid-1960's. Then, as a result of the methods used to control exhausts of hydrocarbons and carbon dioxide, mainly consisting of introducing more air at a point of high temperature in the combustion cycle to burn the carbon and hydrogen more completely, the nitrogen oxide emissions began to increase still more rapidly, so that in 1970 they are over seven times the end of World War II level. The control program now being introduced should begin to bring that down, but even with the present control program the nitrogen oxide emissions will by 1985 still be about two and one-half times that of World War II.

This increase in nitrogen oxides has prevented the decrease in eye-irritation and ozone which would otherwise have resulted from the decrease in reactive hydrocarbons. But the projected drop in nitrogen oxides in the early 1970's should pay off in eye-ease.

All these improvements are feasible, the Caltech study group concluded, under the new standards to be imposed on piston engines through 1972, and they can be achieved with currently available technology. So, probably, can the more stringent standards which the ACPD has proposed through 1975, which could reduce auto emissions further into the 1980's.

The group suggests that the addition of catalysts to the fuel to break the repeated photochemical cycle, which allows nitrogen oxides to produce eye-irritant by-products more than once, should be considered again. Like so many ideas in the control of air pollution, it was originally suggested as a possibility by Haagen-Smit 15 years ago. The additive originally suggested, iodine, has the disadvantage that a small fraction of the population is sufficiently sensitive that it would probably cause much more damage than it would prevent, but there may very well be other such additives which do not have such effects.

An additional conclusion of the group, which was simultaneously (or even earlier) reached by others, as can be seen by the actions they have taken, involves the removal of lead from gasoline. The direct health effects of lead are arguable, but its elimination makes it easier to take other pollution reduction steps in the engine and exhaust. Both the auto manufacturers and the gasoline producers have made it clear that this is not only feasible but will begin to be done in a year or two.

Environmental and ecological studies are more like chess than checkers. You must play two or three moves ahead. Let's do that in this case. By the early 1980's, nearly all autos then in service will have incorporated what is now seen as the limit of economic technology available to reduce pollution in piston engines. But numbers of people and automobile use will continue to rise, so pollution will start up again. The more restrictive standards projected for the mid-1970's could delay this upswing by a few years. Unless a different cycle—

"Unless Caltech can contribute something unique, we don't want to add another element to the activities that have been generated by the enthusiasm to protect the environment."

electric, steam, gas turbine, or some combination—is employed for vehicles, the air will start to increase in pollution contamination again in the early 1980's. It is time to think about new power cycles—and new transportation systems—and to begin some development work.

These projections also assume that as the nitrogen oxide from automobile emissions is reduced, parallel efforts will be made to install equipment in the old stationary power plants burning fossil fuels to reduce their nitrogen oxide emissions. Otherwise, by the mid-1980's they would be producing as many tons (250 per day) of nitrogen oxide as would the motor vehicles. And in addition, these projections assume that essentially all of the new stationary power plants in the area will either be nuclear or be outside the Basin itself. My personal opinion is that because in southern California they can be sited on the ocean where the thermal problem will be less severe than it would on rivers, practically all new stationary power plants should be nuclear in this area. I recognize that such plants have by-products which must be carefully controlled or else they can present a hazard too. But one must weigh various alternatives and choose what seems to be the least damaging. Another alternative, still less feasible, is to forego added stationary power generation entirely. No one seems to be willing to do this for himself, although perhaps he is for the other fellow.

I noted that the projection is for emissions to begin rising in the mid-1980's. This will occur because the population will continue to rise.

Perhaps the most important conclusion of the Caltech study group is that there are other factors which are as important or more important than the technological ones. If the Los Angeles Basin environment is improved, as the APCD and other studies show that it can be, demographic forces will come into play which have a strong effect. The population is likely to increase in this Basin more rapidly. So you see that not only technological and economic, but also political and social factors enter.

Furthermore, one must consider the fact that it will take regulatory agencies of various sorts to produce the improvements that we foresee.

Why? In simplest terms, suppose a $200 increase in cost per automobile is involved in the changes in design that will reduce its smog production by a factor of ten. If the individual consumer is offered a choice, he will probably conclude that spending the $200 extra will bring him almost no benefit—the smog level will be reduced by one four-millionth in the Los Angeles Basin, and reduced no more for him than for his neighbor who buys a car without the smog-reducer. Result—no action.

Shouldn't the auto manufacturer then take the initiative? One could say that if all of his cars have the smog reducer and cost the extra $200, the consumer will have no choice. The catch is simple to understand. Suppose there are no governmental regulations which require all new cars (and later, all cars) to meet the anti-smog standards. In that case the auto manufacturer who puts the smog reducer on all his cars and charges the $200 will eventually go broke, since the consumer will buy his competitor's cheaper but smoggier vehicle.

Thus governmental regulation—local, federal, or both —is required in such forms as legislation, taxation, setting of standards, and inspection. But this regulation itself can create problems.

In the past, as some of the social scientists who have participated in the study pointed out, the regulatory agencies have had unforeseen and not always beneficial effects in the long run. They have tended to identify in one way or another with what they have been regulating. Therefore, new ways of going at the problem which involve substantial changes, in terms either of technology or organization, have tended to be suppressed. This has happened in communication; it has happened in transportation. It can well happen in the case of the ecology and control of the environment.

What lessons have we drawn from our study at Caltech? First, the technique of gathering an interested group of which not all members are expert on the specific problem

"We are thinking about a laboratory concerned with air pollution, solid waste disposal, urban mass transit, water use, noise reduction—in short, an Environmental Laboratory."

to be examined, but some, instead, in the disciplines which are its constituents, can well be applied to other environmental problems. Second, all environmental problems will benefit from the critical look that can be given by a nongovernmental, nonindustrial group. A university group can offer critical and expert appraisal of complex problems in a way that perhaps no other organization can. This can, I think, be of particular value to government agencies and to industries which want information but have learned to be a bit wary of the judgments or solutions they themselves will produce, given the institutional bias which they will tend to have toward those problems about which they know the most.

Finally, those who did the study at Caltech have one very strong cautionary note, and I agree with them. If such a study group consists only of scientists, technologists, and production people, it will almost certainly overlook some of the most important factors and come to the wrong conclusions. Unless expert social scientists are available—and I mean not only economists to examine the economic balance, but political scientists, sociologists, psychologists, and so on—the study will be done in too narrow a context. Although it will give the right answers to its own questions, it will prove to have overlooked questions more important than those which it asked.

What does this all mean to Caltech's own plans with respect to activities connected with the protection of the environment—not just air pollution, but other aspects as well? A group of Caltech and JPL people, headed by Professor Lester Lees of our engineering division, has been looking at this question. Unless Caltech can contribute something unique, we do not want to add another element to the near infinity of activities that have been generated by the universal enthusiasm about the protection of the environment.

What we are thinking about is a laboratory which would be concerned not only with air pollution, but with solid waste disposal, planning and development of a rational urban mass transit system, water use and reuse, reduction of noise emitted by stationary and moving sources—in short, an Environmental Laboratory. A reasonable size to aim for would be 25 to 30 professionals, plus part-time activity by interested Caltech faculty and student. Its staff would need to include economists, systems analysts, social psychologists, and other social scientists.

The social science capabilities would be added to the expertise already present at Caltech and JPL in photochemistry, combustion and chemical kinetics, instrumentation, atmospheric modeling and fluid mechanics, bioengineering, and systems development (especially the problems of interfaces in complex systems). These talents suggest that a most important function would be to provide advice to government agencies and legislative bodies, including independent and objective evaluations of various proposed technical solutions.

I could give a long list of technical questions that need examination by such a laboratory. It would range from work on the fluid mechanics and chemistry of the internal combustion engine to the dynamics of the atmosphere of the Los Angeles Basin; from instrumentation for measuring emissions from pollution sources and the atmosphere, to fuels and additives to inhibit the emission of nitrogen oxides, hydrocarbons, and carbon monoxide. But I want to note that it is easy to find problems in technology, economics, systems design, psychology, or planning—problems which need solution if we are to minimize environmental pollution. Finding the appropriate organizational structure and the necessary funding support is more difficult.

For these reasons, Caltech has not made a decision on whether and how to proceed with such a laboratory. But organizations—more than one—that can handle these disciplines and produce fresh answers to these changing problems will be needed if the human race and its environment are to remain compatible. Only a few years ago, most of us would have assumed that if the two became incompatible, we could easily change the environment to restore a safe balance. Few of us believe that any longer.