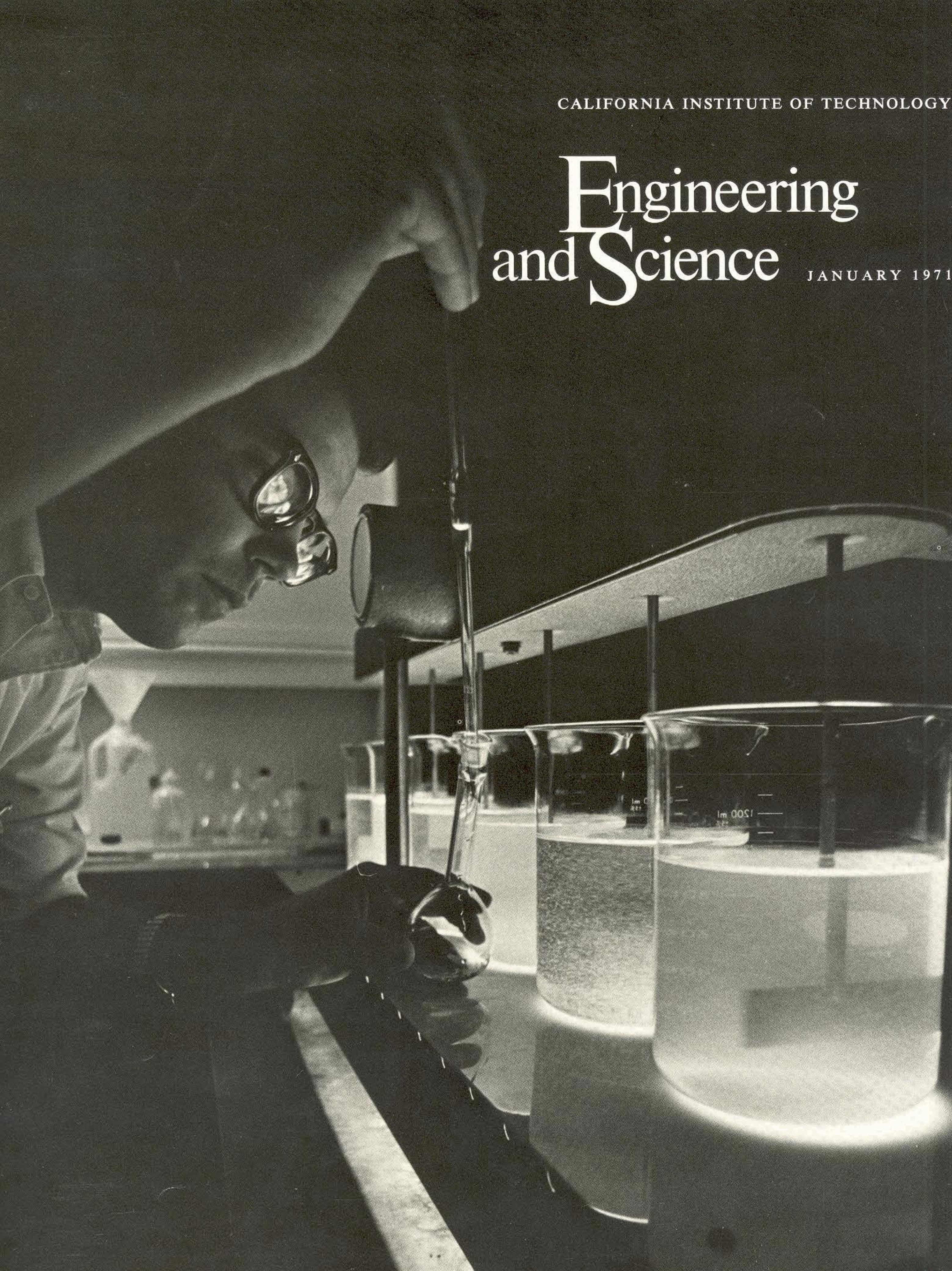
CALIFORNIA INSTITUTE OF TECHNOLOGY

Engineering and Science

JANUARY 1971



"They encourage us to look for original solutions to problems. This sparks inventiveness."

Bill Greiner, Western Electric

Bill Greiner's problem: shaving 10-14 seconds off one operation in the manufacture of integrated circuits, while reducing error factor below .001 inch.

Bill is a staff member at Western Electric's Engineering Research Center, working primarily with the handling and testing of integrated circuits.

Bill came to Western Electric in 1968 after receiving his MS from MIT. He earned his BS in Mechanical Engineering at Yale.

"My work here has given me a better appreciation of the problems in manufacturing," said Bill. His automatic TV system for the alignment of integrated circuits is a good example.

At one phase of the manufacturing process, operators must correct alignment of integrated circuits by hand—*a job that took up to fifteen seconds,* and was accurate to only .001 inch in x and y, and to one degree in rotary.

What Bill did, essentially, was design and build a small dedicated computer that completely automates the process. An operator can push a button to align the integrated circuits automatically. A TV *camera enlarges the image in silhouette form,* scans the pattern, and feeds the voltage signal into Bill's computer. The computer calculates the position measurements and triggers a stepping table to correct the alignment.

The correction time is reduced to one second, the error factor to .00025 inch in x and y, and ½ degree in rotary.

Bill finds the challenge of electronics and logic design extremely stimulating. "We're not channeled: we have a chance to get involved in a variety of fields."

What does he find most satisfying about his *job at Western Electric? "Well," said Bill, "I look* for an amount of responsibility. And here I'm encouraged to take it."

Western Electric

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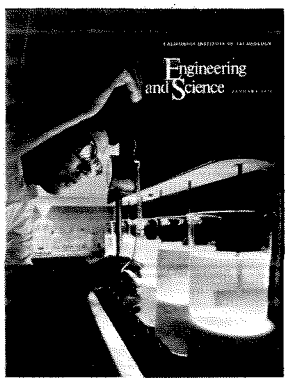

In this issue

The Environment

On the cover—Dennis Kasper is using chains of electrically charged molecules (polyelectrolytes) to hook submicroscopic particles together in water, causing the particles to aggregate and sink to the bottom as sediment.

Kasper is a PhD candidate in Environmental Engineering Science, a new academic program at Caltech that involves teaching and research not only in engineering but in chemistry and chemical engineering, geology, biology, and the social sciences as well. EES is already emerging as a new applied science that brings together engineering and ecology for the solving of specific problems. "Doctors to the Environment" on page 14 tells about this program and some of its current research projects.

The new action-oriented Environmental Quality Laboratory is another major innovation in the Institute's rapidly intensifying focus on environmental issues. Even in its initial studies, described on page 11, the EQL is raising fundamental questions about the quality of life as a whole in southern California. Eventually, its findings and recommendations may influence the decision-making processes in government and industry.

Technological Change and the Human Environment was the concern of a Caltech conference last fall, and the Institute brought in environment specialists from all over the world for the meeting. Two of the most challenging papers given at that conference have been adapted as articles for this environmental issue of *E&S*—"Trend Is Not Destiny" by René Dubos (page 5) and "Energy and the Environment" by Norman Brooks (page 20).

STAFF: *Editor and Business Manager*—Edward Hutchings Jr. *Associate Editors*—Jacquelyn Hershey, Kathleen Marcum, True Seaborn, Laurie Spaulding/*Photographer*—Floyd Clark.

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If you are a senior...

1971

TREND IS NOT DESTINY

by René Dubos

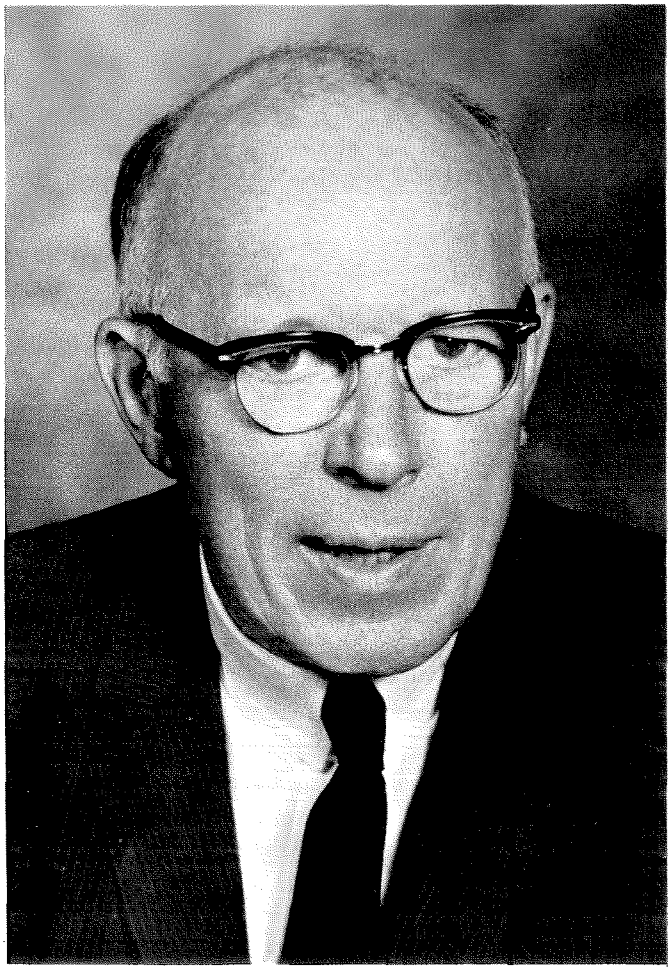
People who are worried about where Western civilization is heading usually ask, "Where is technology taking us?" They should begin to ask, "Where do we *want* science and technology to take us?"

I was raised in farming villages of the Ile de France, close to Picardy and Normandy—on a land which has been under cultivation for some 4,000 years. It is a beautifully humanized land, very different from the primeval forest out of which it was shaped by neolithic and medieval farmers. It remains highly fertile despite 40 centuries of intensive use. It supports a great variety of human settlements—hamlets, towns, and cities—in which human life continues to evolve culturally and to enrich civilization.

These observations on my native country apply just as well, of course, to other parts of the world. Many ancient lands of Europe and Asia remain beautiful and fertile despite the constant pressure of high population densities over more than a thousand years. Even in North America, some of the most attractive and prosperous farmlands are found in areas that have been continuously under cultivation since they were created out of the forest three centuries ago, for example in the Pennsylvania Dutch country. All over the world man has thus been able to transform the wilderness into lands that are ecologically sound, economically profitable, and propitious to the development of civilization. With proper care, furthermore, such humanized lands and the villages, towns, and cities they nurture can be maintained in a healthy state seemingly forever.

And yet! Human history is replete with ecological disasters; the most famous places of antiquity seem to have been struck by a kind of malediction. Mesopotamia, Persia, Egypt, West Pakistan were once the seats of flourishing civilizations which remained powerful and wealthy for long periods of time, but they are now among the poorest countries of the world. Their lands are desert, many of their ancient cities abandoned; and most of their people are so poor, malnourished, and diseased that they have no opportunity to become aware of their magnificent past. Since much the same is true for large parts of India, China, Southeast Asia, and Latin America, there is extensive evidence for the thesis that all civilizations are mortal. Prolonged occupation by large numbers of men has caused in most cases a wearing out of the land through overuse or misuse, and a destruction of human settlements through civil strife, warfare, famine, and disease.

Unwise management of nature, technology, and human life can destroy civilization in any climate and land, under any political system.



René Dubos, Professor of The Rockefeller University, Department of Environmental Biomedicine, is a microbiologist and experimental pathologist with a distinguished career in medical research. His intense concern with the effects that environmental forces exert on human life has involved him in the socio-medical problems of underprivileged communities, as well as in those created by economic affluence in industrialized countries. Dubos is well known as a lecturer and author and received the Pulitzer Prize in 1969 for his book So Human an Animal. *"Trend Is Not Destiny" is adapted from a talk given by Dubos at a Conference on Technological Change and the Human Environment, held at Caltech October 19-21.*

These contrasting views of the relationships between civilization and the environment may not be as incompatible as they appear to be. All great Eastern civilizations which have died along with their worn-out lands were located in arid and semiarid zones. Their demise has been attributed to the fact that, in these parts of the world, agriculture depends on continuous irrigation which—slowly but almost inexorably—causes irreversible damage to the land. In contrast, Western Europe and Japan (and certain other parts of Asia) are blessed with a much greater and more constant rainfall, which enables the land to recover rapidly even when it has been impoverished or damaged by ecological mismanagement.

Climatic conditions, however, cannot entirely account for the sudden disappearance of the Maya, Khmer, and other great civilizations that once flourished in tropical, humid countries. Nor do they account for the rapid deterioration of land, air, water, and cities that is now occurring in many parts of the technological world, irrespective of soil and climatic conditions. Unwise management of nature, technology, and human life can destroy civilization in any climate and land, under any political system.

But there have been many forms of human interventions into nature that we regard as having had beneficial effects. Ever since neolithic times and all over the world, social institutions have created artificial systems which have proved ecologically sound and humanly desirable.

Much of the world in temperate climates used to be covered with forests and marshes which were progressively converted into farmlands—each area developing its own agricultural specialization, social structure, and esthetic quality. The process of change, furthermore, continues as new technical or human needs develop. For example, the enclosure landscapes, so characteristic of eastern England and of French Picardy, are entirely man-made. They were created a few centuries ago for very special agricultural and social reasons.

The temperate forest can undergo desirable humanized transformations other than being converted into farmlands. In Europe parts of the primeval forest have remained forests, but have been carefully cropped and managed for several centuries without decreasing productivity in timber. In Scotland and eastern England, lumbering and grazing slowly pursued over several centuries have progressively transformed forests into moors, which may not be economically productive but have added romance and poetry to English literature. In the United States, fires set by the preagricultural Indians converted part of the primeval forest into the prairies.

These few examples illustrate that man has often created new and desirable environments by accidental or willful interventions into nature. I repeatedly use the word *desirable* to acknowledge my anthropomorphic attitude in ecologic judgments. Ecologic purists notwithstanding, I believe that in the final analysis all ecology is anthropomorphic. When the ecologist laments that modern technological civilization transforms urban areas into environments which are fit only for rats, roaches, and ragweeds, he obviously judges the situation from man's point of view, not from that of rat, roach, or ragweed. Except in the case of absolute wilderness, most of the earth's surface has now been transformed by human activities to serve human ends. In this sense, man is a component of ecological systems; ecology is to a very large extent human ecology. The problem is not whether man will or will not transform nature, but how he will do it. Sound ecological management always implies long-range considerations so as to maintain nature—humanized nature—in a condition suitable for the welfare of generations to come.

Man's interventions into the natural world have progressively led to technological civilization, which in turn has brought about the present environmental crisis. But this unfortunate course was not inevitable and is only the consequence of failure to understand the role of technology in human life.

This role includes the choice of goals, which is as important a part of technology as is the development of tools and methods. Increasingly, however, the technological enterprise proceeds as if its end were growth for growth's sake rather than human welfare. The environmental problems of industrialized societies are largely the product of undisciplined technological growth; they do not arise from technology per se, only from man's surrender to its destructive demon.

The present popularity of ecological thinking is due to the widespread awareness that many things that can be done should not be done because they threaten the quality of our life and our environment. The most important problem today is not to produce more goods and services but rather to reorient technological activity toward the satisfaction of real human needs.

The guidebook to the Chicago World's Fair of 1933 provided an interesting illustration of the extent to which many reasonable and well-meaning people believe that man exists for the sake of technology rather than vice versa, thus implicitly but unconsciously accepting goals that are incompatible with the welfare of mankind. On the assumption that technological development is the same thing as human progress, the writers of the guidebook confidently affirmed that "all races would fall in step with . . . science and industry"; they summarized this shocking social philosophy with the formula

Science finds
Industry applies
Man conforms.

Acceptance of the view that man will *fall into step* and will *conform* implies that we must adjust to the environment as created by industry, instead of designing living conditions and environments really suited to man's nature.

Environmentalists are often accused of being soft-headed and unrealistic daydreamers when they assert that continued technological growth is incompatible with the maintenance of a world suitable for man, unless it is redirected to more suitable goals. Fortunately, there are built into the physical world certain constraints that will inevitably limit technological growth. Shortages of natural resources are the most obvious of these constraints. But the availability of power will almost certainly be the first limiting factor, even if new kinds of low-cost fuel become available and if the production of clean nuclear energy by fusion becomes technologically possible. The limitation will come, not from shortages of energy sources, but from the fact that the injection of excessive amounts of energy into natural systems inevitably disturbs their operations and commonly leads to ecological upsets resulting in unpleasant living conditions.

The population avalanche is, of course, one of the important factors in the ecologic crisis, but it is not the most immediate danger in the countries of Western civilization for the following reasons. The population of the United States is increasing at a rate of approximately 1 percent a year. In contrast, the consumption of electric energy and the accumulation of wastes are increasing at the rate of 6-8 percent a year—which means that they will double in less than ten years! In view of these facts, environmental degradation and loss in the quality of life will continue to accelerate very rapidly in the United States even if we succeed in achieving zero population growth, which is a practical impossibility for several decades.

The impact of technology constitutes a more immediate threat to the quality of human life than the population bomb, and it will be far more destructive in the long run because many of its effects will be irreversible.

The impact of technology therefore constitutes a more immediate threat to the quality of human life than the population bomb, and it will be far more destructive in the long run because many of its effects will be irreversible.

The present trends of technological civilization are clear enough for anyone to see, and even the village fool knows that maintaining them would lead to the destruction of mankind. And yet the writings of sociologists or technologists rarely reflect awareness of this fact.

Futurists write learned books and fanciful articles about the mechanized and synthetic world of the year 2000. But direct extrapolations from the present into the future have a very low order of probability. Indeed, history gives little support to the current belief that the technological forces set in motion during the past few decades will shape the rest of our lives.

It is wise to remember, for example, that the sophisticated administrative structure of the Roman Empire was rapidly upset by the meek Christians and then by the uncouth barbarians; that the overambitious towers and ogives of Gothic cathedrals were rejected by the Renaissance architects; that the academic art and bourgeois conventions of 19th-century France were destroyed by a small band of Bohemians in Paris.

Time and time again the logic of historical and technological trends has had to yield to the choices and decisions of individual men. Similarly, one can anticipate that changes in life style, and the influence of a few strong personalities—and perhaps acts of collective sabotage—will direct our civilization into channels incompatible with the predictions of technocratic futurists, based as they are on extrapolations from present trends. Furthermore, it is almost certain that the kinds of scientific and technological knowledge now being developed will have much less influence on the future course of civilization than the new kinds of knowledge and the new ways of life we shall have to develop if we are to overcome the ecologic and social dangers now threatening mankind.

Stating the problem in its most general way, it is certain that all ecological systems, whether man-made or natural, must be managed in such a way that they are self-regenerating with regard to both energy and materials. We cannot afford to delay much longer the development of a nearly closed system—a dynamic steady state—in which materials will retain their value throughout the system by being recycled instead of discarded.

The concept of "dynamic steady state" is so different from the social philosophy of endless quantitative growth which has guided Western civilization during the past two centuries that it will certainly cause public alarm—a fear that it spells stagnation eventually to be followed by decadence. Yet a dynamic steady state is compatible with *creative* changes of a qualitative nature, provided we accept a reorientation of the scientific and technological enterprise.

The present trends of technological civilization are certainly destructive; but they are not irreversible. On many occasions in the past, the course of social events has been changed by willful acts; this has occurred even in the very recent past, for example, during the two world wars and the space race. Men need not be passive before the technological enterprise. Trend is not destiny.

But a range of qualitative changes are made imperative by the environmental crisis and demand creativeness from ecologists, technologists, and social planners. For example, the use of the land is governed at present by the crassest economic considerations instead of by biological common sense. We must learn to recognize the limitations and potentialities of the land in the various areas of the earth. Since we have enormous latitude in changing the face of the earth, we can, unfortunately, expect that hasty and massive transformations of the earth's surface will occur frequently in the near future. A new kind of ecological science is therefore needed to provide rational guides as substitutes for the empirical and unconscious adjustments that the lapse of time used to make possible in the past.

Classical ecology will not be sufficient. The traditional ecologist tends to be satisfied with studying the natural evolution of systems toward their state of equilibrium—what he calls a climax or mature ecosystem. But in reality the concept of ecologic climax is a postulate that hardly ever fits reality. Final and stable ecological communities are exceptional in nature; ecological systems continuously change, even under natural conditions.

All over the world, natural ecosystems are being destroyed by human activities, and yet human intervention need not be ecologically destructive. There is strong evidence that, in the past, developmental ecosystems (as contrasted with climax and deteriorating ecosystems) have resulted from careful agricultural husbandry. The ancient civilizations that have survived and become wealthier with time are probably the ones which learned, empirically, to manage their ecosystems according to a developmental pattern.

Traditional ecology must be supplemented by the kind of knowledge that will help to predict the likely consequences of technological and other interventions by man. One can safely assume that developmental ecology with man as a major component of the system will increasingly become more important than climax ecology.

New scientific knowledge will be needed also for creating environments really suited to man's biological and psychological needs, which are easier to understand when it is realized that the cradle of *Homo sapiens* was on the plateaus of East Africa. More than a million years ago the human species emerged in a land of hills and valleys, of springs and streams, of varied forest trees, shrubs, and herbs. Our early homes were probably alluvial plains and rock shelters in cliffs. The climate was subtropical, with alternating rainy and dry seasons and with growing and resting periods of vegetation. All in all, this was a type of landscape, vegetation, and climate that most people still associate with pleasant living conditions.

Despite the tremendous changes in the ways of life and in the technological environment that have been constantly occurring during the past 10,000 years, there is no evidence that the genetic constitution of *Homo sapiens* has changed significantly. Modern man still operates with the equipment of genes that governed the life of the paleolithic hunter during the Ice Age and of the neolithic farmer after the ice had retreated. This genetic constancy still conditions all aspects of human life and probably accounts for the fact that human tastes concerning landscape and climate still reflect the natural characteristics of the savannah regions in which *Homo sapiens* achieved his biological identity. Take, for the sake of illustration, man's temperature requirements, his response to crowding, and his need for sensual perceptions.

Temperature requirements. Physiologically, man is still a subtropical animal. Wherever he goes, he tries to create around himself a microclimate as similar as possible to that which prevailed in his evolutionary cradle on the East African plateaus. This is true even of the Eskimos.

As the explorer Vilhjalmur Stefansson picturesquely stated in his book *The Tropical Life of the Polar Eskimos*: "During winter, the Eskimos lived in homes that were stationary tropics. When they went out of doors, they carried tropical warmth with them inside their clothes." And so do the astronauts in their space capsules. Whenever he can afford it, man is likely to seek some Mediterranean, California, or Florida shore if he can no longer cope effectively with the northern climate.

Early man was also conditioned during his evolutionary development by the diurnal and seasonal temperature cycles of the earth. These cycles are inscribed in his genetic constitution and thus govern his physiological and mental processes. The technology of air-conditioning, therefore, should be geared to the cosmic cycles reflected in man's biological nature.

Response to crowding. Man is a social animal. This suggests that early man lived in groups of fairly high density. Even when the total world population was extremely small, local population densities were commonly high. There were crowds in the paleolithic rock shelters and caves, in the neolithic settlements, in Imperial Rome, in the medieval towns, and also in the Pueblo villages. One can postulate, therefore, that most human beings are genetically capable of achieving adaptation to crowding. This does not mean, however, that they can successfully adapt to all the environmental insults which are associated with crowding in modern life. Indeed, it is likely that man will never be capable of achieving complete adaptation to stresses that the human species did not experience during its evolutionary development—such as certain forms of chemical pollution, high levels

Men need not be passive before the technological enterprise. Trend is not destiny.

of noise (and of other unnatural stimuli), the rapid changes in population structure resulting from increased mobility, and the loss of opportunity to function as individual persons or as significant members of the group.

Much of social planning is bound to fail because it is based only on technological, social, or economic considerations, rather than on man's unchangeable biological and psychological needs.

Need for sensual perception. Recent experiments have shown that healthy human beings rapidly suffer mental breakdowns when deprived of stimuli—even when they are placed under otherwise optimum conditions. Sensory deprivation is incompatible with the maintenance of sanity and in fact results in profound and lasting disturbances of encephalographic patterns. Monotony is therefore much worse than simple boredom. Its consequences are truly antiphysiological in that they are reflected in disturbed organization of the brain and perhaps indirectly in abnormal functions of essential organs.

To live is to respond, and the diversity of stimuli thus becomes a part of functionalism in the design of human settlements. Human beings, furthermore, differ in their genetic endowment and therefore in the kind of environment most suitable to their existential expression. Diversity of environments may interfere at times with efficiency of administration. But diversity is more important than efficiency in the long run, because it provides the substratum out of which individual human beings and their societies create the multifarious expressions which exist potentially in the human species and can become expressed only when conditions are suitable.

Persons who are worried about the trends of Western civilization are prone to ask plaintively, "Where is technology taking us?" We should begin to ask instead, "Where do we want science and technology to take us?" There probably cannot be any precise answer to this question because the future is always emergent and therefore cannot be completely planned. But we should acknowledge at least that passive acceptance of undisciplined technological growth is a form of social escapism which amounts to collective suicide. Until a few decades ago, it was still possible to believe that all technological innovations would eventually prove useful to mankind. But experience has now proven that this is not true and that as a consequence, feasibility is not a sufficient criterion for decision and action.

We must learn to regulate the interplay between man and his total environment. Unfortunately, successful regulation is far more difficult than increased production. For example, any competent engineer can learn to produce bigger and faster motor cars in ever greater numbers. But a much higher degree of technological imagination and social awareness is needed to make the automobile industry serve real human needs and values. The viability of our civilization clearly depends on a reorientation of science and technology, but such a necessity should cause no alarm about the future. One of the hopeful aspects of our times is the widespread acknowledgment that, if things are in the saddle, it is because we have put them there. And it is within our power to reverse that situation.

The general awareness of the defects in our present ways of life has already created beneath the surface a social climate that will enable the buried seeds of a richer human culture to root and grow. This does not imply that the past should be forgotten or rejected since the new growth can prosper only on the compost from many various cultures, including the technological culture. What it means, however, is that we must not consent to think of the future only as an extrapolation of present trends. Mankind will achieve salvation and continue to grow only by integrating the store of accumulated knowledge with the yearning for elemental modes of life. Scientific humanism can thus serve as a guide to technological man for a second chance to discover the good life, if he is willing to retrace the steps that led him on the dubious road that we now call progress.

Thoreau introduced his *Walden* with a statement of faith: "I do not propose to write an Ode to Dejection, but to brag as lustily as Chanticleer in the morning, standing on his roost, if only to wake my neighbors up." More prosaically, but in the same spirit, I repeat my own optimistic version of the humanistic faith: Trend is not destiny.

EQL

The Environmental Quality Laboratory—a new action-oriented venture at Caltech—will try to convert environmental research results into technical and social change.

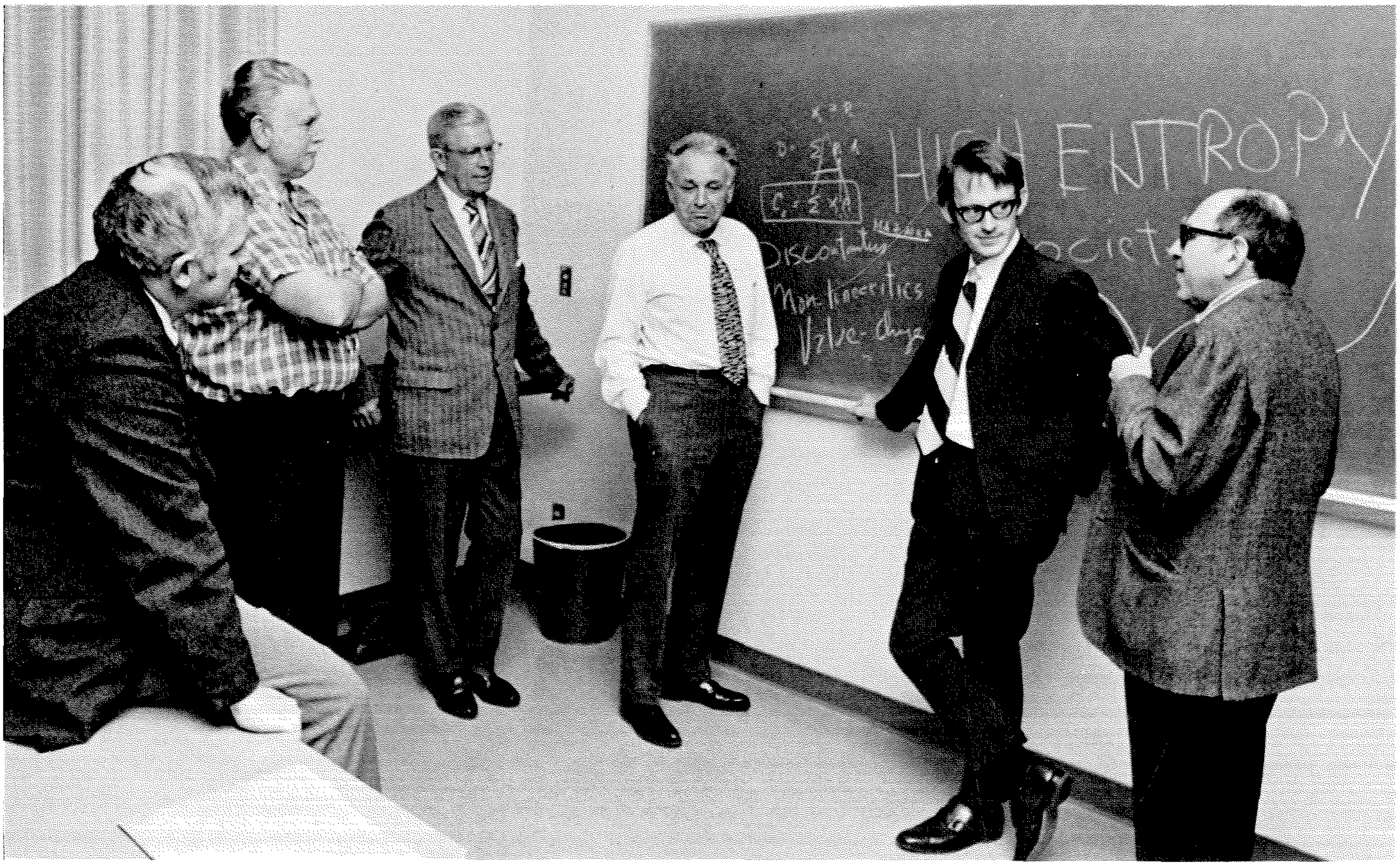
Caltech is no newcomer to the study of the problems of our physical environment. But the mounting urgency of those problems has convinced the Institute of the need to translate the results of its environmental research into effective action. This month Caltech announced the creation of an Environmental Quality Laboratory specifically designed to meet that need.

Like the Environmental Engineering Science Program that preceded it (p. 14), the EQL is committed to solving environmental problems. But the principal activity of the graduate academic program is basic research, and its immediate goal is to educate scientists and engineers to solve specific environmental problems. The EQL is action-oriented. Instead of confining itself to the traditional "scientific problem-solving" approach typically associated with academic studies, the EQL will often be dealing with broader, more comprehensive—and more controversial—problems than those addressed by the Environmental Engineering Science Program.

Even though the EQL represents a big step for Caltech, there is ample precedent for establishing a specialized laboratory, to be operated by—but kept organizationally distinct from—the Institute. JPL is, of course, an outstanding example. The Caltech faculty committee on Aims and Goals stated the rationale in its April 1969 report:

"It must be recognized that occasions will arise where the unique competences present in such an institution as Caltech will be called upon to meet pressing social needs at both national and local levels. It is important that faculty participation in such endeavors remain a matter of individual choice, and that any large-scale direct action programs be sufficiently insulated from the Institute that they do not distort its basic functions of research and education."

During the summer of 1969 the Institute administration and faculty began a series of discussions on the feasibility of establishing a sizable air pollution laboratory at Caltech. A steering committee headed by Francis Clauser, chairman of the division of engineering and applied science, and a volunteer study group headed by Carver Mead, professor of electrical engineering, and John Seinfeld, associate professor of chemical engineering, were set up to evaluate all aspects of the idea. In addition a small JPL group was formed under the chairmanship of



Charter members of the Caltech Environmental Quality Laboratory confer with Samuel Lenher, former Du Pont vice president in charge of pollution control activities—James Morgan, professor of environmental engineering science; Mahlon Easterling, visiting professor of applied science; Mr. Lenher; EQL Director Lester Lees; John List, assistant professor of environmental engineering science; and Burton Klein, professor of economics.

R. E. Covey to investigate such questions as organizational structure, modus operandi, size, location, and funding.

The deliberations of these groups and a further study headed by Lester Lees, professor of environmental engineering and aeronautics—which included faculty members in engineering and in social sciences and members of the Jet Propulsion Laboratory—identified air pollution as only the most conspicuous of a whole series of closely interrelated environmental problems and recommended the establishment of an Environmental Quality Laboratory with a broad mandate to study the whole question of the quality of life in the Los Angeles Basin and, ultimately, in the State of California.

By the summer of 1970 the results of these studies had been accepted in principle, Lees was named interim director, the nucleus of a staff was being assembled, and the guidelines for activity were being further delineated. The EQL was not only to be action-oriented, it was to have an interdisciplinary structure, to remain relatively small in size, and to stress informality and flexibility.

The EQL now has a staff of seven. Four are faculty

In pursuing even the most highly technical environmental problems, we very quickly confront the fundamental question—what kind of a world do we want to have?

members and divide their time between the laboratory and their academic duties: Lester Lees, economist Burton Klein, and environmental engineers James Morgan and John List. The others are Mahlon Easterling, a JPL staff engineer; Guy Pauker, a RAND Corporation political scientist; and Kenneth Heitner, a research engineer and recent Caltech graduate (PhD '69)in applied mechanics.

An ecologist, an additional economist, a cultural anthropologist, a social psychologist, and a young lawyer who is interested in and has some experience with legislation dealing with pollution would be desirable additions in the near future. However, the group has no wish to grow very large, and it will probably never have more than 12 to 14 members. There will also be a few graduate students who will be carrying out projects in the lab under the supervision of faculty advisers who may or may not be part of the EQL. Such graduate students could have considerable impact on industry and government over the next 10 to 20 years, and they may well turn out to be among the lab's most important products.

The EQL staff has already started making studies in two critical areas: 1—the impact of energy use on the California environment, and 2—the economic aspects of air pollution control in the Los Angeles Basin. These problems are typical of the issues that interest the laboratory group. If the EQL is to make a significant impact on Los Angeles and California, it will have to concern itself eventually also with land use, solid waste disposal, water pollution—in short, the whole spectrum of urban problems.

In its first study, the group is examining the growth in energy consumption in California and the effects of this growth on the environment, and is attempting to develop an energy consumption model to investigate integrated power planning and help predict the environmental impact of alternative plans.

In the air pollution study, the staff is analyzing the effects of the growing automobile population and the costs of reducing emission levels. They are finding out that, in the Los Angeles Basin at least, the relationship between emission levels and air pollution levels is highly non-linear, being strongly influenced by such variables as wind velocity, height of inversion layer, and sunlight intensity. Solving the air pollution problem is considerably more complicated than spending increasing amounts of money on controlling emissions from internal combustion engines.

The EQL's first graduate student is participating in the air pollution study. He is John Trijonis, a Caltech alumnus in aeronautics (BS '66, MS '67), who is now working toward his PhD in environmental engineering science under the supervision of Roger Noll, associate professor of economics, and Lees. His part of the project is to assemble data on pollution control costs related to the internal combustion engine, to relate pollutant levels to emissions, and to evaluate the "damage costs" of pollutants.

Although the EQL is already a functioning unit, for the time being it has no real home. The staff currently meets in a conference room in the Karman Laboratory of Fluid Mechanics and Jet Propulsion while waiting for the remodeling of a large classroom in the Thomas Laboratory of Engineering into temporary headquarters. Plans for permanent quarters are to convert one or two of the Institute-owned houses adjacent to the campus when the staff and work enlarge—and when funds become available.

Funding plans are anchored to a $1.5 million proposal to the National Science Foundation for "seed money." Support is also being solicited from industrial organizations and private foundations.

One guideline the EQL has laid down is maintenance of its independence and objectivity as it deals with the somewhat explosive questions related to the environment. It also expects to exchange ideas and information with industry, government, and conservation organizations. As a step in this direction, Samuel Lenher, a former vice president in charge of pollution control activities and current board member of the Du Pont Corporation, spent three weeks with the EQL last fall. Lees himself is a member of the Energy Use Panel of the California State Assembly's Council on Science and Technology.

The EQL will typically address itself to problems having a high technological content—such as the two current studies. This is in keeping with Caltech's traditional strengths. But in pursuing even the most highly technical environmental problems, Lees points out, we very quickly confront the most fundamental of questions—what kind of a world, what kind of a government, what kind of an individual human life do we want to have? To answer such questions requires more than presenting learned papers. "We really want our work to lead to some action," says Lees. "We want it to have real impact on the decision-making process, and this is going to be one of our toughest problems."

The Caltech Environmental Quality Laboratory is admittedly a high-risk project, since it may well be in the thick of some controversial issues. But if its studies can lead to technical and social changes that will achieve a harmonious relationship between man and his environment, the yield will more than justify the risk.

Doctors to the Environment

In response to national concern and to faculty and student interest, Caltech launches a new interdisciplinary program in Environmental Engineering Science.

Environmental engineering scientists at Caltech welcome the attention the public is now giving their field. Problems on which they have worked for years have suddenly become front page news. Water reclamation and reuse, the origin and fate of atmospheric submicron particles, the effect of wastewater discharges on coastal waters—fields in which the members of the environmental faculty have pioneered—are the glamour topics of the seventies.

Members of the environmental faculty hope this awakening public interest is the start of a long-range national commitment to the preservation and protection of the environment.

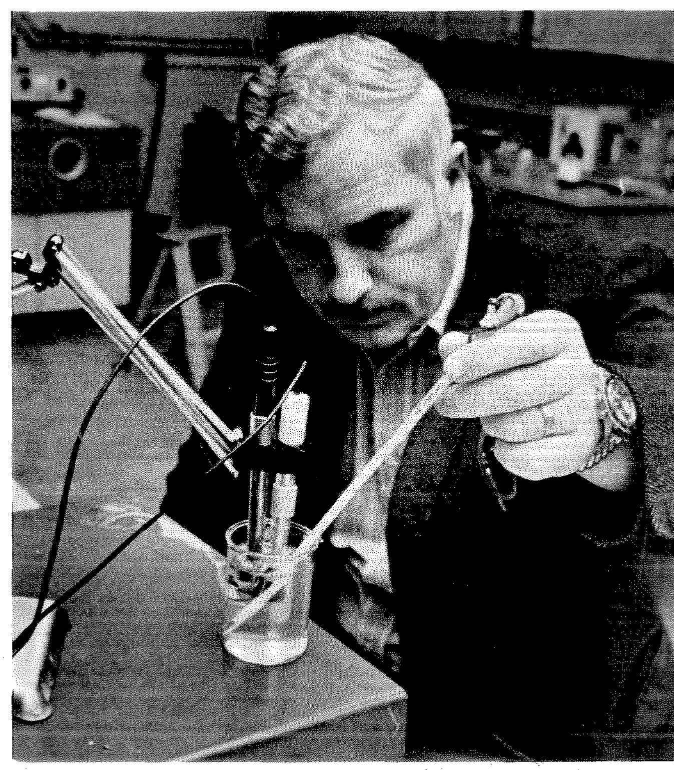
Environmental studies at Caltech go back many years. Key contributions were made by A. J. Haagen-Smit, professor of bio-organic chemistry, beginning 20 years ago when he demonstrated that the primary smog producers were automobiles and power plants—not backyard incinerators as many people had believed. Jack McKee, professor of environmental engineering, has worked for more than two decades on the reclamation of safe, usable water from sewage and industrial wastes. Ten years ago he established the environmental health engineering program at Caltech and helped bring in many of the faculty now playing a major role in environmental studies. A seminal role in the hydraulics field was played by Vito Vanoni, professor of hydraulics and a specialist in the field of sediment transport by natural waters.

In 1969, in response to the national concern and faculty and student interest, a new interdisciplinary program was established at Caltech which allows the Institute for the first time to confer advanced degrees in environmental engineering science. Norman Brooks, professor of environmental science and civil engineering, serves as program coordinator. Based on a solid foundation of research and coursework, EES is passing through an exciting period of innovation; a new applied science is emerging which brings together engineering and ecology. What classical disciplines are basic to this new field? What new topics should be developed? To what extent are studies in air and water pollution dependent on the same basic principles? These are some of the problems with which the faculty is currently wrestling.

Teaching students the physics and chemistry of "messy systems" like dirty air and water has forced the faculty to invent new approaches both in their research and in their classes. The analytical method of the pure sciences, depending for its effectiveness on the study of elementary processes, must be modified in dealing with pollution problems, and these modifications require considerable ingenuity.

The program includes new courses in air pollution engineering and ecology, fluid mechanics, and economics. One of the most successful in arousing student interest has been the undergraduate course "Engineering Problems of Man's Environment." Lectures by faculty specialists on air and water resources, weather modification, and other topics are supplemented by discussions on specific problems by small groups of faculty and students. The course is an introductory one for students considering advanced work in this field.

With engineers and scientists playing a leading role, it is not surprising to find an emphasis on technological solutions to problems caused by an aberrant technology.



James Morgan, professor of environmental engineering science, is directing a series of projects related to water quality and wastewater treatment.

Given the temper of the times, this type of approach is bound to lead to criticism. "There is a conspicuous absence of thought addressed to the ethics, or morality, which should propel such a program," one young woman wrote to Sheldon Friedlander, professor of chemical and environmental health engineering, regarding his proposals for an environmental forecasting program—a study of technological trends and their environmental implications.

Faculty members do recognize the importance of ethical considerations in setting environmental goals. Indeed, such considerations lead many of them to enter the environmental field in the first place. But they also believe that goal determination and implementation should be based on the most complete information possible. That, in large part, is why Caltech has responded to the environmental crisis with the formation of the Environmental Engineering Science Program.

A Sampling of Current Research in EES

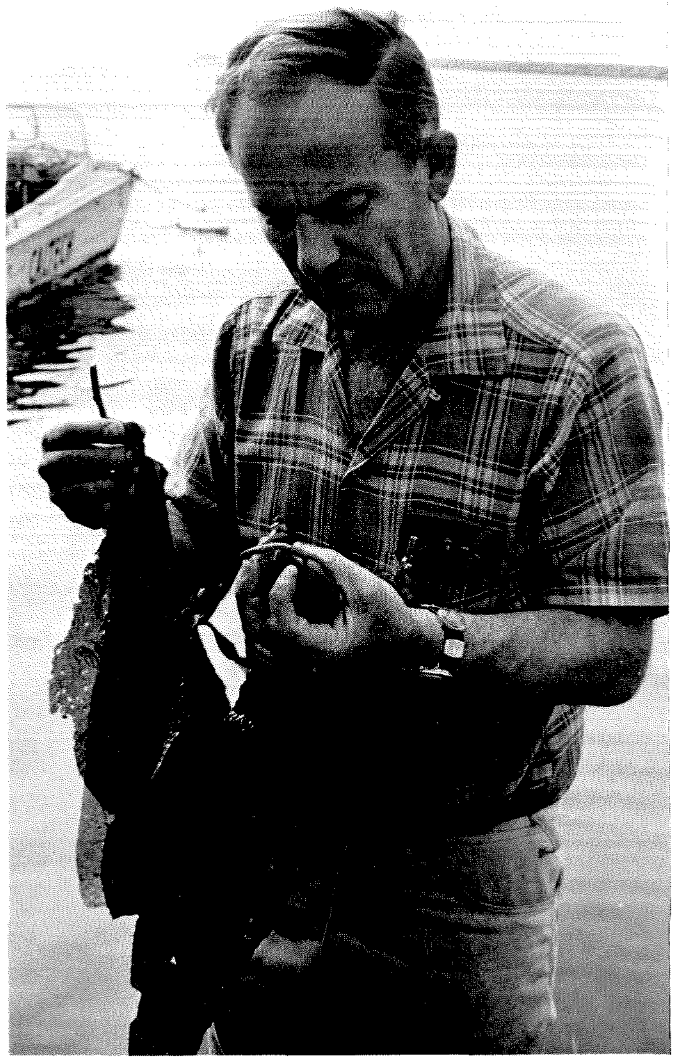
James Morgan, professor of environmental engineering science, is currently directing a whole series of projects relating to water, including wastewater treatment and water quality. One aspect of Morgan's research is directed toward learning how to remove particles that are so small they won't normally settle out or be effectively filtered by most treatment processes. Morgan wants to learn enough about different polymer molecules to be able to predict which kinds are best for removing particles from water. He hopes eventually to find ways of "hooking" the tiny particles together so they can be removed.

Some of this research is being done in cooperation with a Jet Propulsion Laboratory group led by Alan Rembaum, a member of the JPL technical staff in the polymer research section, and also a lecturer in chemical engineering at Caltech. The group hopes to find new substances that can be put to work in removing particles from water.

The particles of interest to the Caltech and JPL researchers range in size from a few microns down to about 1/10 of a micron (a micron is equal to about 1/25,000 of an inch) and may be particles of clays or other minerals such as silica, bacteria, or even synthetic organic products.

What has been learned so far?

For one thing, there is a significant natural variation in the mineral properties of waters in different parts of the world, and these chemical variations lead to

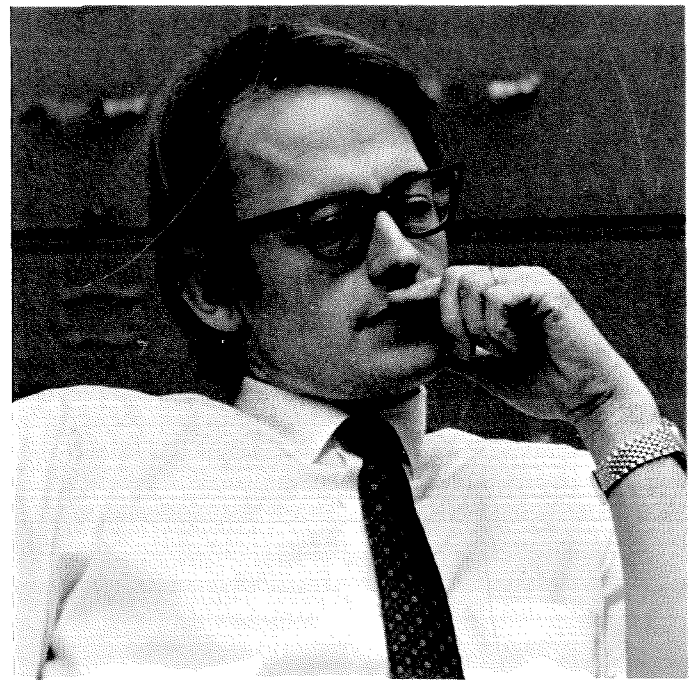


Wheeler North, professor of environmental science, is supervising a project aimed at restoring the kelp beds that once grew off the California coast.

significant effects on the configuration of polyelectrolytes and on their ability to flocculate particles (hook them together electrochemically). For another, the group has learned a lot from graduate student Dennis Kasper's studies about the effect of the polymer's molecular size on its flocculation ability. But they hope to learn more about polymer architecture—and they still do not clearly understand how different sorts of polymers function in different waters.

Another problem Morgan and his colleagues hope to probe more deeply involves determining the effects of urban waste discharges into coastal receiving waters. There are dozens of compounds in both the waste products and receiving water, and the Caltech environmental chemists would like to develop a method for determining what are the significant chemical reactions that could take place in distribution of the wastes into receiving water. This problem is being attacked initially by programming a computer to simulate all the possible reactions in a model system. Eventually laboratory and field experiments will be conducted for those conditions that the computer finds most promising.

The analytical method of the pure sciences must be modified in dealing with pollution problems.



John List, assistant professor of environmental engineering science, is studying the behavior of jets in a density-stratified liquid, hopes to find better ways to design sewage outfalls so the effluent won't be washed back ashore.

The problem of ocean pollution is being studied in a quite different way by Wheeler North, professor of environmental science, who has been working at the Kerckhoff Marine Laboratory in Corona del Mar on a project aimed at restoring the giant kelp beds that once grew just off the California coast. These kelp beds, which contribute an estimated 100 million dollars a year to the regional economy, supply chemicals for more than 300 commercial products and provide a habitat for the fish that support the state's fresh fish and canning industry.

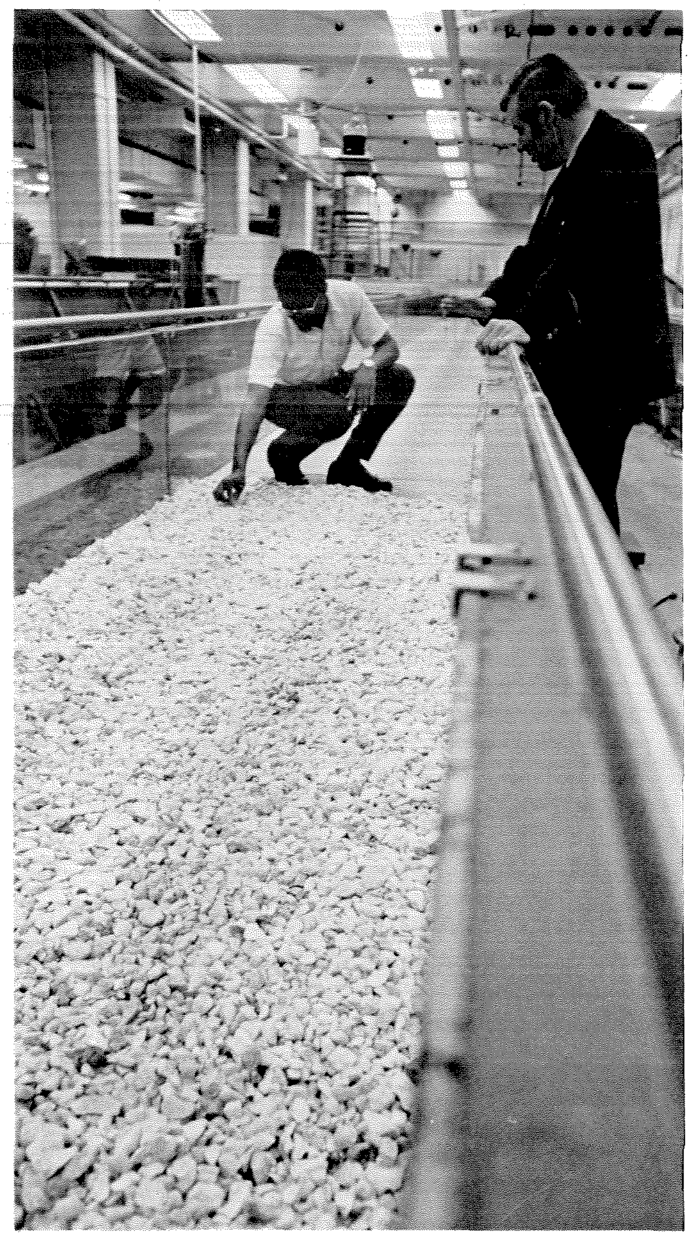
North embarked on his project after it was found in 1960 that 95 percent of the kelp beds had disappeared. His first efforts resulted in successful restoration of large kelp forests in the San Diego area, and he has since worked at devising ways to protect the kelp from grazing sea urchins and to plant new kelp in areas where it used to flourish. He has now developed seeding techniques that may prove successful for large-scale reforestation.

The first attempts to seed the ocean with reproductive spores proved to be laborious and not very fruitful. However, seeding was much more successful when North's group started planting baby kelp plants that had been cultured in the laboratory. When the plants were introduced into suitable areas, the rate of survival changed from about one in 1,000,000,000 to about one in 100,000.

North and two other researchers have been seeding ocean areas with the embryo plants for more than six months off La Jolla near San Diego, at Corona del Mar, and at Palos Verdes. The results at La Jolla and Corona del Mar were about equal, and pretty good, but at Palos Verdes the men were less successful; their young kelp plants were grazed thoroughly by two species of fish that consider them delicacies.

The seeding process involves taking microscopic-size embryo plants, which look like a brown fuzz or scum on the culture dish, and scraping them off with a razor blade. They are then washed into a container with chilled seawater and are taken to sea, where a diver takes the container down and dribbles the plants along the bottom at appropriate places. They need a rocky bottom to grow on, and sedimentation is disastrous for them.

One of the main threats to the remaining kelp forests has been the invading hordes of hungry sea urchins, which make giant kelp plants a major part of their normal diet. In the past, the sea urchin population was kept under control by sea lions. But sea lions have been hunted to near-extinction along the southern California coast. Furthermore, while sewage dumped into the sea nourishes the kelp, it does the same thing for the sea urchins, and upsets the balance between the number of urchins and their food supply. And so, fed by the sewage, and uncontrolled by the sea lions, the urchins manage to stay alive even after their normal kelp diet is gone, and they are ready and waiting to devour new kelp plants as they



Josephat Okoye, one of the first students to earn a PhD in environmental engineering science, and Norman Brooks, professor of environmental science and civil engineering—and coordinator of the EES program—prepare a flume for use in studies of pollution patterns in stream beds.

emerge. The sea urchin problem has finally been largely solved by dumping lime on them.

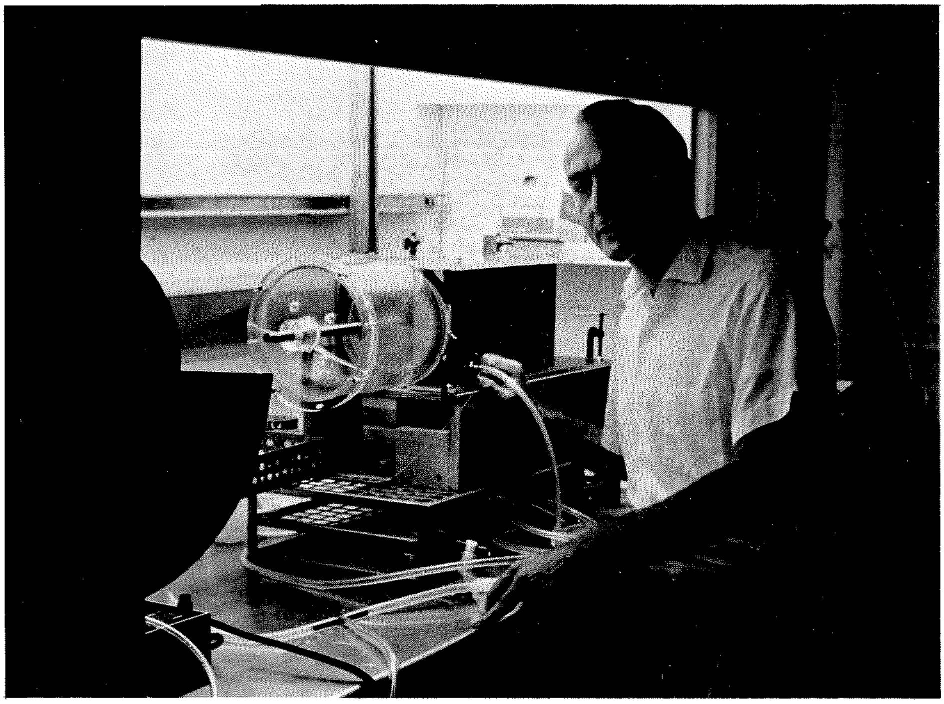
Current plans—under a grant from the National Science Foundation—are to expand production of embryo kelp plants so billions can be seeded in the open sea.

From the total environment point of view, the reutilization of some wastewater that is now being discharged into the ocean represents an exciting alternative. Jack McKee, professor of environmental engineering, has conducted research in this area for many years. A typical study was one carried out by a former student, A. B. Pincince, on oxygen balances in the upper layers of porous media during intermittent percolation of sewage. Research has also been conducted recently on the role of fungi in such operations and the efficacy of conversion of high concentrations of urea to nitrates by percolation through sand columns.

The engineering aspects of environmental quality also embrace problems of solid-waste management, including recycling or recovery of useful materials. Working with personnel of the City of San Diego, McKee collaborated recently in a thorough evaluation of pyrolysis of municipal trash. It is hoped that this study can be expanded soon to the pilot-plant stage.

The fluid mechanics and hydrologic aspects of water quality are being studied by another group in the Keck Laboratories under the direction of Norman Brooks, professor of environmental science and civil engineering, and John List, assistant professor of environmental engineering science. This research is supported by the Federal Water Quality Administration, now part of the new federal Environmental Protection Agency.

Man's use of water involves taking it out of the natural water environs in one place, and returning it often as wastewater somewhere else. The way in which these operations are done has an important effect on water quality. Since many water bodies (ocean, estuaries, lakes, groundwater) are density-stratified because of temperature and salinity variations, the group has studied the mechanics of mixing in stratified fluids. For example, the research on buoyant jets and plumes by Loh-nien Fan, a recent PhD, and Brooks makes possible the design of large multiple-jet outfalls for sewage effluent disposal in the ocean in order to produce a diluted cloud of effluent completely trapped below the ocean thermocline. The design of the new 27,400-foot outfall under construction in Orange County, California, was based on these research results, and it is predicted that the sewage effluent cloud will be completely submerged for more than 11 months of every year. Only for brief periods in January and February does the stratification become too weak to prevent the sewage cloud from surfacing.



Sheldon Friedlander, professor of chemical and environmental health engineering, is studying various aspects of smog, including the behavior of aerosols in the human respiratory tract.

John List is now continuing theoretical and experimental work on the fundamental behavior of viscous momentum jets with or without buoyancy and swirl in a stratified environment. A deeper understanding of the mechanics will quickly lead to better designs of mixing structures of all kinds, including those for thermal discharges from power plants.

John Ditmars, a recent doctoral student in the group, studied the artificial destratification of water reservoirs to improve water quality and reoxygenate stagnant bottom waters. He developed a simulation model incorporating the selective withdrawal of water from the top of a reservoir, pumping through a pipe to the bottom, and jet-mixing it with the surroundings.

Two other students, Ed Prych and Joe Okoye, finished theses this year on transverse mixing of contaminants in river channels, with and without density differences. This work will be useful in predicting how fast a heated effluent introduced on one side of a river will mix fully across the river.

Visiting the Brooks-List group this year are Klas Cederwall from Chalmers Institute of Technology, Goteberg, Sweden; and Ralph Rumer from the State University of New York at Buffalo. Cederwall, a specialist on ocean waste disposal, has been working on mixing produced by line sources of a buoyant flow injected into a current. Rumer, who operates a rotating model of Lake Erie at his laboratory at SUNY Buffalo, is continuing his study of diffusion and current patterns in lakes.

Two other fields of hydraulic research are part of the over-all environmental effort. In the area of coastal engineering, Fredric Raichlen, associate professor of civil engineering, and doctoral student Joe Hammack have an active laboratory project on the generation and propagation of tsunamis, a matter of special concern to important coastal structures like power plants in case of significant fault movements in the California continental shelf. Other coastal problems Raichlen has studied recently include harbor oscillations and resonance, uplift on offshore platforms and docks by impact of large waves on the undersides of the structures, and oscillations of moored vessels in harbors.

A third area of research—sedimentation and stability of alluvial channels—is the interest of Vito Vanoni, professor of hydraulics, who is an expert in a wide range of problems relating to the erosion of sediment from the land, and its transport toward the ocean. As man has disturbed the land, and changed the river systems by a variety of man-made works, there have arisen severe problems of maintaining the sediment balance in rivers—on the one hand, the necessity of avoiding disastrous downward or sideward scour, and on the other, preventing filling and overflowing of river channels with excess sediment. For many years, Vanoni and his coworkers (including Norman Brooks) have contributed to the understanding of the mechanics of sediment-laden flows over alluvial beds. At present, graduate student Brent Taylor is doing laboratory flume research on the effect of water temperature on sediment transport and channel roughness.

Dirty air, like polluted water, is a very complicated system composed of particles and contaminant molecules in a highly non-equilibrium state. Sheldon Friedlander, professor of chemical and environmental health engineering, has been looking for ways to characterize such systems, and has been concentrating on the particulate component and the conversion of gases to particles. Such particles limit visibility, carry harmful chemical components like lead and carcinogens into the lung, and may even affect climate on a global and regional scale.

One of Friedlander's current goals is the preparation of an element-by-element material balance for the Los Angeles Basin aerosol. How much of the existing particulate material is background aerosol and how much originates from man's activities in the Basin? How much particulate material is formed by chemical reactions in the atmosphere? Together with G. M. Hidy, a senior research fellow in environmental engineering, Friedlander has estimated some of these figures and finds that about 30 percent of the aerosol is produced by atmospheric reactions involving gaseous emissions, perhaps 40 percent is introduced directly into air by man, and the rest is natural background. Also working on this problem with Friedlander is Michael Miller, a recent PhD in physical chemistry from Northwestern, who has started experiments on the conversion of smog gases to particulate matter.

The key to understanding the effect of very small particles on health and visibility is their size distribution. About ten years ago, Friedlander proposed that under certain conditions the small particles in a smoke approach a size distribution independent of the original distribution. This means that rather simple and inexpensive measurements can be made to determine the size spectrum. Computer calculations at Caltech and elsewhere have given strong support to this hypothesis; recent calculations by chemical engineering graduate student Francis Lai and experiments carried out at the University of Minnesota have added further support for Friedlander's hypothesis when particles are smaller than the mean free path of the air.

In a related study supervised by Friedlander, graduate student Karl Bell is following the behavior of aerosols in a simulated portion of the human respiratory tract. The lung has about 21 generations of branches; it is well known to engineers that particles in an air flow tend to accumulate at branch points. Such deposition "hot spots" may serve as sites at which lung disorders are initiated. Bell's studies with small polystyrene latex particles confirm the hot-spot concept, but he has found that existing theoretical techniques are not adequate to explain the details of his experimental results.

John Seinfeld, associate professor of chemical engineering, has collaborated closely with Friedlander and is doing computer simulations of the dynamics of smog formation over an urban area. The primary goal of Seinfeld's research is to simulate the formation of photochemical smog in the Los Angeles Basin so that the effect of various proposed control strategies on atmospheric pollutant concentrations can be evaluated.

John Seinfeld, associate professor of chemical engineering, is working out possible air pollution-control strategies with a computer that simulates the atmosphere of the Los Angeles Basin.

The study involves two major tasks: first, learning how to predict what occurs as a result of the chemical reactions in the atmosphere; and second, learning how the great masses of air over the Los Angeles Basin move and distribute airborne contaminants.

The over-all computer simulation will predict—for a given set of weather conditions—the atmospheric concentrations of oxides of nitrogen, hydrocarbons, and ozone as a function of the time of day and location in the Basin.

The ultimate objective of Seinfeld's work is to determine optimal air pollution control strategies or, in other words, to formulate a basis for choosing the best set of control laws for a particular region.

Another area of air pollution research, nitrogen oxide control, is under the supervision of William Corcoran, professor of chemical engineering. Oxides of nitrogen emitted by automobiles and from the stacks of electrical generating stations are primary air pollutants in urban areas. Studies are being carried out in a small industrial burner in Corcoran's laboratory to determine how to minimize nitrogen oxide formation. These studies are supplemented by investigations of reactions involving oxides of nitrogen in the parts-per-million concentrations present in the atmosphere.

Energy and the

by Norman Brooks

Norman Brooks, professor of environmental science and civil engineering, is noted for activities related to environmental control. He is a member of the California State Assembly's Science and Technology Advisory Council and chairman of its Committee on Environmental Issues. At Caltech he is coordinator of the environmental engineering science curriculum. "Energy and the Environment" was adapted from a paper given at a conference on Technological Change and the Human Environment, held at Caltech last October. The full text of the paper is available upon request to Brooks.

The woes of the electric utility industry make daily reading in the nation's press. The power companies have not been able to supply all the electricity the public demands during certain critical periods—as for example during heat waves, when air-conditioners, refrigerators, and electric fans add heavier power loads. The result is more frequent blackouts and brownouts (voltage reductions) as the power companies struggle to keep the load within the limits of generating capacity.

The utilities have faced an array of difficult and coincidental problems trying to keep up with the ever increasing demand. There have been long delays in delivery and installation of nuclear-generating units, following the unusually large orders for nuclear equipment in 1966 and 1967 which swamped that new section of the power-generating equipment industry. In some new large conventional units, operational failures have occurred unexpectedly. Power companies have found that shutdowns for maintenance have been more difficult to schedule because high peaks of demand now occur both in winter and summer.

Fuel delivery has suddenly become a problem for the utilities. For air pollution control, they must use low-sulphur coal, but the supply is inadequate. New mine safety regulations have curtailed some mining operations, and caused defaults in some coal supply contracts. Even railroad coal cars are becoming scarce, and some utilities are having to purchase their own cars to be assured of deliveries. Because of attractive prices, more coal is being exported to Japan. Whereas utilities used to have several months' coal supply on hand, they now have just a few weeks' supply and sometimes only a few days' advance supply. Fuel oil has also been in short supply because of oil import restrictions, and the tanker shortage caused by closure of the Suez Canal and the interruption of the Trans-Arabian pipeline.

Concern about the environment has caused a tightening of air and water quality standards for power plant discharges. Currently there are arguments about the adequacy of radiation standards for nuclear plants. For those who must plan capital expenditures and their repayment for decades into the future, the fluidity of environmental requirements presents a difficult planning problem.

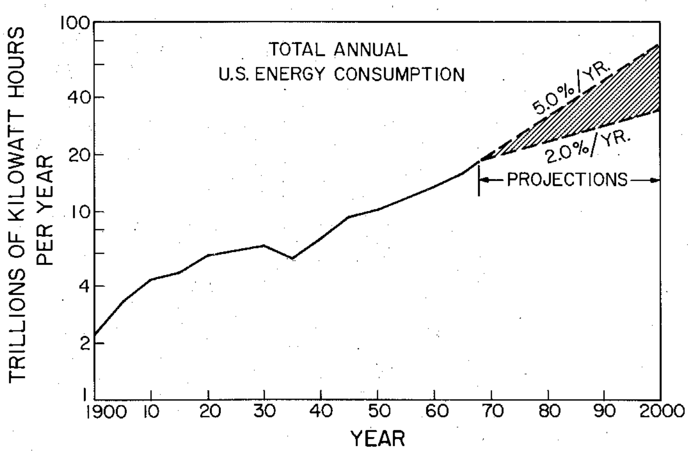
Power-plant siting is an even more urgent problem of the industry. Conservationists and the power industry have had many lively confrontations over siting of plants and transmission lines in the last few years. In general, these controversies have not contributed to recent power shortages because the lead time between final site selection and on-line operation is often five years or more; but a few years hence we shall be able to say that power shortages were caused by arguments over power-plant sites.

Energy Consumption

Electric power is of course just one part of society's total energy usage. Not only is fuel burned to generate electricity at central power stations, but it is also used directly for heating buildings, for transportation, and in industry.

The total energy consumption in the United States in 1968 was 17.8 trillion kilowatt-hours—equivalent to a continuous average use of 10,000 watts per person. In 1900 it was 2.2 trillion kilowatt-hours—an overall average growth in the intervening years of 3.1 percent per year (compounded). But in the period 1935 to 1968, the rate was 3.6 percent per year, and in the most recent four years, 1964-68, the rate of growth was 4.9 percent per year. A growth rate of 5 percent per year in the future would lead to an energy consumption of 76 trillion kilowatt-hours in the year 2000—over four times the present yearly usage. If the growth rate were only 2 percent per year, the figure for 2000 A.D. would be less than half as much—34 trillion kilowatt-hours. The important point is that the growth rate, when compounded over many years, has an enormous leverage on how our resources and environment are going to be affected.

I am not a "futurist" because I do not think we must plan for whatever the demands may be; on the contrary, it will be necessary for society to *control* this growth rate



Historic growth of U.S. annual energy consumption with a high and a low projection to the year 2000.

to keep energy use and its environmental effects within tolerable limits.

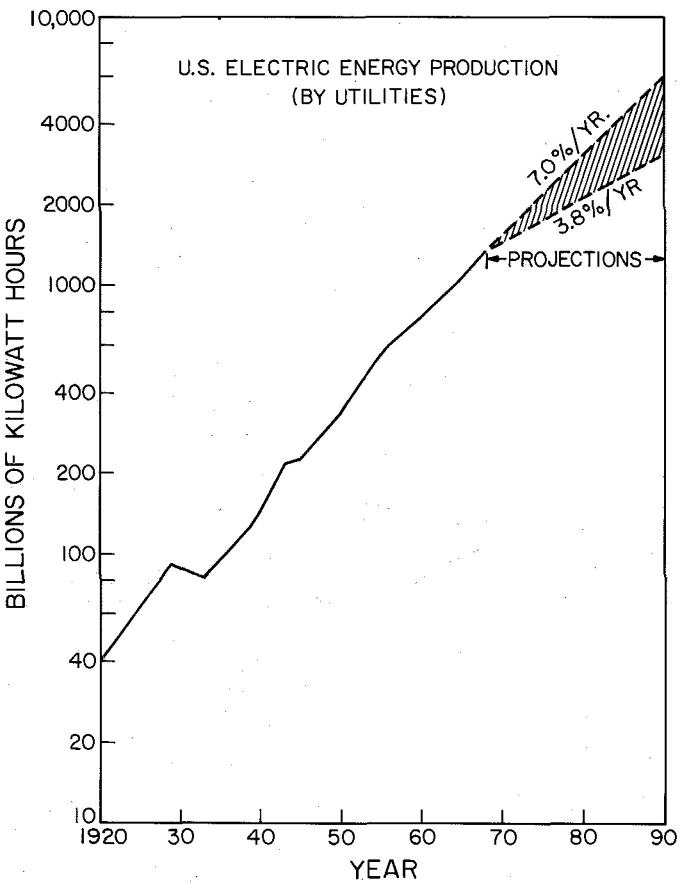
The primary sources of the energy were, for 1968:

Crude petroleum	40.7%
Natural gas	32.1
Coal	21.9
Natural gas liquids	3.8
Hydroelectric generation	1.3
Nuclear energy	0.2
Total (17.8×10^{12} kwh)	100.0%

Fossil fuels accounted for 98.5 percent of the total, while nuclear energy was only 0.2 percent. The nuclear fraction will grow very rapidly in the near future as it displaces fossil fuels in production of electricity. Hydroelectric power is also a very small percentage and will probably continue to stay small because most of the feasible hydro sites have already been built. It should be noted that hydropower is the only energy source which uses the current energy budget of the earth rather than energy stored from some other geologic age. There are other small sources of energy—wood, refuse, geothermal heat—which do not usually appear in the statistical summaries, but the amount for the U.S. is probably only a few tenths of one percent of the total. Direct beneficial use of solar energy (agriculture, drying, heating, etc.) cannot be computed; the amounts mentioned here refer only to man-made energy-distribution systems.

Electric Power

Of the total energy consumed in 1968, only 8.0 percent —1.43 trillion kilowatt-hours—was converted to electric power. However, an additional 14 percent of the total was discharged as waste heat by the thermal power stations, operating at an average efficiency of 33 percent.



Growth of electrical energy production by utilities from 1920 to 1968, with range of projections to 1990.

Hence 22 percent of the total energy supply was used to run the electric power systems.

Electric power production by utilities was 1.33 trillion kwh—a growth of 9 percent over the preceding year. (The small remainder—0.10 trillion kwh—was produced by industry for in-plant use.) For the period 1920-68, the average growth rate was 7.5 percent per year—or doubling every 9.5 years. If the demand continues to grow at 7 percent per year, the production by utilities will have to increase over fourfold by 1990 to 5.9 trillion kwh. Even a much lower projection of only 3.8 percent growth per year leads to 3.0 trillion kwh. The difference between these two projections for 1990 is more than twice the current production, which illustrates the enormous impact that the growth rate has on problems of power-plant siting. How many sites will *really* be needed in the future?

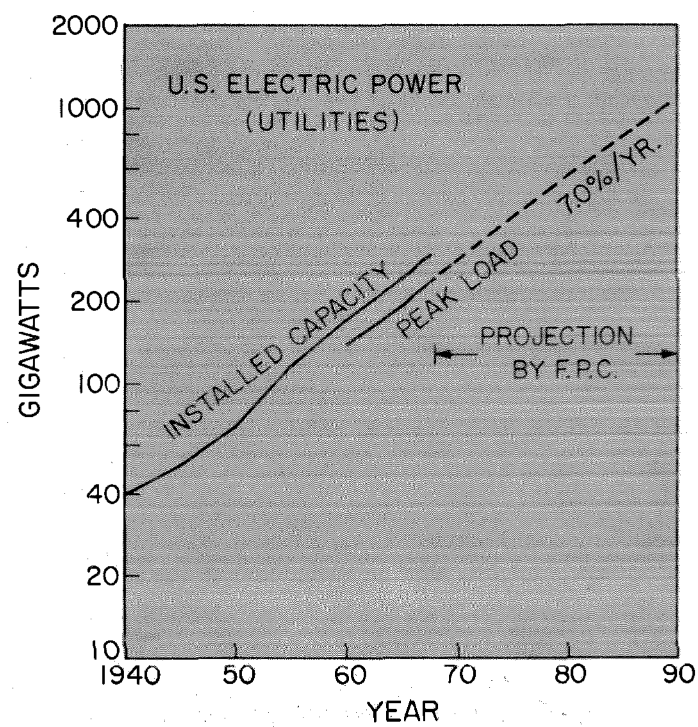
The electrical energy produced by utilities in 1968 came from the following primary sources:

Coal	51.7%
Gas	22.9
Oil	7.8
Nuclear	0.9
Hydro	16.7
Total (1.33x10^{12} kwh)	100.0%

By contrast, hydropower accounted for 36 percent in 1945. In the future, as in the past few years, the vast majority of the new installations will be thermal power, with nuclear power becoming a rapidly increasing part. Although practically all the feasible conventional hydropower sites have been developed, large pumped-storage plants for peaking are being built and will be sought increasingly in the future to allow higher load factors at thermal plants by pumping water up for storage during off-peak hours.

Gross electrical generating capacity (not allowing for shutdowns for maintenance and repairs) is just a very few years ahead of the peak load. At the present growth rate the peak-load forecast for 1990 is over 1,000 gigawatts (or 1,000,000 megawatts) compared to the 1968 peak of 243 gigawatts.

At thermal power plants the maximum size of a *single* generating unit has increased from 200 megawatts in 1950 to 1,300 megawatts at present (or the equivalent of the



Historic growth of installed capacity and peak load, with projection by the Federal Power Commission.

entire generating capacity at Hoover Dam). The largest power plants may have several of these huge units; for example, Brown's Ferry, TVA, 3,400 mw (under construction); and Point Conception, S. California Edison Co., 6,600 mw (being planned). Still larger size units are not anticipated because there are few further economies of scale to be realized and because an extremely large generating unit can be a disadvantage because its breakdown takes out too large a fraction of a given system capacity.

California

The power problems of the State of California have recently been summarized by the Resources Agency, which projects growth at 8 percent per year until 1990, at which time the demand will have increased fivefold over 1969. Per capita demand is predicted to rise from 1.17 to 4.0 kilowatts (about 6 percent per year compounded), while population growth is projected at 2 percent per year. Considering the current difficulties of finding acceptable sites, it seems almost impossible to believe that siting for over 90,000 megawatts additional can be accomplished in 21 years. Furthermore, it is hard to believe that we really need three to four times as much power per person—and can afford it.

I suspect that predictions of future power demands have often been self-fulfilling prophecies. If a power company decides to build large new generating stations to meet "projected" needs, it urgently requires that the new demand be realized on schedule in order to make a return on the company's capital investments, and it will conduct the necessary advertising and promotional campaigns to achieve the expected growth in business.

If the growth rate could be cut in half—to 4 percent per year—the positive impact would be enormous. The projected peak demand in 1990 would be only 52,000 megawatts—63,000 megawatts less than the State's projection. This would still allow a 2 percent per year increase in demand per person. If this reduction in growth rate could be accomplished, the reduction in capital costs for power plants and transmission lines would be about $20 billion dollars in 21 years—and not only do the capital costs keep going up, but so also do the intangible damages to the environment.

Even if we could survive the expansion to the year 1990, how many more doublings every 8 to 10 years can we stand? We do not need further research to prove that the environment remains finite. Its capacity to absorb wastes never doubles—it just remains fixed. Can we realistically expect technology to solve the environmental problems and side effects of energy usage?

Why does electric power get so much emphasis when it accounts for only 22 percent of all the energy consumption? It is because the power plants are such concentrated energy centers that the power plant surroundings are subject to more intense environmental effects than other places where energy conversion and usage is more diffuse—as in our homes, businesses, and automobiles. There is a tendency to replace small-scale combustion of fuels—in furnaces, stoves, automobiles—with electricity. In other words, instead of distributing so much fuel to individual users, we burn the fuel at a central power station, and distribute electricity instead. This is an environmental trade-off, for while you relieve the problems at one place where electricity is substituted for fuel, you add to the problems of siting enough power plants and controlling their emissions. Electricity is also a great help in solving other environmental problems too—such as building and running sewage treatment plants. Thus in the *long* run does the strategy for locating, building, and operating central power stations assume critical importance.

HISTORIC ELECTRIC POWER DEMAND FOR STATE OF CALIFORNIA

Year	Peak Power Demand (megawatts)	Population (thousands)	Ratio: kw per capita
1940	2,300	6,907	0.33
1950	5,300	10,586	0.50
1960	11,500	15,717	0.73
1965	17,400	18,207	0.96
1969	22,800	19,476	1.17

HISTORIC GROWTH RATES (State of California)

Years	Peak Power Demand	Population	Ratio: kw per capita
1940-50	8.7%/yr	4.3%/yr	4.4%/yr
1950-60	8.0	4.1	3.9
1960-65	8.6	3.0	5.6
1965-69	7.0	1.7	5.3

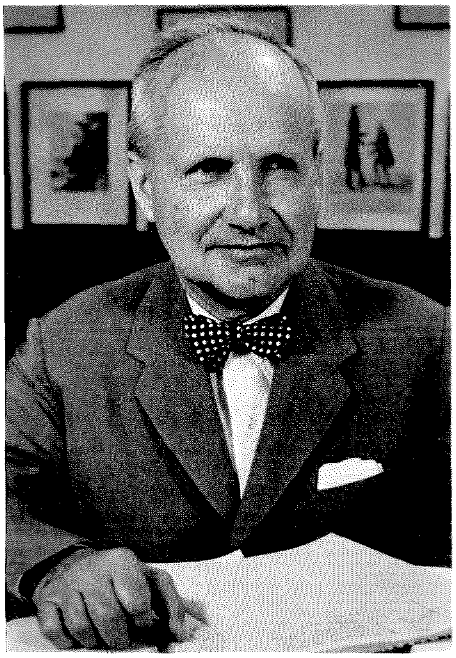
The Waste Heat Problem

There are many adverse environmental effects associated with electric power generation. One set of problems is associated with the mining, processing, and transporting of fuels to the power plants; another set arises from the combustion of fossil fuels and disposal of ashes and residuals extracted from the flue gases (for air pollution control); more problems arise from the transportation, processing, and disposal of spent nuclear fuel elements; another major problem is the dispersal of waste heat; and finally there are a multitude of land use and aesthetic questions associated with power plants and transmission lines. The problem of waste heat should be considered in detail because of its fundamental nature.

At every thermal power plant a very substantial amount of waste heat is rejected—by means of cooling water systems—into the surrounding environment. Both fossil fuel and nuclear plants operate on a steam cycle which converts part of the heat from a hot source (the furnace or the reactor) into work (electric power), and the remaining

continued on page 30

EARNEST WATSON
1892-1970



Earnest C. Watson, retired dean of the faculty and emeritus professor of physics, died suddenly on December 5 at his home in Santa Barbara.

Mr. Watson was born in Sullivan, Illinois, in 1892, where his father was a Presbyterian minister in the home missions field. In 1906 the family moved to San Francisco, and Earnest made the journey from the Middle West by freight train to tend his pet ponies.

After graduation from high school in San Francisco, Earnest attended Lafayette College in Easton, Pennsylvania, from which he was graduated in 1914, having been elected to Phi Beta Kappa. Lafayette in 1958 awarded him a ScD degree. From 1914 to 1917 he did graduate work in physics at the University of Chicago, leaving for service in World War I, in which he was engaged in antisubmarine research work.

After the war Earnest returned to the University of Chicago as an assistant professor of physics, but soon was sent to Pasadena to supervise the building of the first physics laboratories at Throop Institute, soon to become the California Institute of Technology, in preparation for Robert Millikan's move to the school.

The remainder of Earnest Watson's career was at the California Institute of Technology where, working closely with Dr. Millikan, Dr. A. A. Noyes and George Ellery Hale, he played an important role in the development of innovative programs in science education. He was made a full professor of physics in 1930, and dean of the faculty in 1945, a post he held until his retirement in 1959. He also acted as chairman of the division of physics, mathematics and astronomy from 1946 to 1949. During World War II he was a member of the National Defense Research Committee and acted as administrative director of a research and development project on artillery rockets, torpedoes, and other ordnance devices.

An interest in the history of science led Earnest Watson not only to write many articles on facets of the subject but to develop an important collection of books, manuscripts, and works of art in the field, which he has presented to Caltech. This interest also spurred some of his travel to remote areas of the world.

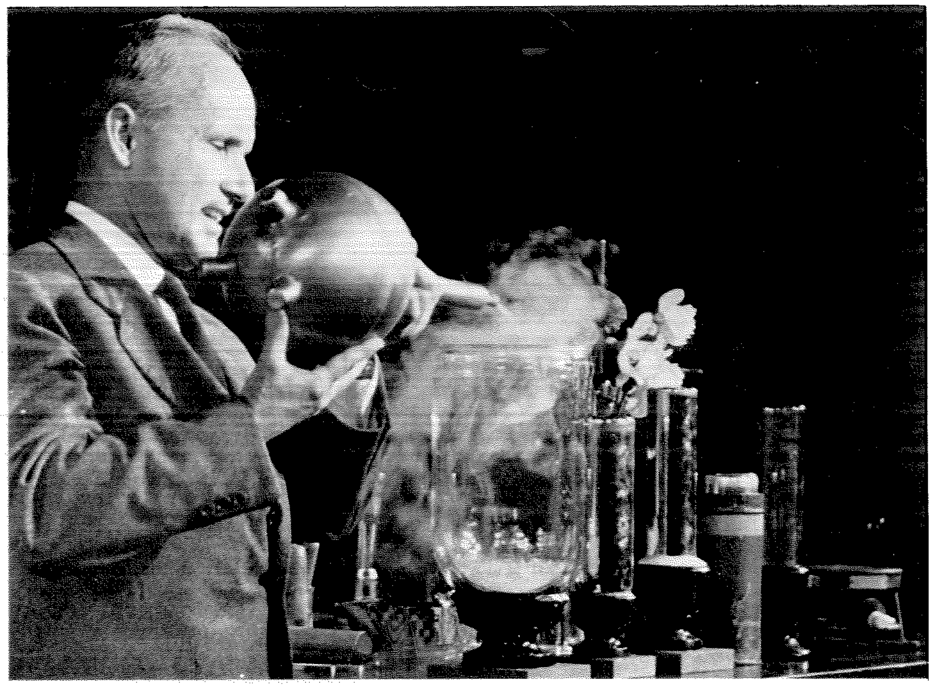
In 1954, while on a sabbatical leave, Earnest married Elsa Jane Werner in Tarbert, Scotland. Until his retirement from Caltech, the Watsons spent weekends and holidays in their Knollwood Drive home in Santa Barbara, where they made their home after 1962.

In 1960 Earnest was appointed science attache to the United States Embassy in New Delhi, India, where the Watsons lived for two and a half years, making a large collection of Indian arts during this period. As a result of the Indian experience and his long career in science education, Earnest was made a consultant to the Ford Foundation on educational projects in India and Pakistan, and was still active in this work at the time of his death.

A memorial service was held in Dabney Lounge on the campus on December 10. Arnold Beckman, chairman of the Caltech board of trustees, presided at the service—since President Harold Brown had been called back that day to the Strategic Arms Limitation Talks in Helsinki. Beckman and three of Earnest Watson's associates reviewed some highlights of his half-century-long career at Caltech. These are some excerpts from their tributes to him:

Ernest Swift, professor of analytical chemistry, emeritus, and former chairman of the division of chemistry and chemical engineering: Earnest had been at Throop College of Technology only a few months, and was an assistant professor, when I arrived in the spring of 1919 as a graduate student. I remember that our first meeting was by chance in a small restaurant on Colorado Street between Raymond and Fair Oaks where one could obtain at that time a very acceptable dinner for 65 cents. It was common practice to take the streetcar at the entrance to Tournament Park, ride down, then walk back when it was cooler. Earnest always had a relatively youthful appearance for his age, and I remember questioning on this first meeting how this quiet, somewhat reticent, even shy-appearing person had acquired the, to me, exalted title of Assistant Professor.

Then I remember my enlightenment when, a couple of years later, I began attending faculty meetings as a lowly instructor. This apparently shy person would sit through an aimlessly wandering debate on an ill-conceived motion until he could no longer contain himself.



Earnest Watson performs his famous liquid oxygen experiment.

He would then rise, and in forceful, vigorous, and at times devastating, terms bring the proposal into logical focus. He would be likely to conclude with that little smile of his, and a disarming remark such as, "At least that is how I see the matter."

I have memories of seeing Earnest and Dr. Noyes sitting on a bench somewhere on the campus in deep discussion. I know that Dr. Noyes valued these discussions, and valued Earnest's friendship. Often these discussions were continued on camping trips to the mountains and the deserts. Those were the days when many policies were formulated and many projects initiated. We will never know the contributions Earnest may have made to those policies and projects—projects such as the European travel prizes for junior students and demonstrations and lectures for high school teachers and students. I remember seeing Earnest loading his car prior to one of his often long and strenuous trips with his famous liquid oxygen demonstration. I think those trips were one of the most effective means ever used for establishing good relations with the high schools of the west.

It was later, and during the time that Earnest was planning and building his house in Santa Barbara that we became most closely associated with him.

I think that the period when he was planning and building his house there was one of the happiest in his life up to that time. It was a delight to see his enthusiasm. He originally planned to remodel simply a one-room shack that was on the place. But he got together with Lockwood DeForest, a landscape designer and frustrated architect with original and most effective ideas for making the most of the outstanding natural features of the site. They were indeed a synergistic couple.

But I think that after completion of the house he was lonely and became restless. So he decided to take a trip around the world. Quite some time after his departure, we received a letter which provided one of the surprises of our lives. He wrote, and the words are still clear in our memories, "I have something surprising to tell you. In fact, I'm still surprised myself. I'm going to be married." He then told us about Jane and her accomplishments and concluded by saying that we were free to tell others. Helen and Winch Jones were staying at his house at the time, and Elizabeth promptly called to share the news. Winch answered the phone, and the news produced the only occasion in our memory when Winch admitted being speechless. Naturally, many of us wondered about the outcome of this shipboard romance, about Jane, and about how this independent, sensitive bachelor would adjust to the vicissitudes of matrimony. You all know the answer, and Earnest's happiness has been a joy to all of his friends. We all know the contribution Jane has made to this happiness. It should be a great comfort to her, and we all love her for having made this happiness possible.

H. F. Bohnenblust, professor of mathematics and dean of graduate studies: When I arrived at Caltech, it was at the end of the war, and during the transition period from one president to another. The man who guided Caltech through this difficult time, and who held it together, was Earnest Watson. Even if I failed at that time to recognize the extent of his involvement in Caltech, it was evident that he was the person to turn to with one's own difficulties. A quiet listener, attentive and sensitive to the problems of those who approached him for advice and help—that was my first impression of the man whom I knew then as chairman of a division, as chairman of the faculty board, as dean of the faculty, but also who carried many other jobs for which he neither expected nor received any formal recognition.

This first impression failed to recognize more important facets of his character. My respect and my admiration for him grew constantly as throughout our acquaintance he revealed again and again new aspects of his personality and evidence of his exceptional qualities.

Outstanding was his strength, his courage, and his dogged determination to carry out the ideas he judged important, never compromising with his ideals. Luckily for the Institute, he had great ambitions for Caltech, and an unshakable loyalty to it—an intelligent, critical loyalty. Caltech has been remarkably fortunate in being able to attract to its top positions the right men at the right time. Watson was one of these men. He was active here at a period which used his talents—a period of individualism when the burden of leading Caltech was carried by relatively few people while the rest of the staff were free to pursue their own work, unhampered by time-consuming (and often resented) responsibilities.

The faculty gave him their full confidence and happily let him take the brunt of the many crises which had to be faced. We knew, each of us, we had a champion, but I don't believe that any of us realized how much he did for us.

As often as he could, Watson spent weekends in his house in Santa Barbara for relaxation. Usually, "relaxation" meant hard and critical discussions with trustees. In politically troubled times he fought our battles. He defended the faculty and its rights. On campus, he educated the faculty to accept a sense of responsibility in Institute problems through his Friday afternoon informal discussions. He played a leading role in the reorganization of the faculty, the formulation of its bylaws, the creation of the Committee on Academic Freedom and Tenure, and the over-all strengthening of the position of the faculty. All of us who, either directly or indirectly, benefited from his devotion, owe him a great debt of gratitude.

Lee A. DuBridge, president, emeritus: There are many ways, and there were many times, during the past 50 years when Caltech would have been a very different—and a much poorer—institution, had it not been for Earnest Watson. No one served the Institute so long in positions of such high responsibility. And no man in any position served the Institute more effectively and more devotedly. No one had a more continuing, a more beneficial, a more constructive influence on Caltech.

Let me testify that two rather long Caltech administrations found Earnest's services indispensable, and two Caltech presidents received great credit for successes, activities, and qualities of this institution for which Earnest was often the chief architect and frequently the managing engineer.

It is a matter of history that during the two decades between 1920 and 1940, the Norman Bridge Laboratory became famous throughout the world. (It amused me when I first arrived here in 1946 as president, and was introduced on several occasions to various gatherings as Dr. Norman DuBridge.) The fame of that lab rested not only on the achievements which emerged from it, but from the many great people who came to work there—because it was such a wonderful place to *be.* Millikan, of course, was the great inspirational leader. Watson was that essential supporting colleague who made sure that things went pleasantly, efficiently, smoothly.

Beginning in 1940 the Institute went through a great upheaval, and a relatively small handful of Caltech faculty soon found itself running not one, but several large military research, development, and production enterprises, employing thousands of people and spending millions of dollars. It was those millions of dollars which were a great worry to the Caltech trustees, as I learned many times later. James R. Page, then chairman of the board, told me of the bad dreams he used to have, in which some careless professor made a mistake so costly that the Institute's endowment was completely wiped out. (Jim Page, as many of you remember, never trusted any professor when it came to money.) Nevertheless, the trustees soon realized that there was a steady hand at work, making sure there were no mistakes, that contracts were properly written and carried out, that project teams were organized in such a way as to be effective. Hence, there were these great achievements, and not a dollar of Caltech endowment was lost. And as Jim Page often said, "It was Earnest Watson who kept us all out of jail." That was about as big a compliment as Jim knew how to pay to any professor.

A college president often gets a lot of blame when things go wrong. And so he should. But he often gets too much credit when they go right, and that is curious, for, while the president all alone can make things go badly, to make them go right, he needs a lot of help. He needs the help of strong, experienced, devoted, and farsighted people all around him, and how fortunate we have been these past 25 years to have had so many such people around. Personally, I shall always be grateful that for 16 years I had at my right hand one of these great figures of Caltech history—one who was always loyal, always devoted, always perceptive, always honest, always modest. And always aware that it was people who made any institution, and that an institution could become and remain great only as it brought together the best people, and created the conditions under which they could work together, individually and collectively, most happily and most effectively. That's just what Earnest made it possible for us to do at Caltech.

Arnold Beckman: We are saddened at the passing of a good friend, but we can be thankful that Earnest Watson was able to live such a full and fruitful life. He has enriched and eased the lives of many. I should like to mention two small personal items.

When Dean Watson was scientific attache to the United States embassy in New Delhi, I had occasion to make a brief business trip to India. I wrote to Earnest, asking if he could advise me of the best ways to get to some laboratories that I wished to visit. When I arrived in New Delhi, Earnest briefed me on the scheduling he had worked out. It was incredible. He had managed to make arrangements for me to meet, in the short space of ten days or so, more scientists and businessmen, and to visit more laboratories and industrial plants than I normally would attempt to meet and visit in several weeks.

This brutal schedule was not for me alone. Earnest himself accompanied me on the more difficult portions. How cheerfully he would start out at four o'clock in the morning with a driver and a jug of safe drinking water to take me to a remote village where laboratory apparatus was being made under the crude cottage industry conditions. Back at midnight, after driving all day over the rough roads, then up early again the next day for the next day's trip. Surely, this was service above and beyond the call of duty. The experience illustrates the meticulous planning and effective execution that characterized all of Earnest Watson's activities. It also testifies to his remarkable energy and vitality and his great desire to help others.

The second item relates to the auditorium. At the time of its completion, there was much discussion about who should give the first lecture in it. Obviously, it would be a milestone event, so a lecture had to be one that would be truly characteristic of Caltech, one that would focus attention on some important facet of the Institute's activities. Thinking back over my early years on the campus, I recalled the popularity and usefulness of the Friday Evening Lectures, and how much I enjoyed them. I stated that my first choice would be the liquid air lecture by Professor Earnest Watson. There was enthusiastic agreement. Although Earnest had retired, he graciously consented to give the opening lecture in the new auditorium. It was a great success, and an auspicious start for the popular Monday night lectures.

The Month at Caltech

C. J. Pings

New Posts for Pings

C. J. Pings, professor of chemical engineering and chemical physics and executive officer for chemical engineering, is the new vice provost and dean of graduate studies at Caltech. As vice provost—a newly created position—Pings shares some of Provost Robert Christy's responsibilities for supervision of faculty appointments and promotions, and for coordination of curriculum development.

As dean of graduate studies, Pings succeeds H. F. Bohnenblust—dean for the past 15 years. Bohnenblust will continue as professor of mathematics, a position he has held since 1946.

For the time being Pings is continuing as executive officer for chemical engineering. He is also going on with his research into the behavior of liquids and with supervision of a large research group.

Caltech Rates

In a survey of the graduate schools of 130 American universities, the American Council of Education ranks Caltech first in the nation in the quality of faculty and the effectiveness of the graduate educational program in the following fields: astronomy, geology, physics, and developmental biology (which combines genetics and embryology).

In other faculty ratings, the Institute was second in chemistry and molecular biology; third in mechanical engineering; fourth in civil engineering and microbiology; fifth in electrical engineering and physiology; sixth in biochemistry; ninth in chemical engineering; and fifteenth in mathematics. Caltech received a rating of adequate for its graduate botany program, and good in psychology, where it has no explicit program or permanent staff. The psychology rating presumably is for work in behavioral biology.

In the effectiveness of doctoral programs, Caltech received additional first-place ratings in molecular biology and chemistry. It ranked third in civil engineering, biochemistry, and microbiology; fifth in physiology and civil and electrical engineering; seventh in chemical engineering; eleventh in mathematics; and seventeenth in botany.

The survey was conducted by more than 6,000 scholars to determine the excellence of graduate programs and faculties.

Lunar Landmarks

Craters on the far side of the moon, nameless through the centuries because of lack of knowledge about that face, are finally being christened and put on lunar maps. More than 500 far-side craters (out of thousands of newly discovered features) now bear the names of internationally famous scientists—and other very interesting people as well.

Among the scientists, 17 men noted for their work at Caltech and the Hale Observatories have been honored. They include Robert A. Millikan; J. Robert Oppenheimer; Theodore von Karman, aerodynamicist; Harold D. Babcock, early solar astronomer at Mt. Wilson; and Paul Merrill, a pioneer in spectroscopic astronomy. Other Caltech and Hale Observatories astronomers who now have their names on the moon maps are John Anderson, Armin Deutsch, Arthur S. King, Kenneth Mees, Seth B. Nicholson, Francis G. Pease, H. P. Robertson, Carl Seyfert, Charles E. St. John, F. H. Seares, and Adrian van Maanen. Frank Borman, Apollo 8 astronaut and Caltech alumnus, is one of the 12 living men (six American and six Russian) who represent a breakthrough in the long-held policy of naming lunar features only after scientists who have died.

Systematic nomenclature for the front side of the moon was begun in 1932 by the International Astronomical Union. Among its early selections of names for features on the lunar face were George Ellery Hale, Edwin Hubble, and Walter Baade—all Caltech astronomers. In 1961 the IAU approved 18 far-side designations proposed by Soviet astronomers from Lunik-3 photographs, but it was only when Russian Zond and American Orbiter and Apollo pictures made fairly detailed maps of the far side possible that it became necessary to set up an internationally recognized nomenclature. A working group of the IAU, headed by Donald H. Menzel of the United States, was appointed in 1967 to draw up the list that was approved—with minor amendments—at the IAU meeting in Brighton, England, in August of last year.

In addition to including the names of the living, the IAU has made other innovations in the guidelines for new lunar terminology. Now the features

The Bacher File

Caltech produced two versions of a dossier on Robert Bacher on the night of November 20. The first, an album of photographs, was presented to the Bachers by Clarence Allen, chairman of the faculty, as a gift from Bacher's colleagues to honor him upon his retirement as Caltech's provost.

After a farewell dinner at the Athenaeum, the second dossier, in words and music, was presented in Beckman Auditorium. "The Bacher File," a musical revue written by Kent Clark and Elliot Davis, featured members of the Caltech faculty, staff, and distaff, and recalled some of the highlights of Bacher's Caltech career.

Bacher came to the Institute in 1949 as chairman of the division of physics, mathematics and astronomy and director of the Norman Bridge physics laboratory. A specialist in high energy physics and atomic energy, he began his academic career as an instructor in physics at Cornell University in 1935. By 1946 he was director of Cornell's Laboratory of Nuclear Studies. During World War II, Bacher worked first at the MIT Radiation Laboratory, and from 1943 to 1946 at the Los Alamos Laboratory in New Mexico on the atomic bomb project. He has served on the Atomic Energy Commission, President Eisenhower's Science Advisory Committee, and as a delegate in 1958 to the Geneva conference on the cessation of nuclear weapons testing. At Caltech Bacher created an experimental program in high energy physics, and supervised construction of the 1.5-billion-electron-volt synchrotron, with which by 1957 he and a group of other Caltech physicists succeeded in the photo-production of heavy mesons and hyperons from hydrogen.

His appointment as provost in the fall of 1962 made it increasingly difficult for Bacher to keep up with the projects he had initiated. Now he has retired as provost, but he remains on the faculty as professor of physics and has resumed teaching. He hopes, he says, "to find out a few of the many, many things that have been happening in high energy physics."

may be named for people associated with rocketry and spaceflight as well as for famous scientists. The list is also as thoroughly international as possible.

These criteria—somewhat freely interpreted perhaps—provide a varied list indeed. For instance, from mythology come the figures of Daedalus and Icarus; there is also the legendary Wan-Hoo, who around the year 1500 is supposed to have made the first attempt at manned rocket flight. He attached a seat and 47 gunpowder rockets to a box kite—and died in the attempt to take off.

Another rocket scientist on the list is the Russian Nikolai Kibal-chich (1853-81), better remembered as a bomb maker executed for his part in the assassination of Czar Alexander II. The name of Alfred Nobel, the inventor of dynamite, also appears on the moon maps.

Other inventors among the 500 are the telescope makers Cassegrain, Clark, Gregory, and Ingalls; and representing the poets are Dante, Chaucer, and Omar Khayyam.

Honors and Awards

Gerald J. Wasserburg, professor of geology and geophysics, is the 1970 winner of the Arthur L. Day Medal awarded by the Geological Society of America. The Day Medal honors "outstanding contributions to geologic knowledge through the application of physics and chemistry to the earth sciences."

Described by the society as holding a "place among the most brilliant and productive men in earth sciences today," Wasserburg was cited for his major research in determining the time scale of the solar system. He was also honored for the establishment of dating methods using long-lived natural radio isotopes, the study of geologic processes using natural isotopes as tracers in nature, and the application of thermodynamic methods in the study of geologic systems.

Gerald J. Wasserburg

Wasserburg is also a recent recipient of an Exceptional Scientific Achievement Award from the National Aeronautics and Space Administration, given for his work in examining material returned from the lunar surface. NASA officials describe his success in age-dating lunar samples as one of the most outstanding scientific achievements of the Apollo program.

Robert G. Bergman, assistant professor of chemistry, has been awarded a $25,000 grant from the Camille and Henry Dreyfus Foundation of New York. Bergman is one of 14 young scientists who were the first to receive assistance under a new foundation program. Their selection was based not only on their potential as scientist-educators but also on their proven talent in promoting "new concepts in teaching, research, and other creative ideas related to higher education."

John N. Bahcall, associate professor of theoretical physics and staff associate of the Hale Observatories, has been awarded the Helen B. Warner Prize of the American Astronomical Society. He is the first theoretical physicist to receive the award, which is given to a scientist for significant work done before he is 35 years of age.

Bahcall, now 35, was honored for contributions to cosmology in two areas: for theoretical work on an experiment to detect solar neutrinos, and for using quasars to help determine the distribution of matter in space.

Something in the Wind

Anatol Roshko, professor of aeronautical engineering and applied science, is chairman of the new Universities Council on Wind Engineering Research. Formation of this organization, which will promote research and disseminate knowledge that could save the U.S. some of the $750 million a year in damage caused by high winds, was a major outcome of a two-day conference held at Caltech last month.

Attended by 130 meteorologists, engineers, and government officials, the conference on Wind Loads on Structures provided the opportunity for an extensive exchange of information among wind experts. The new council plans to organize similar technical conferences on progress in high winds research every two years. It will also provide advice to universities and government agencies upon request.

George Housner, professor of civil engineering and applied mechanics, who was a member of the organizing committee for the conference, pointed out that the move to organize this continuing council places wind research on the same footing as that for earthquakes. Housner was instrumental in the establishment of the Universities Council on Earthquake Engineering Research in 1966.

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heat is discharged into a cool sink (the power-plant environs). Typical thermal efficiencies of new plants are as follows:

	Thermal Efficiency	Waste heat per unit electrical output
Conventional (fossil fuel)	35-40%	1.5-1.8
Nuclear	30-35%	1.8-2.3

By the laws of thermodynamics, higher efficiencies in a steam cycle can only be achieved by operating at higher steam temperatures and pressures. Efficiencies of nuclear-powered steam plants will probably catch up to conventional steam plants in another decade, as operating experience will permit using higher temperatures in the steam cycle. But limitations on materials and safety will prevent any dramatic improvements above 40 percent for the presently used steam cycle. Any possible replacement of the steam cycle by more direct means of electrochemical conversion for *large* central generating stations is at least two decades away as the technology does not exist today. Also, direct conversion of nuclear energy to electricity without use of the steam cycle is not likely very soon; the future use of fusion energy will still probably be coupled with a steam cycle.

Thus, the waste heat problem will be with us for a substantial period of time, and technological change in power generation cannot be expected to solve the problem for us. But there is another more fundamental waste heat problem arising from consumption of electricity. Practically all uses of electricity ultimately lead to conversion of the energy back to heat; it occurs directly for electric space heating, electric stoves, electric furnaces and the like, and indirectly for lighting, transportation, power tools, and so on. (To be sure, a small amount of energy is locked up in increased potential energy—mechanical or chemical—and some electromagnetic radiation—light and radio—escapes to space, but these are estimated to be only a very few percent of society's total consumption of electrical energy.) Thus, we may think of a power plant of 40 percent efficiency as releasing 60 percent of the heat in a concentrated dose at the power plant site and the other 40 percent over the points of use, primarily the urban areas.

If by some miracle all power plants could be made 100 percent efficient, the total heat release would be cut back to about 35 percent of what it is now. But if the power demand keeps doubling every ten years, the gain in efficiency would be all used up in just 15 years of continued growth. This illustrates that any technological breakthrough in environmental control is equivalent to a one-time gain of time which can be wiped out by unchecked growth in production.

The waste heat from electricity is but part of the total waste heat released by all forms of energy use by society. The density of heat released in urban areas has already increased atmospheric temperatures significantly. Ultimately the excess heat is diffused in the atmosphere and radiated to space. On a *local* basis the total waste heat released is substantial (for example about 5 percent of solar radiation in the City of Los Angeles), but on a *global* basis it is still very small (less than 0.01 percent of insolation at the surface).

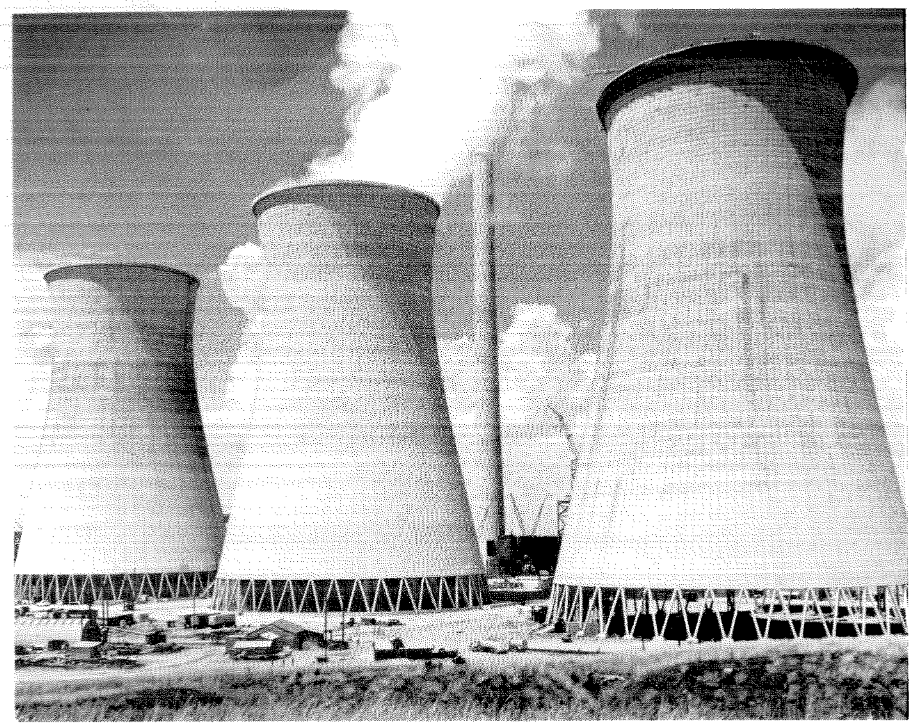
In fact, heat as a pollutant has a unique characteristic. Because of the basic laws of thermodynamics there is no treatment as such; any efforts to concentrate it (by heat pumps) simply require more mechanical energy, which means more waste heat is generated at the power plants. Other types of environmental pollution can be alleviated by various processes, which usually consume power and ultimately produce waste heat. *Thus, heat is an ultimate residual of society's activities.*

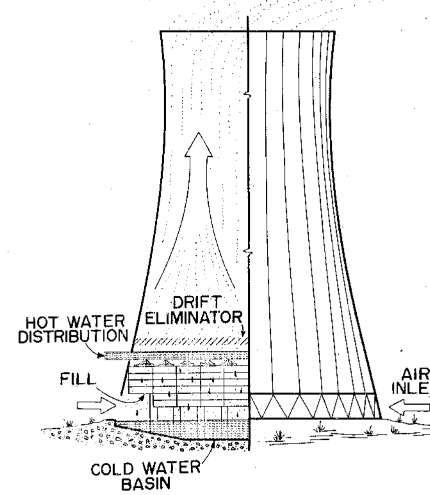
Cooling Water Discharge

The waste heat rejected from power plants is unusually concentrated compared to the overall release of heat by society. For example, at the proposed 6600-megawatt nuclear power station at Point Conception on the California coast, the waste heat will be 13,000 mw (thermal) or equivalent to insolation on about 70 square kilometers of the ocean (assuming 100 percent load factor at the power plant, and insolation at 400 langleys/day = 193 mw/ki^2).

Thermal power plants use cooling water to transfer heat from the condensers (on the low-pressure side of the turbines) to the environment. Once-through systems, which are the least expensive, take water from the environment and return it about 10° to 15°C hotter. Fresh water sources have been frequently used in the past, but with stringent thermal requirements (such as not more than 3°C rise), there are few remaining opportunities to use once-through fresh water cooling for new major plants of several thousand megawatts. Most rivers simply do not have enough flow to provide sufficient dilution during critical summer months, and those that do (like the Tennessee) are already being used extensively for cooling.

Lakes and reservoirs can be good heat sinks, but the currents are often too small to provide good advection of heat away from the plant sites. Furthermore, lake biota and water quality are particularly sensitive to thermal changes. For Lake Michigan, for example, the new rules now being proposed are so strict that new large power plants will be forced to use cooling ponds or cooling towers.





Cooling towers at TVA's Paradise Steam Plant in Kentucky are designed, as in the diagram above, to supplement the capacity of the Green River to cool the plant during the summer months. Each tower is 320 feet in diameter at the base, and 437 feet high. Power plant capacity is 2560 megawatts.

Many estuaries are also too small to take large additional heat loads, and increased temperatures aggravate water quality problems. The open ocean is still an excellent heat sink, but increased attention is needed for development of logical temperature criteria and effective diffusion structures for hot water discharge.

In once-through cooling systems the natural water environment is being used as a giant heat exchanger between the power plant and the atmosphere. Thus, in setting thermal requirements and designing cooling water outfalls, more attention should be given to the next step in the heat transfer chain. Some questions:

1. Is it desirable to minimize the temperature rise in the receiving water by wide dispersal of the heat?
2. Should the transfer of heat to the atmosphere be maximized (by keeping the temperature increment high instead of low)?
3. Should discharge be arranged to avoid complete "blockage" of a waterway with heated water?
4. Should waste heat be stored below thermoclines in lakes and oceans to avoid any direct effect on surface temperatures during the summer?

The current regulatory practice by FWQA (the Federal Water Quality Administration) and the states is the specification of maximum temperature increments in the receiving water (objective 1), but this may be contrary to desirable objectives 2 and 3. Furthermore, following objective 4 in lakes might have serious consequences for the annual regime of a lake, although temperature increment requirements are satisfied. Within the overall limits of the heat assimilation capacity, there are various strategies for design of outfalls to control the heat distribution in the environment—such as submerged outfall diffusers for high dilution or channel outlets for surface spreading of hot water with little dilution.

It is urgent that we have a better understanding of the ecological effects of heat in each case, and find out whether it is better to disperse waste heat widely (disturb a vast region just a little) or to set aside a much smaller aquatic region to be heated significantly, allowing other regions to remain undisturbed. Millions of dollars are going to be spent for thermal pollution control for ecological objectives that are not yet defined or understood. Even when we do understand the ecology, there remains the problem of evaluating tradeoffs—how much disturbance of aquatic life should be tolerated, considering the many benefits derived from electricity?

Electric utilities understandably find it desirable to use the ocean water for once-through cooling if the load centers are near the coast. But the coastlines are strongly desired for other uses, too. In California, the public wants the shoreline reserved for recreation and its natural beauty rather than for unsightly thermal power plants. There is a limit also to how much heat the coastal ocean can assimilate, although we are apparently still far from this limit in California.

When once-through cooling is not desirable, cooling ponds or evaporative cooling towers may be used. The use of cooling towers instead of once-through cooling systems increases the cost of electricity only about 1 to 2 percent for residential customers or 3 to 4 percent for industrial customers. But these systems also have their hydrologic

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impacts especially where water is scarce. In either case most of the heat exchange to the atmosphere in warm weather occurs by evaporation of water from the pond surface or from the cooling tower spray. For each kilowatt-hour of electricity generated, the evaporation is about 2 liters.

In the last few years large natural-draft cooling towers have come into use in the U.S. When the circulating water is sprayed downward into the rising air current, a small fraction of the water (a few percent) is lost by evaporation and by upward drift of droplets, necessitating a continuous inflow of makeup water to the system. Since such water usage is evaporative, the salts are left behind and have to be flushed out occasionally, thus degrading the quality of the remaining natural water supply. Dry (non-evaporative) cooling towers have not yet been developed for large power plants of hundreds or thousands of megawatts.

Planning for the Future—Braking the Growth Rate

The waste heat problem is not readily solved by technological change. Different outfall arrangements or siting alternatives can convert and distribute the heat in ways which minimize adverse effects, but the waste heat discharges are not *eliminated*. Gradual small improvements in thermal efficiency of power plants will give barely perceptible relief on the waste heat problem in the next few decades.

We shall continue to depend on large central power stations. One alternative, solar cells, has the advantage of using the present heat budget of the earth and circumvents the waste heat problem (like hydro power), but the huge requirements for land and material will make it impractical for generation of the large blocks of additional power to meet projected needs in the next few decades.

The "globalists" would have us believe that we are far from environmental limits on energy use because man's energy input is small compared to the global heat budget. But they fail to allow for the fact that local and regional environmental impacts (such as in California or the northeastern U.S.) are rapidly becoming severe. Furthermore, heat dissipation is not the only problem; on all the other fronts as well (air pollution, mine debris, nuclear waste management, aesthetics), it is highly doubtful that technology can reduce the impact per unit of consumption at a continuing annual percentage rate anywhere near the current rate of growth of consumption. Each single technological improvement in environmental control is equivalent to only a one-time gain of a few years in an exponentially growing business; in some instances the improvement due to a new control technology may be counteracted by growth even faster than the new control technology can be implemented (as may well be the case for air pollution from automobiles).

Our most powerful tool for environmental control in the next few decades is a *drastic reduction in the rate of increase of consumption.* Society *must* set limits on the total release of heat and all other contaminants to protect the quality of our finite environment.

A decade ago energy planners were primarily concerned with the adequacy of our fuel reserves. But now nuclear power has proved itself, and with breeder reactors probably to be in use soon, there is little concern about running out of nuclear fuel. The next step will undoubtedly be fusion reactors using deuterium derived from a huge supply in the ocean waters. The great optimism on the fuel picture is well illustrated by a promotional booklet for nuclear energy entitled "Infinite Energy" issued by the Westinghouse Company a few years ago.

The "scarcity" of the environment is now replacing the scarcity of fuel as the critical constraint in growth of the energy industry. The environment can no longer be regarded as *infinite*. One hundred years ago it must have seemed to our forebears as though there was infinite land in the United States; but the frontier days are past, and we have become adjusted to thinking of our land as a scarce and limited resource. Any freedom to use land has been reduced by government regulations like zoning. We have also of course already recognized the finiteness of fresh water supplies, and have established rights, priorities, and regulations to control their use.

Now we have passed the last frontier of the infinite environment concept. We must stop talking about meeting the demand for energy and instead devise ways to allocate a limited potential supply and to change people's attitudes toward energy. The first step is to reduce the annual rate of increase—in a sense, to reverse the curvature of the growth curve. This does not imply an actual decrease of energy consumption but rather an attempt to level the growth curve off below some upper limit which is not too far above our current position.

Limiting the total growth of the energy usage is not a new idea, but somehow technologists always seem to concentrate just on reducing the adverse effects of each unit of usage, optimistically assuming that the overall growth will not overwhelm them. But the thought is beginning to appear in various reports. In its report "Electric Power and the Environment" (Aug. 1970), the Office of Science and Technology says:

"... It may well be timely to re-examine all of the basic factors that shape the present rapid rate of energy growth in the light of our resource base and the impact of growth on the environment. We raise the issue here for further study and discussion."

I would have been happier if it said, "We raise the issue for action!"

A December 1969 report on energy forecasting for OST by Battelle Northwest slipped in just a one-sentence paragraph on the growth-environment issue:

"It is even possible to envision Federal policies designed to slow the growth of energy consumption due to adverse environmental effects through rate-making policies and emphasis on increased efficiency."

It's not a question of whether it is "even possible"; it's a *necessity* to develop such policies if we want to survive this energy "explosion." It's not a case of saying the public is not ready for growth control. It's time for the technologists to say, "You must recognize the limitations of your environment and live within your environmental means."

The Elements of an Energy Policy

The federal and state governments need to develop more comprehensive and better defined energy policies and strategies, such as:

1. All forms of energy must be considered together, so that comprehensive strategies involving tradeoffs between different fuels and energy systems can be adequately evaluated.

2. It must be recognized that energy usage must ultimately be limited because of unavoidable environmental effects (such as the release of heat). The attitude of unlimited development to meet unlimited demands must be replaced by a willingness to keep energy demands within reasonable limits, considering the limitations of the environment. Heat is an inevitable residual of industrial societies.

3. The growth rates must be drastically curtailed in the near future. This will not be easy, and a carefully developed strategy would probably include many of the following features:

a. The consumers of electricity and fuels should be charged for all environmental costs, including both direct costs for environmental pollution costs and indirect damages to the environment. Present pricing policies simply do not imply a high enough value for the environment which must be shared by all.

b. Regressive rate structures should be revised, as necessary, to discourage wasteful usage of energy by large users who often enjoy preferential rates.

c. Stopping advertising and promotional programs, especially by electric utilities.

d. Establishment of taxes to increase the cost of energy use to discourage excessive usage.

e. Establishment of adequate licensing procedures and priorities for large new users of electricity or other energy sources. In some circumstances permits for use of energy should be denied where the environment cannot tolerate such additional energy uses.

f. Setting limits on unit consumption of energy by automobiles, electric appliances, houses, etc.

g. Discourage use of electricity as a simple source of heat, unless it is necessary for air pollution control. Whenever one unit of electrical energy is used for heating, approximately two units of waste heat must be rejected to the environment; thus, even though electricity is a "clean" source of heat to the consumer, it loads more heat altogether into the environment.

h. In urban planning, limitations must be set for the areal density of total energy release in urban areas, in order to avoid excessive climatic change.

i. The consumer must learn not to use energy wastefully or carelessly, and realize that his consumption inevitably produces some environmental degradation.

4. A vigorous program of research and development on alternative long-range energy strategies should be undertaken. In a broadly interdisciplinary way, the new Environmental Quality Laboratory at Caltech, under the direction of Lester Lees, has already started a study of these problems (see p. 11).

5. More research is needed on the individual components of environmental control (e.g., air pollution, water pollution, radioactive wastes), and power-plant-siting alternatives (e.g., underground or underwater).

6. Establish adequate organizations to manage the environment in all aspects, with the ability to make tradeoffs between different kinds of environmental effects. (Should air pollution be solved in one place at the expense of a thermal pollution problem somewhere else?)

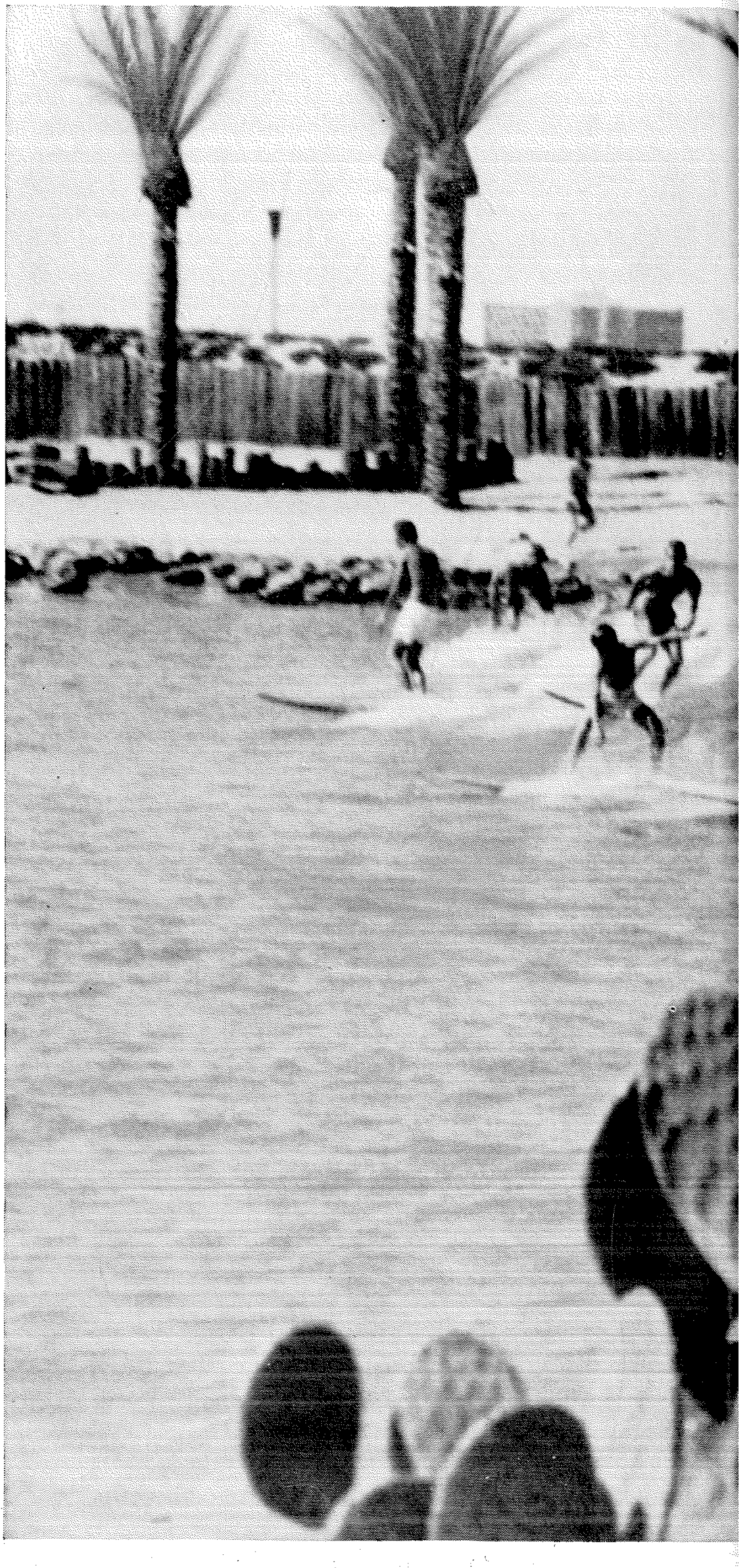
7. Clarify environmental goals and damages especially in the fields of medicine and ecology.

8. Energy systems and environmental limitations must become a central element in regional and urban planning.

9. Adequate long-range planning is vital, as illustrated by the electric power industry. Since the time required for licensing and construction of electric power plants is often ten years, tentative site identification must be made 15 years before expected startup. The overall planning for a given utility must extend even further, say 20 years. Finally, basic policy planning for the whole energy industry must extend about 30 years into the future in order for orderly planning to proceed. It is because of this pattern that I sound the alarm for basic long-range questions of growth and other strategies rather than for any particular argument over a power-plant site.

Environmental control is the civilian counterpart of arms control. We now have the technology to do vast damage to our environment, even by the "normal" peacetime activities of society. We must accept some profound changes and restraints in our societies to control man's overall effects on the environment. The environment *is* definitely finite, and it simply can no longer tolerate man's unrestrained activities and new developments, whether of military or civilian nature.

They're "shooting the curl" in Phoenix.



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Surfing has come at last to the Arizona desert.

The ersatz ocean is called Big Surf*. At 4 million gallons, it's believed to be the biggest "pool" ever built: 400 feet long by 300 feet wide, and nine feet at its deepest point.

And it makes its own waves.

Every 60 seconds, the crashing surf propels an army of Arizona's finest toward a sandy 4½ acre beach.

Now about the waves. They're made by pumping water into a 160 foot by 41 foot tank-like "reservoir." Up to 100,000 gallons are released through 15 gates at the reservoir base. The water passes over a custom concrete "reef," and is formed into a wave up to five feet high.

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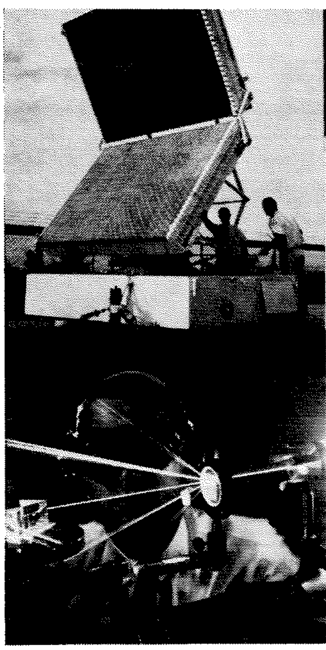

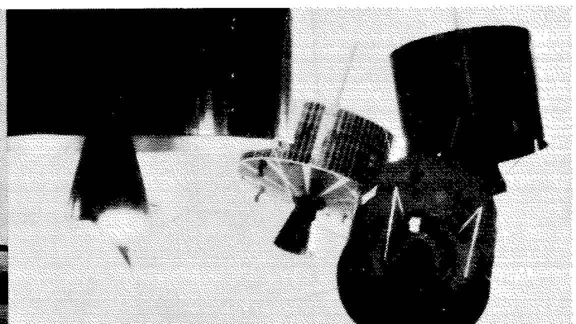

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Campus Interviews
February 26, 1971

For information on opportunities offered graduating engineers and scientists at Hughes, and to arrange for an interview with Staff representatives, contact your College Placement Office. Or write: Manager, Personnel Administration, Hughes Aircraft Company, P.O. Box 90515, Los Angeles, Calif. 90009. An equal opportunity M/F employer. U.S. citizenship is required.

Or, for that matter, is Los Angeles? Or Chicago? Or Philadelphia? Or Dallas?

Or any other city groping its way to an uninhabitable anachronism.

A curious situation has developed in America. Eighty per cent of the people in this country live on less than ten per cent of the land area.

There used to be a good reason for this.

At the time of the industrial revolution, we congregated in cities because that's where the sources of energy were. Coal. Water. Electricity.

And our communications network was so limited that we had to be in close proximity to each other for business and social purposes.

No more.

There are no longer any good reasons to continue this hopelessly outmoded life style.

With the advent of the whole spectrum of new communications available to us (wide-band communications, laser beams), we will have the opportunity to live in significantly less dense population centers.

This is no idle prophecy.

The concept is quite realistic and well within the bounds of engineering capabilities which we already have.

Not only do we have the tools to provide the means for new styles in human settlements, but also to rebuild, in a sociological sense, the crowded inner core of our major cities.

The combination of international satellites and cable will provide the means of bringing individuals all the information they need or want without interference or control.

And without the need to be in any specific place.

(Think for a moment about the Apollo 11 moon landing in July, 1969. 500 million people around the world saw, via television, *precisely the same thing at the same time*. Being in New York or Los Angeles held no advantage over being in Keokuk or Harrisburg.)

Historically, we've been preoccupied with moving people and objects. Thus, our intricate network of highways and railroads and airlines — all of which have become enormously inefficient (not inherently, but in application).

The future will see us moving *information*, not, by necessity, people and things.

Your home will be the absolute center of your life.

You will work from home, shop from home, "visit" with family and friends from home, receive in your home any intellectual or cultural achievement known to man.

Fantastic, yes. Fantasy, no.

It is quite within reason to expect these changes by the 1980's.

If we want them.

If we want to change. If we want a better life for ourselves.

Technology has advanced to such an extent, that man is now, literally, capable of changing his world.

Yet, today, a certain gap has developed between the potential of technology and its use by mankind.

There is an obvious contradiction in a method which can land a man on the moon, yet tolerates, perhaps even accepts as inevitable, poverty and ignorance here on earth.

There is a contradiction in a method which affords the best of everything for some, and next to nothing for others.

So we must, in a sense, catch up with the technological potential and apply it for the benefit of all mankind.

All we need sacrifice are the antiquated work practices and our anachronistic traditions.

At RCA, through research and product development, we are committed to closing the technology gap and cancelling the contradictions.

This is the age of the engineer. Nobody understands this better than RCA.

If you're an engineer, scientist or systems programmer, and want to be part of RCA's vision of the future, we invite inquiries.

If you are interested in a comprehensive index of over 1100 technical papers published by RCA scientists and engineers during 1969, let us know.

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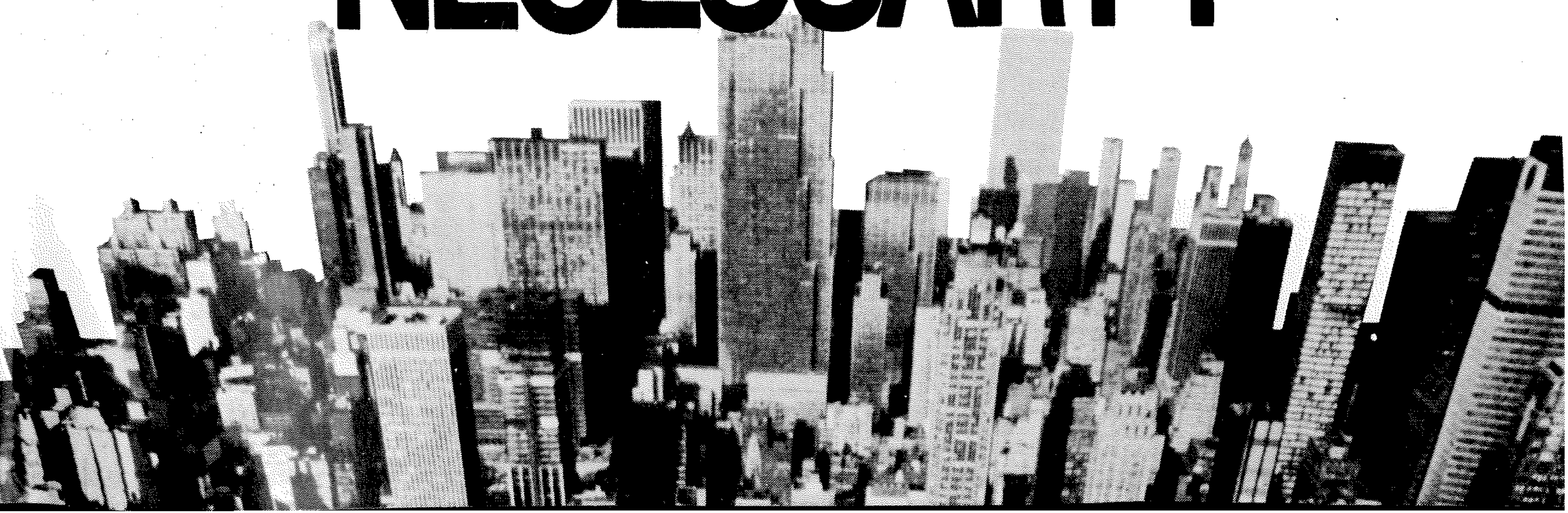
IS NEW YORK REALLY NECESSARY?



Even if you don't like the air you breathe, you can't stop breathing.

When was the last time you went out for a breath of fresh air and got it? How long has it been since the sky looked really blue?

Every day, our cities dump hundreds of thousands of tons of waste into the air. Carbon monoxide. Sulfur dioxide. Fluoride compounds. And plain old soot.

If something isn't done about air pollution in your lifetime, it may cut your lifetime short.

Air pollution can be controlled. The key is technology. Technology and the engineers who can make it work.

Engineers at General Electric are working on the problem from several directions.

Rapid transit is one. In many cities, the automobile causes more than half the air pollution. In some cities, as much as 90%. But engineers at GE are designing new equipment for rapid-transit systems, encouraging more people to leave their cars in the garage.

Another direction is nuclear power. General Electric's engineers designed the very first nuclear power plant ever licensed. A nuclear plant produces electricity without producing smoke. And as the need for new power plants continues to grow, that will make a big difference.

There are other ways General Electric is fighting air pollution. Maybe you'd like to help. We could use your help. But don't expect to come up with an overnight solution to the problem.

The solution will take a lot of people, a lot of talent and a lot of time. You'll breathe easier—once you get started.

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