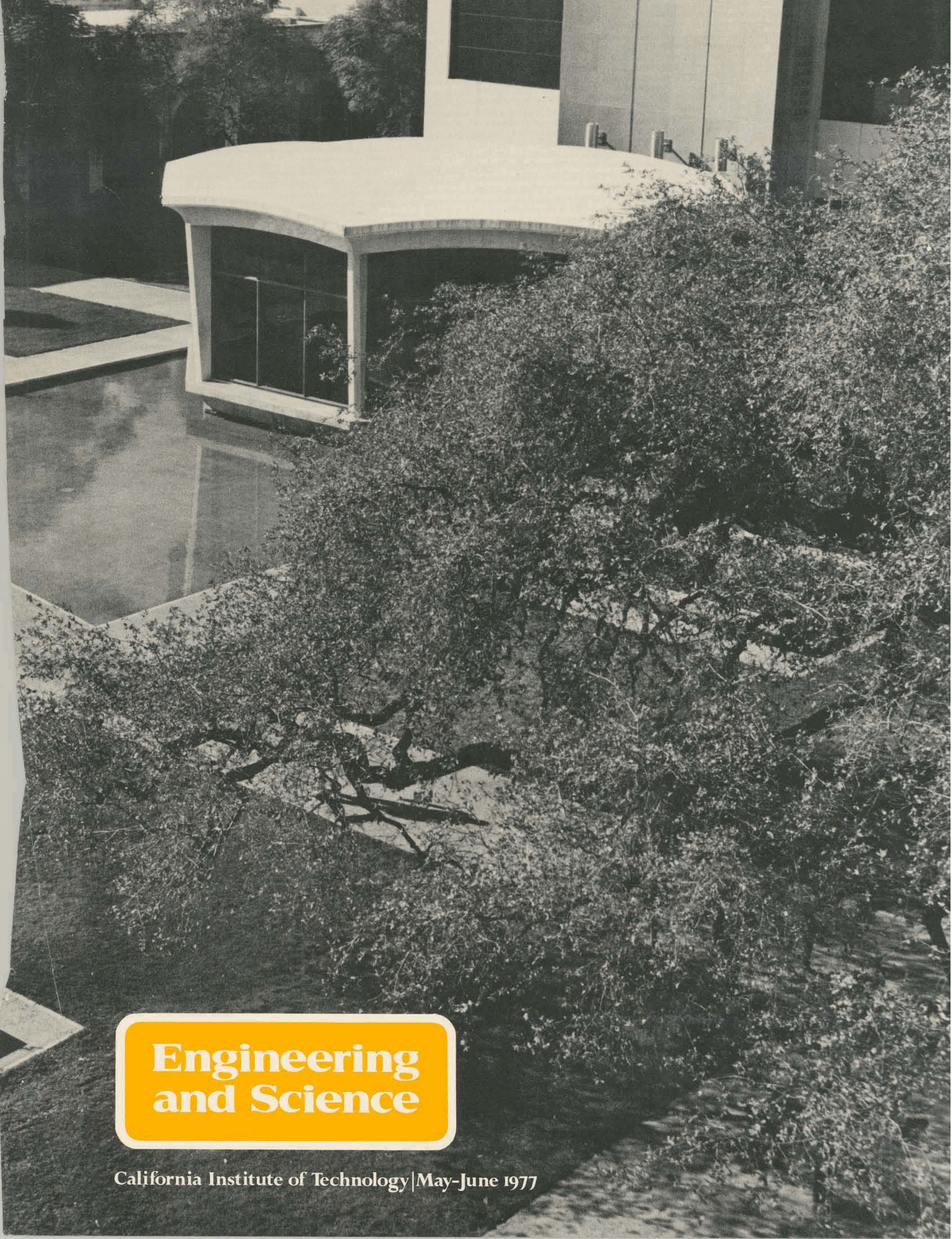

Engineering and Science

California Institute of Technology | May-June 1977

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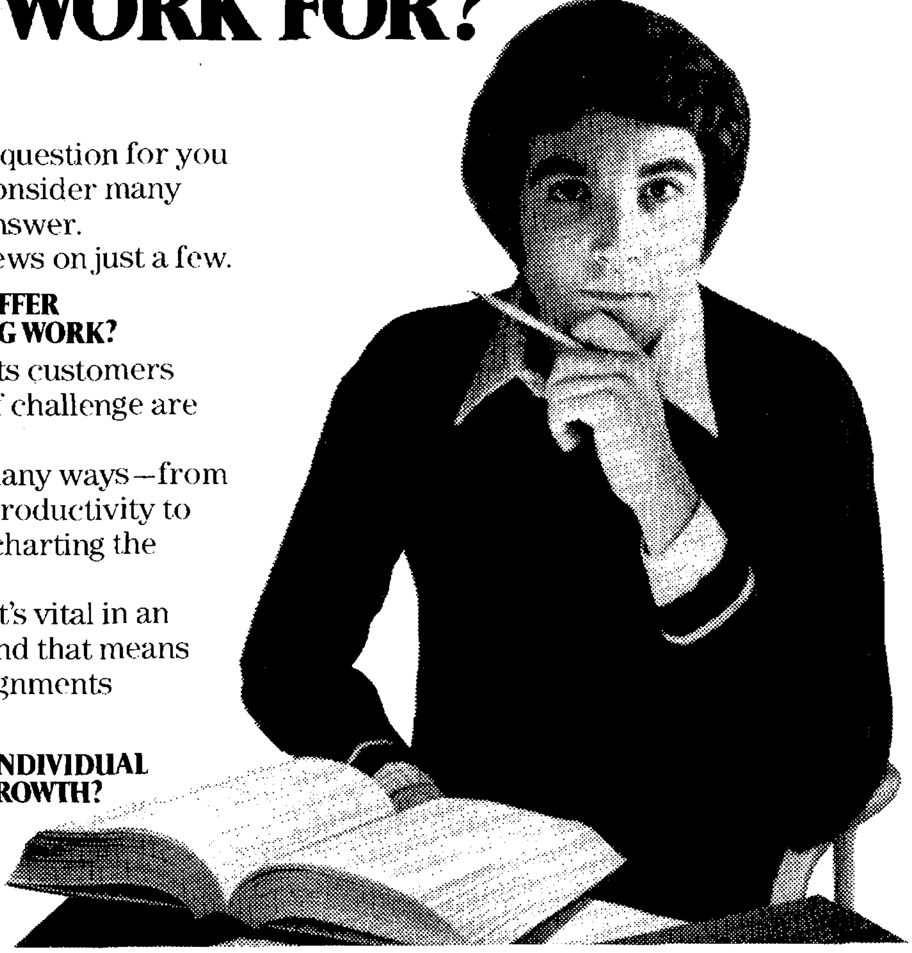

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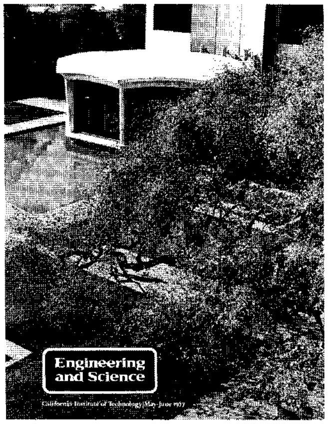
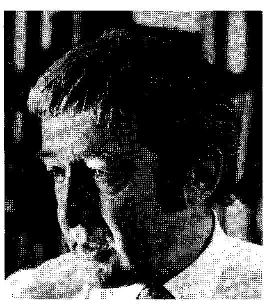
Engineering and Science

May-June 1977/Volume XL/Number 4

In This Issue



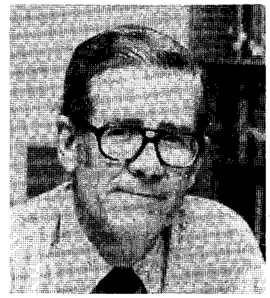
Progress Report
On the cover — A bird's-eye view of two campus landmarks: Millikan Library, which is currently celebrating its tenth birthday, and the 400-year-old Gates Oak, which is recovering nicely from a near-fatal attack of oakroot fungus.



Another Look
There's nothing unusual about predicting man's future, even in 100-year segments. Publicly revising the prophecies may be a bit rarer. Nevertheless, it has happened twice in the 20 years since three Caltech professors — James Bonner, Harrison Brown, and John Weir — first organized a conference to inquire into the problems and possibilities they saw looming up ahead. They called it The Next Hundred Years, and in due course it was followed by The Next Ninety Years and, this spring, by The Next Eighty Years.

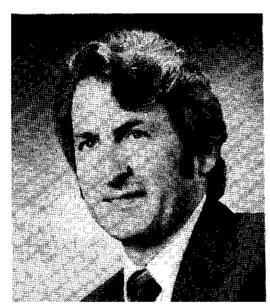
Harrison Brown led off the most recent of these meetings with a long look at the 20- and 10-year-old forecasts, analyzing where they were wrong, where they were right, and why. "The Next Eighty Years" on page 3 is adapted from that talk.

Energy Policy
The importance of establishing a national energy policy has become a major subject for discussion and debate in the U.S. One man who is deeply concerned is John



Teem, who is on campus this year as a Sherman Fairchild Distinguished Scholar. "Why Don't We Have a National Energy Policy?" on page 23 is adapted from his recent Watson Lecture.

Teem is spending a lot of time consulting on energy projects at Caltech and JPL, bringing to them the considerable expertise and experience he has acquired most recently in jobs at the national level. From 1975 to 1976 he was assistant administrator for solar, geothermal, and advanced energy systems for the Energy Research and Development Administration. From 1973 to 1975 he was assistant general manager for physical research for the Atomic Energy Commission, and he received their distinguished service award in 1974.



Truth and Consequences
Scientifically accurate earthquake prediction seems to be an increasing possibility, and one that has already begun to generate studies of the implications for society. A model of its kind, the first empirical assessment of likely responses to such prognostication has been carried out over the last two years by a research group from the University of Colorado's Institute of Behavioral Science. The project was headed by two sociologists — J. Eugene Haas, professor of sociology and program director of the Institute's research program on technology, environment, and man; and Dennis S. Mileti of Colorado State University — and financed by a grant from the National Science Foundation.

Since March 1975 the group has been collecting data by means of more than 1000 interviews. When Caltech's Earthquake Research Affiliates recently held a Conference on the Nature of Great Earthquakes, they invited Haas to describe some of the results. "The Impact of Earthquake Prediction" on page 7 is adapted from that talk.

Life Line
Biologically, the partnership of two dissimilar organisms in a mutually beneficial relationship is called a symbiosis. Academically, the process can be described as interdisciplinary. In the case of biologist Lynn Margulis, who is spending several months in Caltech's geology division as a Sherman Fairchild Distinguished Scholar, both words apply.

Margulis is interested in the early evolution of life on the earth, and she traces some of its history in the very oldest rocks. Among the things she finds is evidence for symbioses between microorganisms of distinct and ancient ancestry, some of which led to plant and animal cells. At a recent Athenaeum Lecture she described some of the new tools and concepts she is using to unravel our previously unrecognized legacy of life from Precambrian times.

"Life on the Early Earth" on page 13 is adapted from that talk.

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Managing Editor — Jacquelyn Bonner
Photographer — Floyd Clark

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Engineering and Science
MAY-JUNE 1977

The Next Eighty Years

by HARRISON BROWN

I suggest that our industrial society may be far more vulnerable and far less resilient, in the ecological sense, than we have assumed

THIS IS the 20th anniversary of an attempt on the part of (originally) three of us — James Bonner, professor of biology; John Weir, then associate professor of psychology; and myself — to examine where our world seems to be heading from the points of view of such parameters as population, resources, food, industrialization, and technological change. We called this examination The Next Hundred Years.

Ten years ago we subjected our forecast to scrutiny and asked such questions as, "Where are we going wrong — and why?" We found that exercise was illuminating, and naturally we entitled it The Next Ninety Years.

Now another ten years have passed, and we are taking still another look. Naturally, we have entitled this The Next Eighty Years.

In rereading the published proceedings of The Next Hundred Years and The Next Ninety Years, I am surprised first of all that our batting average has been pretty good. But I am surprised far more by some of the things we *didn't* talk about. With respect to what we did talk about, I will cite two successes, if I can call them that, and one dismal failure.

First, world population is still moving up pretty much as we expected it to 20 years ago — though somewhat more rapidly. Twenty years ago we suggested that the population in the year 2000 would be five billion. It is now over four billion, and by the year 2000 it cannot be much less than six billion. There are, however, encouraging signs from some large countries such as China, India, and Indonesia that birth rates are beginning to decline. This change appears to be largely the result of substantial official family planning programs. Political upheaval like the recent one in India can always change the picture and change it rather rapidly. But if the trend persists, there is a fighting chance that world population can be stabilized eventually at somewhat less than ten billion persons.

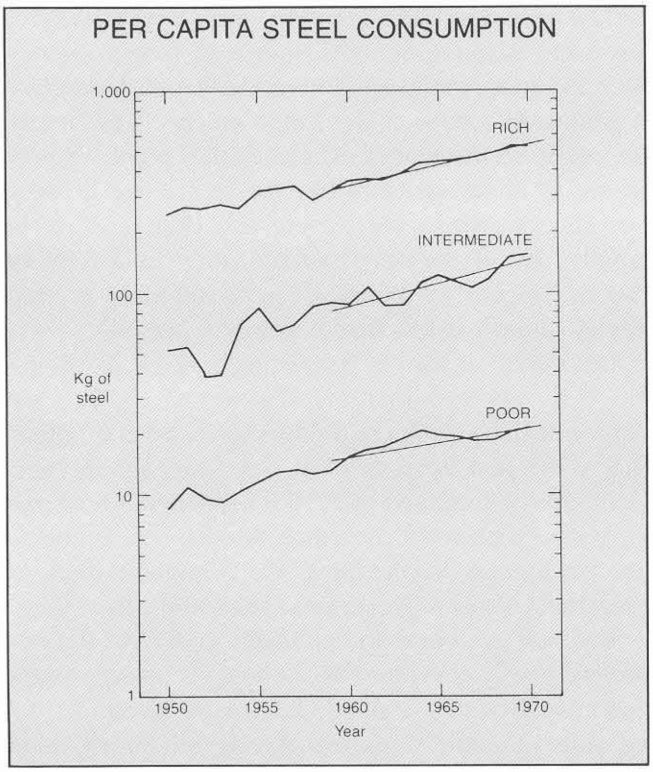
Secondly, we had an interesting success involving the U.S. energy situation. Twenty years ago we suggested that petroleum production in the contiguous U.S would peak at about 1970. Ten years ago this still seemed to be true, and in 1970 it happened. Of course we will experience a rise when Alaskan crude comes into production, but as far as the contiguous U.S. is concerned, it seems likely that it's downhill all the way.

And now we come to our major goof. We did not become overly concerned about the U.S. energy situation in spite of this peaking. To be sure, even in 1957 we were substantial importers of crude oil, but we knew that we were endowed with large reserves of coal and oil shale, and nuclear technology was being developed very rapidly. We assumed pretty much that all of these sources would be rapidly developed in the course of the 20-year period and that the transition away from domestic and imported crude oil would be a smooth one. And how wrong we were.

Ten years ago, I think we were infected by a general optimism about the future of nuclear power. It was pointed out that the unit power cost for power from a nuclear reactor fell off with increasing size of the reactor — and all one had to do was build large enough reactors to undercut the price of electricity generated from petroleum, and everything would be fine.

This turned out to be not quite correct — not just from a technological point of view of course, but from a very human point of view. We certainly did not foresee the tremendous mystique that grew and spread over the land concerning nuclear technology and nuclear power, concerning the safety of reactors, concerning the security of fissionable materials. So now I can say emphatically that I, for one, am extremely worried about the future course of events.

The things we *didn't* talk about? It's really incredible in a way that we didn't talk about environment. Again, I think it was just a tacit optimistic assumption that environmental problems would arise but that we would come to grips with them as quickly as they came up. Here we were quite wrong. We did not talk about climate, and the possible impact of changing climate upon the world scene, even though in 1957 there had been a constant, steady drift downward for some 17 years of the mean temperature of the northern hemisphere. Even at that time we suspected fairly strongly that increasing concentrations of carbon dioxide in the atmosphere could eventually have a substantial effect upon the whole world's climate in the opposite direction.



Per capita steel consumption is increasing in all countries, but there is no sign that the poor nations will ever catch up with the rich.

Another thing we didn't talk about, because we didn't know anything about it, was world modeling. Now people are trying to model things all over the place, and it certainly is a very interesting development. How important it will turn out to be is difficult to say.

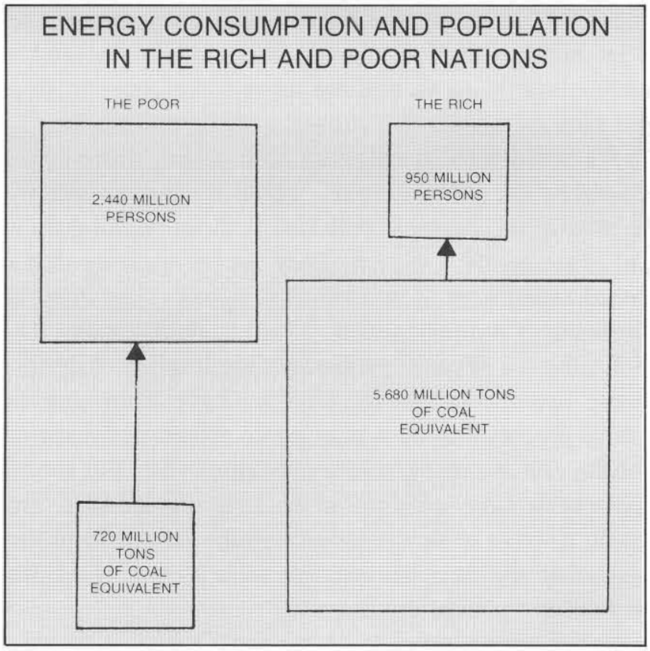
Lastly, again in our optimism, we pretty much thought that when we look at the world as a whole, the main problem is with the developing countries: If we can help them develop, everything will be fine. We failed to think of ourselves and the other industrial societies of the world as having our own vulnerabilities. We neglected to ask the question — What is the real nature of this new society that has emerged in the world? It has existed in one form or another for fewer than 200 years, but it has never been really put to the test of how resilient the society might be, how vulnerable it might be to disruption, particularly given the situation that now exists in the world where we essentially have two quite separate cultures — that of the rich and that of the poor.

One of the most important characteristics of our own society has been a steady increase in per capita energy consumption. There have been ups and downs in economic activity, but the general trend is up, and I think it behooves all of us to ask how high it will eventually become. How large need it be? But if we look at per capita energy consumption in the world as a whole and ask ourselves how many people live under various levels of per capita energy consumption, we find that since World War II there has been a startling development.

We've always had rich nations and we've always had poor nations, but we've also always had nations in between. But for the last 30 years there's been a "fissioning" of human society into two cultures. When we look at the numbers of people who live at various levels of energy consumption, we find there is one large clump living at very low levels of energy consumption, another large clump of people living at high levels of energy consumption, and virtually nothing in between. We now have two separate worlds, the rich and the poor. Since the end of World War II the rich world has been getting relatively richer and the poor world has been getting relatively poorer from the point of view of energy consumption. There isn't the slightest trend toward convergence. Indeed, if you look carefully, there's actually a divergence. In other words, the gap between the two is getting wider.

What are the ultimate consequences of these two worlds living side by side, cohabiting the earth into the indefinitely long future? I would suggest that something is bound to give.

Let's look at what this means in terms of resource consumption. In the poor countries we have 720 million tons of coal equivalent going into the support of 2.5 billion people. In the rich nations we have 5.7 billion tons of coal equivalent going into the support of 950 million people.



A highly unstable situation exists for rich and poor nations because of the imbalance — and inequity — between their populations and their energy consumption.

Before the Industrial Revolution there were peasant villages all over the world. In India there are still over 500,000 villages. Similarly, there are huge numbers of villages in China. Those villages have a very important common characteristic. They are basically self-sufficient. The people grow their own food very close to the village. They don't live very well, but they are self-sufficient.

When we look at the industrial culture such as ours in the U.S., we see an enormously complex network of mines, factories, transportation systems, communications systems, and power grids, all linked to each other — a single system, as distinct from the peasant village culture which has many hundreds of villages very loosely coupled with each other. In the U.S. the coupling is intimate. How much perturbation, how much of a shock can that system take without coming to a grinding halt? To what extent can the system repair itself? To what extent are there redundancies within the system that will permit it to continue functioning?

I suggest that we don't know, that we may well be far more vulnerable, and far less resilient, in the ecological sense, than we have assumed.

Let us examine some of the kinds of shocks that should concern us. Obviously, given a large-scale nuclear war, the system would probably come to a standstill, and would be very difficult to get started again. Growing dependence upon energy imports is another kind of shock. Indeed, it was the shock of the 1973 Arab oil embargo that began to get me concerned about such problems. Here in the U.S. we saw the lines of automobiles in front of gasoline stations. We saw wave after wave going through the entire economy. We were far from dying, but it was interesting how large those waves became — particularly when we recognized afterwards that the Arab oil embargo represented only a 4 percent decrease in total energy availability in the U.S. for a period of three months or so. It really wasn't a large shock, yet the effects were substantial. We must ask ourselves what would have happened had there been a 20 or 30 or 50 percent cut in energy availability. I suggest it would have been very serious.

In the case of Japan, which does not have any petroleum resources of its own, that sudden shock had a profound effect — a 180° about-face in foreign policy in about three microseconds. In the case of the United Kingdom, there was almost a synergism in operation. First there was a strike of electrical workers so that power plants and transmission lines could not be repaired. Coincidentally, there was a strike of coal miners. Then, also coincidentally, the Arab oil embargo came along. The net result was the declaration of a state of national emergency and a three-day workweek that persisted for several months.

A third kind of vulnerability involves the growing need to import non-fuel minerals. We are now almost completely dependent upon the importation of several critical minerals. Japan is even more vulnerable from this point of view. Europe is highly vulnerable as well. The poor countries have the overwhelming preponderance of exportable energy and mineral resources, and we should realize that they have discovered that this can be a very effective weapon.

Growing dependence in major regions upon food imports is another vulnerability. The U.S. is a major food exporter, but as affluence has grown, Europe has

Activity	Percent
Pipeline transport	0.02
Water, steam and sanitary employees	0.07
Petroleum refining	0.17
Coal mining	0.18
Oil and gas extraction	0.31
Fire protection	0.31
Air transport	0.39
Mining (other than coal)	0.54
Railroad transport	0.63
Steel production	0.65
Police protection	0.70
Electric and gas utilities	0.73
Telephone communications	1.06
Truck transportation	1.27
Total	7.03

Work stoppages by a mere 7.03 percent of key segments of the U.S. labor force could completely paralyze this country's complex industrial system.

imported increasing quantities of feed grains and the like from the U.S. Japan too has imported increasing quantities, and indeed Japan buys up a large proportion of our soy beans. Soy beans are a staple in the Japanese diet, and Japan has become even more dependent upon us for soy beans than we have been dependent upon Saudi Arabia for oil. Then in 1973 came what my Japanese friends call "the first Nixon shock" — a soy bean embargo, because we were afraid the price of food was going up too rapidly. The Japanese have not forgotten that, and I think they are very wisely taking remedial measures. When I was in Japan in September, the president of Brazil was there with an entourage, and they signed three billion dollars worth of agreements, including a major agreement on agricultural development in Brazil, with Japan to receive substantial quantities of foodstuffs.

Technology is fragile — it can break apart by itself, and it can be broken apart by outside interferences. We have already seen considerable airline hijacking. I would suggest that, with the upsurge of terrorism in the world, as terrorists get smarter, and as the weapons in their hands become increasingly powerful, there will arise dangers of no small proportions. We will have to ask ourselves just what the ultimate consequences might be.

Terrorism has emerged as a new form of warfare. Until recently its main objective has been essentially to draw attention to political causes — to make people sit up and take notice. Terrorists would try to get on TV, and one way to get on TV is to kill somebody. But largely as a result of research and development efforts on the part of the West (which are meant to compensate for the very large Soviet manpower presence in Europe), many powerful weapons have now been miniaturized to the point where they can be carried by a single individual. In the case of antiaircraft missiles, for example, both the missile and the launcher can now be carried and set up and fired by an individual. As time goes on, I think we will see more and more of these kinds of weapons — particularly as terrorists get smarter and are able to identify the points of vulnerability in this massive, complex industrial system. One of the advantages of this kind of terrorist activity is that conventional large military systems can be bypassed.

But, quite apart from terrorist activities, consider what can be done peacefully through work stoppages. About 0.02 percent of the labor force handles all of the pipeline transport in the U.S.; water, steam, and sanitary employees come to 0.07 percent; petroleum refining — 0.2 percent; coal mining — 0.2 percent. If one were highly selective, the nation could be paralyzed if only a tiny proportion of the labor force chose to stop working.

So-called wars of redistribution are beginning to be waged by the poor countries, which are understandably becoming increasingly belligerent about wanting their cut of the world's wealth. They are recognizing that a broad assortment of economic weapons — as distinct from direct military action — are in their hands.

Lastly, we have the problem of the fragility of democratic institutions. In the past we have been able to afford procrastination in making decisions, because our wealth and our resources have been so vast. But if one looks at the time scale within which major decisions are going to have to be made throughout the world in the course of the next decade, we have to ask: Can our democratic institutions survive?

In this connection I think we must examine the following facts. Constitutional democracy is really not very old; it's about as old as the industrial state. It has disappeared in the greater part of the third world. The industrialized states of eastern Europe are totalitarian.

From the point of view of resources, the Soviet Union is independent, and will continue to be independent for its energy and mineral needs for the forseeable future. It exports large quantities of natural gas and crude oil to other eastern European nations — many of which have become dependent upon it. Under those circumstances, who needs armies?

These, then, are some of the problems we did not talk about 20 years ago, or 10 years ago, which have surfaced (at least in my own mind) as a result of the recent actions of the OPEC states — in increasing the price of crude oil by a factor of four and by the imposition by the Arab states of the oil embargo. □

The Impact of Earthquake Prediction

by J. EUGENE HAAS

With an early scientifically credible prediction, it may be possible to have a large earthquake and only a small disaster

THOSE WHO ARE involved in the scientific side of earthquake prediction are sometimes accused of wearing blinders about the social impact of what they are doing. The charge is unjust to the extent that they have had little concrete evidence of what that impact may be, and also because earthquake prediction differs greatly in at least one major respect from the warnings that exist for other natural hazards. In earthquake prediction, lead times up to several years are possible, whereas they amount only to hours, or at most a day or so, in warnings of hurricanes, for example.

Since social scientists are sometimes regarded as being in the "soft" sciences, I want to be very careful in explaining what my group at the University of Colorado has been doing in this field. Our approach was to try to estimate, through very careful empirical research, what the consequences of a scientifically credible earthquake prediction would be. Our procedure involved interviewing individuals who would be directly involved in making decisions when faced with such a prediction. In the course of this study, we secured such a quantity of data that I can present only the highlights here — some of the findings, the major implications, and a few of the questions the study raised.

In terms of average annual loss figures in this country, earthquakes do not rate very high, either in loss of life or in direct property damage. But the potential catastrophe from earthquakes is very large, perhaps one of the largest we have to face. A single event could not only be a local disaster, but it could have statewide, regional, or even national impact. For example, suppose a great earthquake occurred in Santa Clara County. If you know where the semiconductor industry in the United States is based, how it relates to the whole computer industry, and all the other things that are tied in with it, you'll see that though it might be a local disaster in terms of direct damage, it would also be a regional and to some extent a national catastrophe. It is in that context that we need to recognize earthquake hazards and the potential of earthquake prediction.

As a nation we try to cope with earthquake hazards not only by attempting to prevent or decrease losses but also by trying to share the losses and making an effort to pick up the pieces after the damage has occurred. Eventually, we will have scientifically based earthquake prediction, and it will be characterized by long lead times (ranging from months through years), specified location and magnitude, and some statement about probability. With this information, we almost surely will change our attitudes and activities. It was with this in mind that we made our study.

The work was done almost entirely in California (though we also checked some of our findings against the actual consequences of a quasi-prediction that was in effect for about seven months in the Kawasaki area of Japan in 1975). The data were taken from approximately 200 organizations, mostly in California — federal, state, and local government agencies (both legislative and executive branches) and businesses ranging in size from multinational corporations to local firms in two communities. One of these communities was in northern California and one in southern California; one had a population of about a million and the other about half a million. In one of those two communities we also interviewed a stratified random sample of over 200 families to try to get an understanding of the response that could be expected from the general public in addition to that from business and government.

Unlike the usual survey, we attempted to move sequentially. First, we learned as much as we could from the seismologists about what the early predictions would probably be like, how the information might be released, and what problems they foresaw in the process. We then discussed those findings with California's large news media and tried to understand how they anticipated carrying such stories, particularly where there might be an extended lead time.

We then went to federal and state agencies, summarized what we had learned so far, and discussed with them what they saw as their major responsibilities for problems that might develop. From them we went to the large business firms, told them what we had learned, and asked what they would plan to do in this situation.

The source from which the prediction comes is the most critical factor of all

Moving to the local scene, we talked first with the local news organizations. By this time we could tell them in general what would be happening in the state and nation with respect to the prediction. After talking to people in local government, we went to local business firms, and finally to the families.

Our research approach differed in one other respect from many surveys. We were concerned that we might get off-the-cuff answers from those we interviewed, answers that might not relate very well to their later behavior if they were actually faced with such a prediction. To avoid that possibility we conducted extended informal discussions with people in each of these categories, using only a check list of potential issues as the basis of the discussion. We took extensive notes, then summarized what seemed to be the major trends and put them together in two short stories or scenarios that reflected what we thought we had been hearing from them.

We then sent those scenarios back to the people we had interviewed and asked them to review them. Were we overemphasizing certain things and omitting other things? About two weeks later we went back and had a more formal, structured interview and asked them to answer a series of standardized questions.

In that two-week interim period they had an opportunity to discuss the issues with other people. Some of them called up their friends in other organizations — banks or insurance companies, for example — and asked whether they had been talking to "the researchers from the University of Colorado." This is precisely what we hoped would happen. It meant that they were giving careful thought to the whole process, and when we came back a second time, they could give us realistic estimates of what they thought their organizations would actually do.

When we finally were ready to interview the families, we realized that by this time the findings were so voluminous and so involved that we probably couldn't expect the average husband and wife to read them. We had to make selections. After a lot of pretesting, we decided to present the major findings on an audio tape, followed by a series of flip charts that would portray them graphically. We realized that most people have never thought what they would do in the face of an earthquake prediction, so again we went back and asked for a more considered opinion two weeks later. Altogether, we had more than 1,000 interviews.

One of the things we discovered early in the study was that the source from which the prediction comes is the most critical factor of all. A prediction from a place such as Caltech or Berkeley that has a long history of doing careful research in the field is going to have a different impact — regardless of the content of the prediction — from one from a different kind of source.

Roughly, then, this is how we got our data, and I would like to discuss some of the findings as summarized in one of our scenarios — Scenario B — which deals with a large expected earthquake. The dates were arbitrarily chosen for convenience. They are not real, or at least they are not intended to be.

In this scenario, we suggest that in July of 1977 the U.S. Geological Survey announces that there are some anomalous seismological data from a particular area (we changed the area depending on which of the two communities we were working in at a given time). These data suggest that the area ought to be intensively studied. It is made clear that it is not an official prediction. Asked by newsmen to evaluate the data from the Survey, a couple of seismologists say, "It's not clear, but if I have to make an estimate, I would say that in about three years there is going to be a damaging earthquake." When pressed further, they give a 25 percent probability estimate.

Let me emphasize that we did not dream up this scenario. It came out of our discussions with seismologists. We asked them for their best estimates of what the very first predictions are going to be like. What is likely to precede them? How are they likely to develop over time? No single seismologist wrote this plot; it is a compilation of ideas that we discussed at length with them. Notice the trends that the data indicate will start to develop — which are presented below in simplified scenario form.

In the 13-month period after July 1977 there is an increase in the purchase of earthquake insurance, or at least attempts to buy it. There will be evidence of a slowdown in construction, both public and private, because investors and public officials are beginning to think they had better play it cautious. There is some evidence of a slowdown in population growth and some indication of a decline in new business starts in the area.

In August 1978 we see the announcement of the first official prediction. The prediction is for an earthquake to occur two years hence during a two-month time window — September or October of 1980. The expected magnitude is 7.0 or larger, and a 50 percent probability is assigned. Now a second important event occurs. It deals with whether there is public evidence that the recognized experts in the field also see the prediction as scientifically valid.

In this scenario we say that the California Earthquake Prediction Evaluation Council certifies the U.S.G.S. prediction as a reasonable interpretation of the data. When they so inform the Governor, he asks relevant state agencies what they have done about it and what their responsibilities are. What, in addition, needs to be done? Local officials are a bit more dubious, and they hesitate to express their views for public consumption. Behind the scenes, however, they start planning and taking some action.

The State Insurance Commissioner makes a decision in what he considers the best overall interest of the public. He decides that new earthquake insurance policies will no longer be available for that particular area. His argument is straightforward: Those persons who have been paying premiums over the years for earthquake protection have a right to solvent companies after the earthquake occurs — if it does. If every Johnny-come-lately can now come in and buy earthquake insurance on an event that is relatively certain (whatever you mean by that term), some companies might not be solvent after it is over. So leaders in the insurance industry, real estate, and other interested sectors of the economy start calling for an alternate insurance program or something that is functionally comparable to it.

Within a few months damage-estimate maps begin to appear in the newspapers. The maps show projections of major and moderate damage areas. (We shall see later that the maps have considerable impact on what happens to property values in the area.)

Buildings already under construction are completed because they will be less vulnerable that way, but within a few months new construction comes to a halt. As a result, unemployment in the building trades starts to skyrocket. There is a sharp reduction in mortgage availability. Some local lenders who have to live in the area will continue to offer mortgages, but on a highly selective basis. As the availability of mortgage money declines, real estate transactions also slow down.

As a spin-off of what happens to the construction industry and those parts of the economy that support it, there is a general decline — moderate at first and then accelerating — in the business activity level. Sales tax revenue starts to decline within about nine months, and so the long-term projected revenues for city and county government have to be revised downward. Long-term city planning is reconsidered. City officials begin to wonder which public services will need to be trimmed if revenues continue to decline. They begin making some tentative decisions. Parks and recreation, libraries, and eventually trash collection and street cleaning will be cut back if revenues continue the downward slide.

About a year after the first official prediction, Congress begins to hold hearings on possible alternatives to insurance. (If that seems dilatory, remember that we are talking about a possible disaster in a single community in one of 50 states.)

A number of homeowners have their houses inspected to find out how they are going to respond to the earthquake. They take steps to improve safety in the home — water heaters are bolted to the walls, bookcases fastened so they are less likely to topple, and the like. At this stage about a quarter of the families delay or cancel planned purchases of automobiles, TV sets, refrigerators, deep freezers, boats, and things of this kind. As a result, savings deposits begin to climb. Some of the sharper property owners realize that there is some indication that property values are falling. Many are owners of rental properties, and once they get some supporting data, they appeal to have their property reassessed for tax purposes. As others find out about the appeals, they follow suit. Within a year about a third of all homeowners have requested this kind of reappraisal.

Now imagine that it is about nine and a half months from the predicted earthquake time. The prediction is refined. The earthquake, it is now said, will occur during the month of September; the magnitude estimate is made considerably more specific (7.1-7.4); and the probability is increased to 80 percent.

According to the data we have, a certain time has to pass before you have convincing statistics for significant economic impact on the community. Once you have those statistics, they can be used as the basis for the Governor asking for a Presidential declaration that a state of emergency exists. The law, by the way, is not very clear as to whether there can be such a declaration in advance of the actual disaster, and there is a long delay in this case before the President responds to the Governor's request.

The Governor, citing statistics that show a strong negative economic impact on the community, asks for a Presidential Emergency Declaration. Employers now start to talk about the possibility of having vacations for all of their employees during the month of September 1980 instead of the usual staggered vacations. There is a lot of activity at the government level, and there is no shortage of information, since a number of educational campaigns are under way in the local community.

A few firms move out of the area. They are large national firms with a considerable resource base, which gives them other options. With an extended lead time, they relocate simply to avoid whatever difficulties might arise. As an example: A national insurance firm has a two-million-dollar facility, which they operate every day of the year, doing a lot of computer work. Their top executives will not tolerate, if there are any reasonable options, the disruption of their business activities that would come with an earthquake — even if there were to be no serious damage. So, with two years lead time, they are willing to take as much as a 50 percent loss on their property and try to move elsewhere. They encourage their employees to go with them.

Local governments make an effort to maintain fire, water, and police protection, and other basic services, but some services are cut as both sales and property tax revenues continue to decline.

A number of employers announce in the early summer of 1980 that they will cease operations during the month of September. Most employers believe that their buildings and facilities are going to stand up adequately, but they have two main concerns. One concern is with legal liability. They are not sure what change, if any, there is in their legal liability as an employer in the face of a prediction that has broad scientific support. If they ask their employees to come to work as usual and the earthquake does occur roughly as predicted, what is their legal liability? Since they don't know, many of them don't want to take a chance.

The other side of that coin is a moral question. They don't want to have to face the possibility that because they asked people to come to work some of them got killed or injured. They don't want that on their consciences when they could have just taken a financial loss. There is a kind of underlying caution running through much of the decision-making.

More than half of the families are continuing to delay large purchases, and so they are saving more. More than half have now asked for a reappraisal of their property for tax purposes. Some few are buying extra life, fire, and medical insurance. More than half the families and the businesses have made special plans for emergency responses and for stockpiling supplies such as food and water.

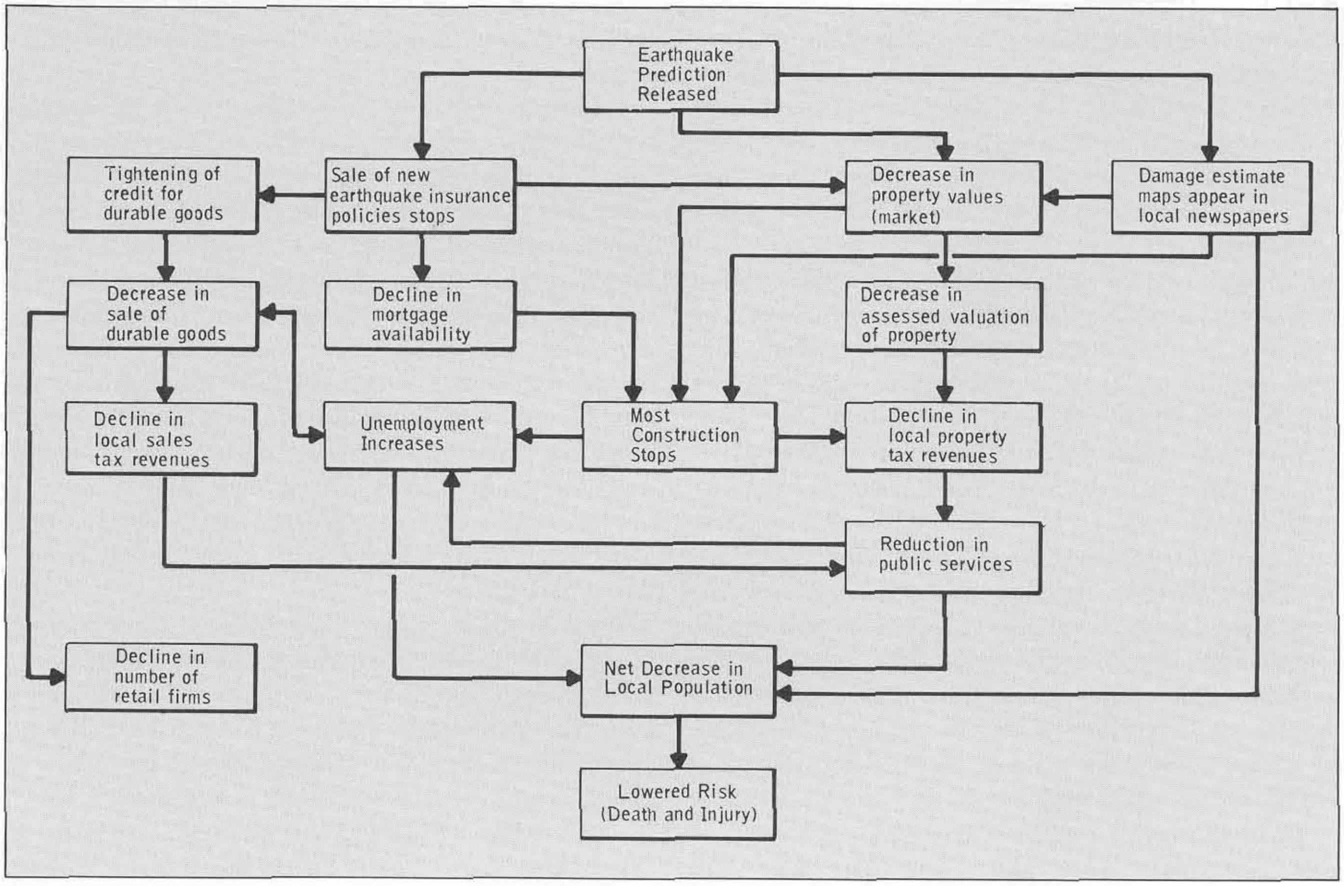
Some families move family heirlooms and other prized possessions out of the area entirely. During this time period something like 5 to 10 percent of the families in the area have moved out intending to stay away permanently. (Incidentally, we have no information on how many families who might ordinarily move into the community during this time period will not do so in the face of the earthquake prediction. The same thing goes for new business starts.)

Coming down to the final 60 days, the prediction is revised again and made more specific. It is now reported that the earthquake is supposed to occur during the first week in September 1980. The magnitude is narrowed to an estimated 7.3; the probability remains at 80 percent.

Now that the earthquake is expected during a specific week, planning can be much more specific. There is no serious discussion of forced evacuation. In certain high-risk areas — such as near dams or reservoirs, where landslides might be expected, and where there are numerous old hazardous buildings — people are urged to evacuate well ahead of the expected earthquake. Citizens ask local authorities whether they can provide protection against vandalism during the time when they are gone. Many people worry about what will happen if half of the houses in their neighborhoods are standing empty or if many businesses are closed in an area. Local officials can't provide guarantees against vandalism especially because revenues are down and they can't afford to augment the police force. This is a real source of tension between the local officials and the residents.

Hospitals and prisons transfer their charges. Unemployment is up sharply; property values continue to decline, and real estate sales are sporadic. Finally, a year after the Governor's request, the President grants a Declaration of Emergency.

Some retail stores, particularly supermarkets, lo-



Coming events cast their shadows before — as is evident from this chart of the consequences that slowly develop at the local level when a 7.3 earthquake has been predicted and is believed. Planning and action before the actual event, however, could lessen some of the negative effects, including ruinous economic impacts and very serious social disruption.

cated in single-story buildings that their owners believe are solid remain open for business. Some post signs that say, "We don't run in the face of an earthquake prediction." Inventory that remains is given special protection, particularly fragile equipment such as computers. In addition, inventory generally in the community is sharply lower as managers try to preclude losses. Outside firms that normally provide goods on consignment no longer do so because they are unable to secure insurance to protect them in case of damage.

A large proportion of the families (roughly 75 percent) are staying home more than usual and away from what they consider to be the more dangerous areas, which they define as older areas of the city and tall buildings. Businesses in these areas suffer sharp declines in sales. Families who stay as well as those who leave the area turn off their utilities to avoid fire and water damage and other kinds of problems. The final safety measures are taken now by most families — covering furniture, taking breakables down off shelves, packing things away. With so many people leaving town, savings withdrawals are now up sharply.

As the time of the expected earthquake grows near, surveys show that about one-tenth of the families have moved away permanently and another half have left temporarily. So while the community is not a ghost town, it is very sparsely populated as the end of August 1980 approaches.

All public buildings are vacated — not because they are expected to collapse, but because of the liability and moral questions. The majority of businesses also close temporarily. Critical services are continued, though some personnel are working out of mobile or temporary locations, where they presumably will be safe. The National Guard, located on the periphery, is on the alert.

Now let me try to summarize briefly some of these findings. There will be a lowered risk of death and injury, and the major reason is that there will be a net decrease in the local population. In the wake of the earthquake prediction, the sale of new earthquake insurance policies will be stopped, and that decision will have a series of impacts that link together, and finally come down to a reduction of public services and an outflow of the population.

As you might expect, the drop in the market value of property and the damage-estimate maps also have some unfavorable consequences. Now, depending on your perspective, you can look at this and say, "Terrible. Terrible. It would be better if we had no earthquake prediction. Look at the negative economic impact; the community is going to be on its economic knees." On the other hand you can say, "But look, if you have a prediction that is generally believed and the earthquake occurs approximately as predicted, you can have a large earthquake and only a small disaster — at least so far as casualties are concerned. Property can be rebuilt, but lives can't be replaced." It depends on your emphasis and the values you have.

Moving companies will do pretty well, and so will a lot of engineering firms. Many companies and government agencies are going to want to know how their facilities will perform, so physical-vulnerability assessments are going to be widespread. There will also be a good deal of economic-vulnerability assessment largely applied to two questions: First, what will the earthquake do to the firm economically? Second, what will the prediction do? Those who are good at that kind of analysis will have a lot of work, especially for a period of time right after the prediction comes out.

Our data suggest that these trends and consequences will occur unless we take some prior action and change some policies. Many of these negative impacts do not need to be nearly so strong if we try to handle the problems in some reasonable way before the first prediction. Here are some of the issues to which we might address ourselves:

If you own a business in a high-risk area, how would you feel about having that area cordoned off a few months ahead of time? What will that do to the income from your business?

For every family that leaves the area and for every business that closes down for a time, the probability of casualties is reduced, but that very same act is also a sharp negative blow to the local economy. If you want to save lives, you will encourage some people to leave the area at some point. What that point is, is very difficult to determine on the first prediction. Do you recommend that they wait till the very last day, the last week, the last month? Or do you just say, "Use your own judgment, folks, as long as you're gone by twelve midnight on August 31, 1980."

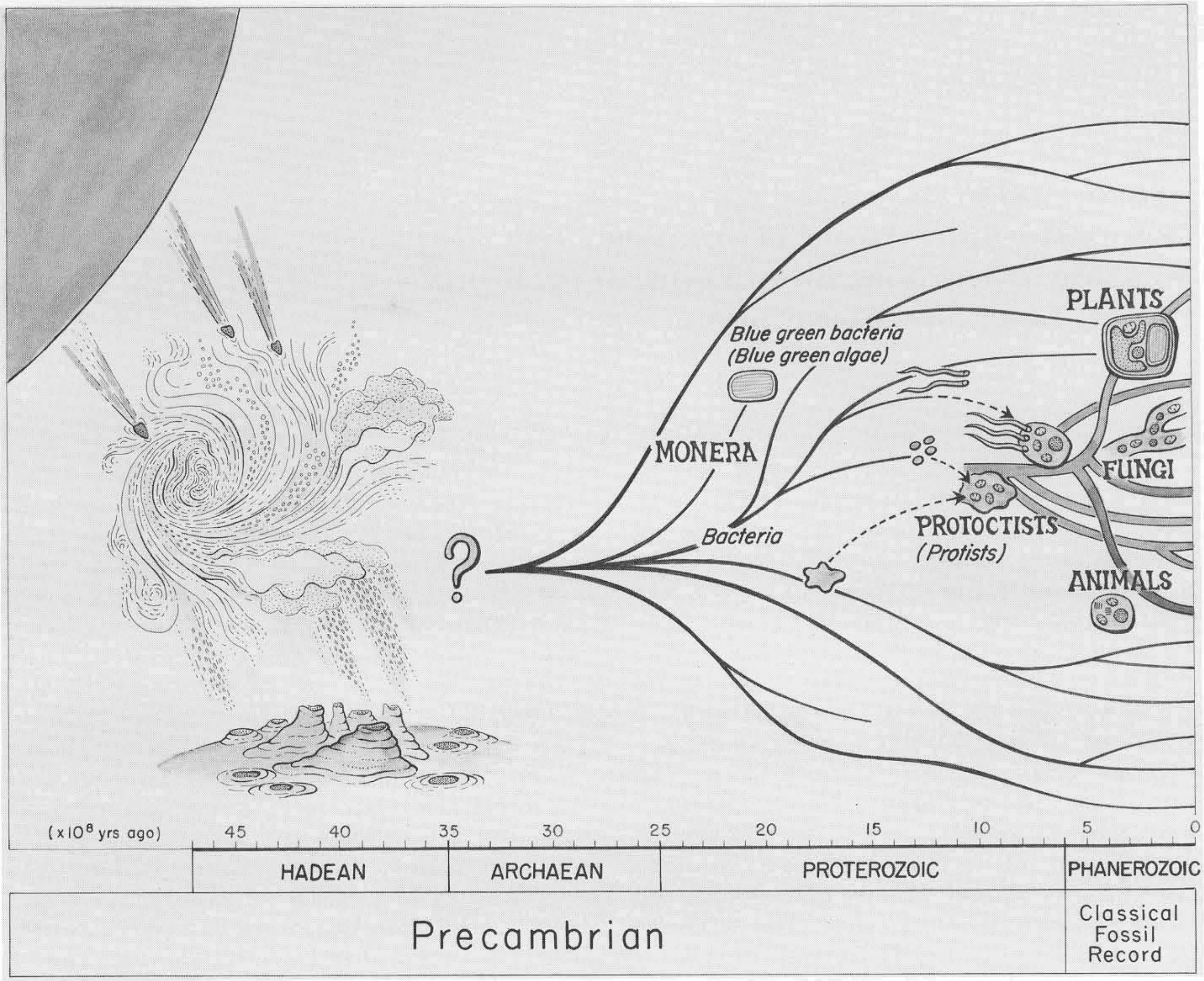
After a year of unemployment, a number of people are not going to be able to make their mortgage payments. So, some of them will put their homes on the market and sell them for whatever they can get to get their equity out. That kind of panic selling is going to drive property values way down. One of the basic questions, therefore, is whether there is some way to provide at least a minimum financial base for such persons.

Another problem is which damage-estimate map to believe. How good are the data? How competent are the people who put these maps together? What if several different maps appear in the local media? Much confusion and economic uncertainty can be avoided if local leaders agree in advance how they are going to proceed with respect to projected damage maps. If they agree to work with, say, the U.S.G.S. and announce soon after the prediction that within 90 days there will be an official map based on the best available data, the media might be persuaded not to print any other maps. Those maps are going to have a tremendous impact, and it's not fair for those who have responsibility to sit around and wait to see what happens when that first prediction comes along.

It would be nice to have some mechanism for pooling resources to make at least some mortgage money available. Even in heavily damaged areas not all buildings suffer serious damage. From the point of view of prospective damage there is no reason why all construction should stop, but in the absence of mortgages it is likely to do so. Is there some way that industry as a whole, or industry backed by governmental reinsurance of some kind, can provide some mortgage money so that the construction industry won't have to go clear to the bottom?

The California legislature passed a bill in August 1976 that attempts to release from liability all public officials who act in good faith and with good professional judgment in the face of a scientifically credible prediction. It does not change the liability of private employers. Unfortunately, a recent opinion of the Attorney General's office suggests that this piece of legislation may have muddied the water more than it clarified it. It may be that more attention needs to be paid to what the liability is, because clearly many problems will arise out of lack of knowledge.

Overall, it seems pretty clear that scientifically based earthquake prediction, generally believed — which it will be if it comes from a reputable source and has broad scientific support — will have three major types of consequences: First, there will be very few casualties; second, there will be considerable reduction in the property loss that would otherwise have occurred. Finally, there are going to be very serious negative economic impacts and social disruptions, some of which can be avoided or softened if we make some reasonable and meaningful decisions before the first predictions come along. □



A most unusual geological time chart puts into proper proportion the time scale on which life probably evolved. Reading from left to right — the earth was formed something like 4500 million years ago; by 3500 million years ago a primitive form of life had appeared, probably a microorganism that then developed, combined, and became more complex through all that vast stretch of time called Precambrian. It was not until a brief 600 million years ago that plants, animals, and fungi finally evolved and began to leave behind them the traces that we call the classical fossil record. Man's time on earth is too short to be shown on a chart of this scale.

Life on the Early Earth

by LYNN MARGULIS

SCIENTISTS who look for evidence of life in the past have been mainly preoccupied with the last 600 million years, the period known as the classical fossil record. But what was happening for the 3000 million years before that? Many different theories have been offered, and there are now discoveries from several fields that give us an idea of what was happening.

Life did not originate with animals 600 million years ago. The earliest fossils are remains of microorganisms greater than 3000 million years old. They went through the same sort of evolution that the human line and the fish line and all the other lines of more conspicuous animals and plants did. Their effects are very large and their numbers prodigious, even though their bodies are very small. The period of time before the appearance of animals, the Precambrian, was a time of an enormous amount of evolution, mainly biochemical evolution.

The period of time before the appearance of animals was one of an enormous amount of evolution — mainly biochemical evolution

All the major evolution was on the micro-level — the level of tiny cells which had profound effects on the environment. These statements can be strongly supported by recent evidence.

All organisms that are around today are very good at what they are doing, or they wouldn't be here. These enormously successful kinds of adaptations to environment are what is behind evolution, even at the microbial level. Evolution works, very briefly, like this: A pair of fish will have 10,000 to 50,000 eggs in a season. If left unchecked, each of those eggs would grow up, pair off, and lay more eggs; and those eggs would develop into fish laying more eggs, and so on until very soon the mass of the earth would be all fish. That doesn't happen because, out of those 50,000 eggs, only one or two survive to become parents of the next generation. And, like it or not, that is the rule of evolution — that only a tiny fraction of potential numbers of organisms actually survive into adulthood. This is the rule for microbes just as it is for animals. Microbes, too, evolve; the ones best adapted to their environment leave the most offspring. That has been the rule since life originated on the planet something like 3500 million years ago, and it will be the same from here on.

In many places around the world there are large outcrops, surface rocks that have been dated from very ancient times. Much of southern Africa, for example, is very ancient. Large areas of West Africa, South America, and Canada consist of rocks that date from before the emergence of animals. These rocks have been an enigma for a long time, because they seem to have been subject to normal temperatures and atmospheric conditions. Many seem to be remains of sediments deposited at ocean and lake margins; yet they do not have any animal and plant fossils in them. Why?

The breakthrough to an answer came when Elso Barghoorn of Harvard hypothesized that macroscopic life was preceded by microscopic forms that probably left a detectable record. A diamond saw was used to cut certain rock samples so thin that light passed through them. The rock slivers were looked at through a microscope. Their secret was revealed. Many kinds of well-preserved microorganisms were seen. Since then we have figured out what kinds of microorganisms they were because they are similar to organisms now living in environments like those in which the rocks were made.

Compare live microorganisms with some 1000 million years old, and you will find in some cases that they are really very similar, not only in appearance, but in the kinds of communities they form. Most scientists find it difficult to preserve and stain microorganisms as beautifully as these rocks have done. Of course, the abundant microbes cannot be seen unless the right tools and techniques are used. On the other hand, without using microscopic techniques one could probably tell from as far away as Mars that the earth has been inhabited for several thousand million years because these microorganisms have had profound effects on the earth's surface and atmosphere.

Take, as one example, the production of oxygen. The oxygen we breathe is produced by photosynthetic microorganisms very similar to those found in rocks as old as 2000 million years. Probably before 3500 million years ago there was no free oxygen because the microbes that give off oxygen had not yet evolved. But 1000 million years later the world was teeming with life — not dinosaurs or forests, but life nevertheless. The earth's atmosphere was composed of about 20 percent oxygen by then, a gas that on chemical grounds alone would not be a prevalent component of a planet's atmosphere. Evidence for this oxygen-producing life has not only been found by microfossil studies but deduced from the widespread appearance of ancient layered rocks called stromatolites. Stromatolites are actually made by communities of microorganisms, many of which excrete oxygen gas — the same oxygen we breathe in. In fact, without the organisms that are responsible for the appearance of stromatolites we wouldn't have the oxygen we breathe, nor would we

Communities of microorganisms were producing layered rocks like these stromatolites more than *3000 million years ago. Once* animal life was made possible by the oxygen they emitted, however, stromatolite-production was reduced. From the beginning, animals have liked to eat the blue-green algae microorganisms that made the stromatolites.

— genus *Homo sapiens* — ever have evolved.

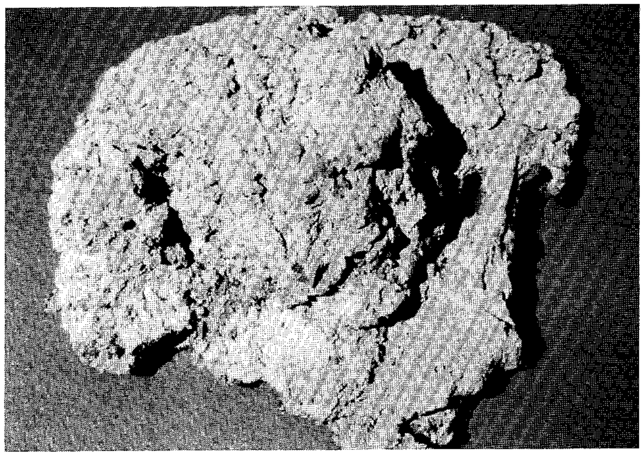
Stromatolites were extremely abundant before there were animals. They are also found in the fossil record after the appearance of animals. But many marine animals eat the organisms that make the stromatolites, and so their frequency and diversity went down — and now stromatolite-formation is restricted to only a few regions of the world.

Often what looks like a clump of mud will be a potential stromatolite. Cohesive clumps of mud often really are "microbial mats." The underside of such muddy stuff may be blackish green. Under a microscope this turns out to be intertwined filaments of microorganisms. The kind of microorganisms that trap and bind the mud, sand, and rock particles have been living in this way at the seashore, in sunny warm zones over the world, for the last 3000 million years. These ancient oxygen-producing photosynthetic organisms are called blue-green algae. You are familiar with them too, because they often appear in sinks, toilets, and on shower curtains as a greenish scum. Some don't mind soap — unlike most other organisms. And they love running water and sunlight. Soon after the Lascaux caves were lit and opened to the public, the blue-green algae started to grow on the paintings; eventually the caves had to be closed. Blue-green algae are abundant and prevalent wherever they are not out-competed; they have been on this earth for several thousand million years.

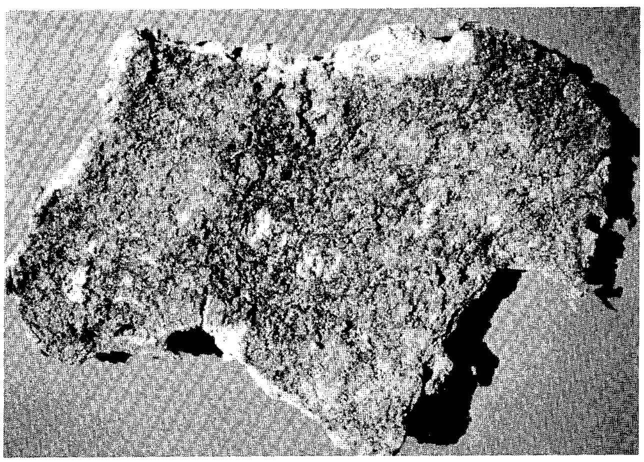
In tropical western Australia today there are stromatolites in the process of forming. Like their ancient ancestors, these layered rocks with a living coat of blue-green algae on top give off oxygen, and trap and bind the sediment in the process of rock formation. The detailed structure of these rocks is practically identical to that of rocks in northwest Canada dated older than 2300 million years. The big difference is that, no matter how hard you look at the ancient Canadian stromatolites, there is no evidence of animal or plant fossils in them. On the other hand, if you look at the modern stromatolites, you find an occasional crayfish-type or clam-type animal in them. This is one way we deduce that animals were simply not on the earth 2300 million years ago. The question is — Why not?

Until very recently, the biological world was divided into animals and plants. This classification is the same in almost all cultures. The Aztec civilization used it, as recorded in the Florentine codex. But it turns out that with the use of modern techniques the traditional plant-animal dichotomy is much less profound than it seems. In all cellular details animals and plants are very much alike when compared to dissimilar organisms like the blue-green algae. Most biologists now recognize a very different dichotomy: They first classify all organisms into simple (prokaryotic) or complex (eukaryotic) on the basis of their cells. The first group includes the blue-green algae and the bacteria, while the animals and plants go together with other forms like fungi into the second group.

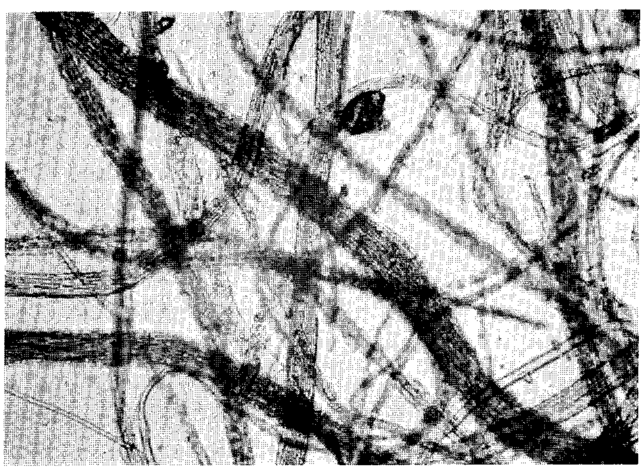
All organisms on earth are made of cells, but of these



From the top it looks like just another clump of mud, but the mud, sand, and rock particles of which it is composed are trapped and bound together by a living microorganism.



The binding agent — blue-green algae — shows up on the underside of the stromatolite.



Magnified several hundred times, the thread-like structure of this "microbial mat" becomes evident.

two fundamentally distinct kinds. Like all animal cells, all plant cells have a nucleus with a membrane. All green plant and animal cells have little bodies in them called mitochondria, which allow the cell to respire — to take oxygen from the air and "burn" food. Animal and plant cells often have flagella or cilia, like small whips, that have a very characteristic substructure. (When you smoke, if you do, you may rip your throat cilia off. But it doesn't matter too much; as long as they have their basal granules, they'll grow in again.) The whipping part of the cilium is exactly like the tail of a sperm. This cell structure, the flagellum — or its shorter analog, the cilium — is completely absent in all blue-green algae and bacteria. It is one of the characteristics that distinguishes simple bacterial cells from the complicated cells of plants and animals.

Furthermore, plant cells contain chloroplasts, or green bodies, that allow them to use sunlight directly. Plants make their food by using their sunlight-to-chemical-conversion factories, the sites of photosynthetic activity.

The punch line is that those microorganisms that dominated the earth for its first 2300-3000 million years were the bacteria and their relatives the blue-green algae-organisms of simple cell construction. They did not have any mitochondria, they did not have any cilia, they did not have nuclei, and they lacked the photosynthetic ability packaged into chloroplasts. Before there could have been animals and plants, the complex sort of cell from which they are made had to evolve.

I don't think anyone would disagree with anything I've said yet. They would only disagree with this: It is my opinion, and I think many people now agree with at least part of this, that the complex cells that make up our bodies (and those of all other animals and the green plants) — become complex through a series of what we call cell symbioses. These cells, which contain nuclei, cilia, and mitochondria packages for oxygen utilization, evolved as a result of populations of simple bacterial-type cells setting up partnerships. Partnerships in some cases did better than individual cells. The partners came from microorganisms of quite distinct ancestry, that had evolved with different sorts of selection pressures on them. Not until simple cells formed stable partnerships could the potential to grow large be realized.

Symbiosis, by definition, is when an organism of one type, one species, lives in a regular association with an organism of quite a different species. For example, certain vitamins in our digestive tract are provided by bacteria that live symbiotically within us, never hurting us. We hurt *them*, in fact, when we take too much penicillin; antibiotic-induced diarrhea sets in when our microbial symbioses get out of balance. Our symbiotic partners must be in there in proper numbers and proportions to maintain normal digestive processes.

Thus, we are involved in symbioses, and it's pretty obvious in this case who is the dominant partner. But many symbioses have been established between much more equal-sized partners, partnerships on the cell level. Study of cell symbioses may be useful in providing models, analogies to what happened to give us the complex animal, plant, and fungal cells that have been so conspicuous all over the world in the last 600 million years. For example, the British Soldier lichen, one of the most common lichens in the northeast, is a symbiosis of fungi and algae. Lichens are never made by either partner alone; all lichens are partnerships. The British Soldier lichen is one of the few symbioses that has been disentangled experimentally; the green partner that uses the sunlight, the photosynthetic partner, has been separated from the protective fungus partner.

It is possible that just this kind of partnership was involved in the origin and evolution of all the cells in your body.

Here is another example of a symbiosis. On the beaches of Brittany and the Channel Islands, people who go swimming are sometimes annoyed at the seaweed that covers the beach, interfering with their enjoyment. If you get close enough to this seaweed, you will see that it's not seaweed at all; it's worms. When these marine worms hatch, they eat certain special photosynthetic microorganisms — flagellates. Their skins are so thin that the sunlight penetrates them, and the flagellates multiply and photosynthesize in the worm tissues and provide their hosts with all of the nutrients they require. The worms may never eat again. They have developed a way of life as a seaweed — but use their muscles to swim down through the sand when the tides are out, protecting themselves and their symbionts from being swept out to sea. So something that looks and lives like seaweed is really the product of symbiosis between worms and photosynthetic flagellates.

There are many examples of symbioses involving a moving partner teamed up with a stationary photosynthesizing partner. For example, some of the snail-like animals called mollusks are products of symbiosis.

The coast of Brittany at low tide is littered with "seaweed" that on closer inspection turns out to be living worms. Whenever the tide is out, the worms come out of the sand so that the algae living in their tissues can be exposed to light and produce the food on which the worms live.

One, *Elysia,* is a green sea snail that lives like a plant. It takes in CO_2 from the air and makes food using sunlight. It comes out in the sun, it goes back among the rocks in the dark. Unlike most photosynthetic animals, such as corals, it lacks algae in its tissues. *Elysia* doesn't really want the algae. It wants the photosynthesizing machinery of the seaweeds. At a young age it sucks out the chloroplasts from its seaweed food — that is, it eats only the parts of the cells responsible for photosynthesis. It eats, but does not digest, these chloroplasts. It moves them to special places in its digestive tract and uses them for the rest of its life for its own photosynthesis. The snail does not feed any longer; as an adult it only basks in the sun. This is a symbiosis between an animal and parts of seaweed cells.

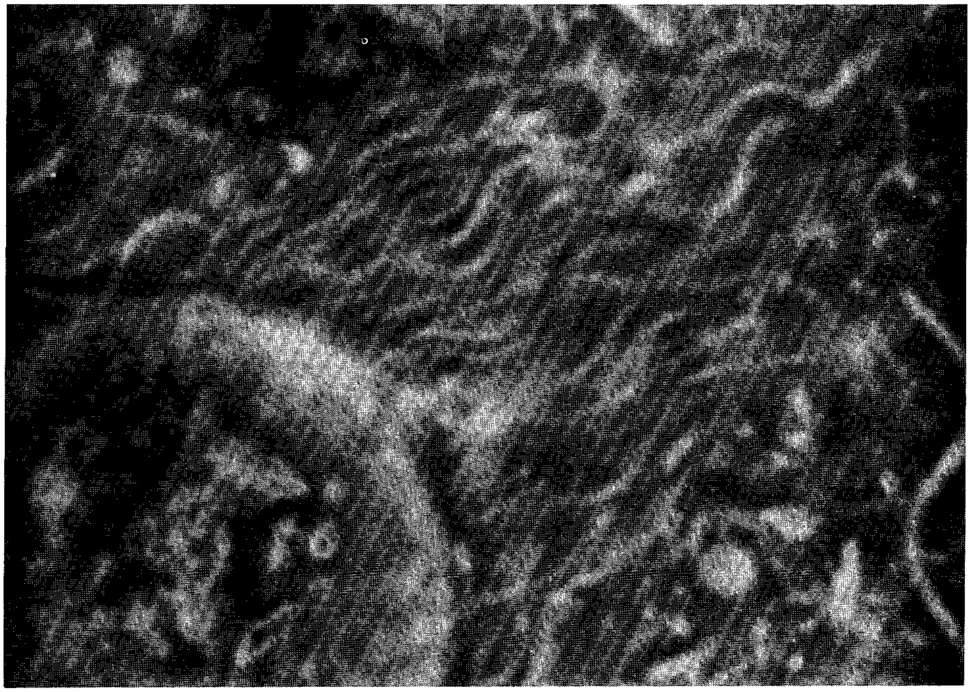
Symbiosis is indeed very common. However, I am aware of only one documented case in the modern biological literature where a microorganism association that began as a lethal disease ended up as a required partnership. This occurred in some amoebae grown by Kwang Jeon of the University of Tennessee. Over a period of time he noticed his laboratory amoebae were becoming ill. He became worried as many died. At first he didn't know what was killing them. Being very persevering, he looked at the amoebae very carefully. First he saw dots, and then discovered they were tiny microorganisms in the bodies of the dying amoebae. These dots were bacteria; his sick amoebae were dying from a bacterial infection. So he carefully isolated these bacteria-filled amoebae and by gentle care and feeding succeeded in saving some. These survivor amoebae had over 100,000 bacteria each.

It happens that Jeon is one of the best microsurgeons in the world; he can transplant a nucleus — that is, the genes — from one amoeba and stick it into another, often without any loss of life. Jeon showed that five years after the infection the few amoebae that survived had completely recovered their health. Their growth rates had become normal again. However, these recovered amoebae were still loaded with bacteria. They could no longer live without their previous so-called disease. By careful nuclear transplantation experiments Jeon showed, in other words, that the nuclei of the host amoebae had become completely dependent on something that was produced by its original bacterial enemies. Disease organisms had become, by all criteria, integral parts of the amoebae cells. Something starting as a bacterial infection went through a period where it was an indifferent symbiont, and by five years later it was necessary to the life of the host amoeba cell. It is evident that new symbioses still are forming; it does not necessarily take millions of years to establish such cell associations.

Another fascinating symbiotic organism is a little protozoan called *Mixotricha paradoxa*. Actually, we are not permitted to work on it directly because it lives only in a certain termite species in Australia, one of the most devastating termites known to man. People in the Outback say it takes two years for these termites that harbor *Mixotricha* to take an old ranch and convert it to dust. (Obviously, the U.S. Department of Agriculture has a vested interest in not letting those termites into southern California.) The termite host is primitive, but the flagellated *Mixotricha* symbionts living in the termite gut are very complex organisms. They have nuclei and complex flagella, as we do, but they do not use these normal flagella to move; they only use their flagella as rudders to change the direction of their movement. The *Mixotricha* move steadily forward in the fluid of the hind gut of the termite by means of the action not of flagella but of other hair-like surface structures that on close inspection turn out to be surface spirochetes. Spirochetes are a type of highly motile bacteria. There are half a million of these spirochete "hairs" per *Mixotricha,* and when they wave together, they move the *Mixotricha*.

I think there's a lesson in this story. The *Mixotricha* has normal flagella, basically indistinguishable from sperm tails and cilia in the human body, but it is moved by its symbionts. The 500,000 surface spirochetes, the special moving-bacteria, live and grow permanently on the surface of *Mixotricha* protozoan — conferring motility on their host.

Why do I tell you about this bizarre organism? Spirochetes, unfortunately, are notorious because they are the causative agent in syphilis. Of course, *these* spirochetes have nothing to do with syphilis — they simply move like syphilis spirochetes and look superficially like them. Though I disagree with most biologists in this, I personally believe that the cilia/flagella system that is so universal in complex organisms has an ancestry that once was free-living. At one point some spirochetes nosed up around cells, liked the materials that were leaking out from the membrane, and used these as food. Some populations of spirochetes then "decided" not to let go of a good thing. So they hooked on (the way they're hooked on to the *Mixotricha*), and they duplicated on the surface of the host organism, just as the spirochetes of *Mixotricha* duplicate on the surface of their hosts. With time, these spirochetes became the familiar, integrated complex flagella of our ancestral cells. Subsequently at various occasions, in several different groups of organisms, some flagella (which



The wavy "hairs" are really spirochetes living symbiotically on the surface of a protozoan (lower left). The movement of the spirochetes propels the host protozoan.

had once been spirochetes) crawled inside their host cells — permanently — and made available to them all kinds of movement inside.

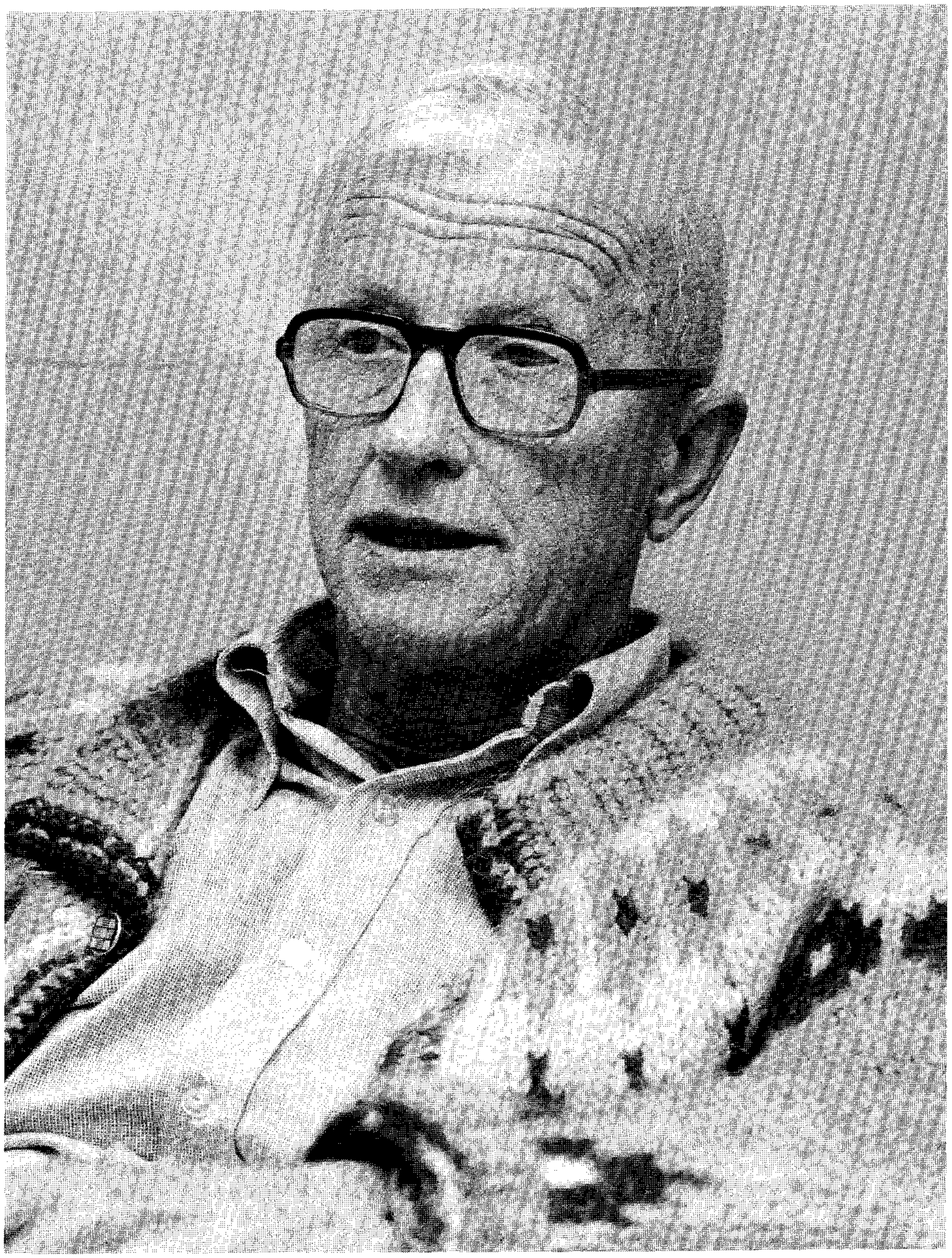
The reconstruction of the possible origin of the cilia/flagella system is a long story. It has to do with the origin of mitosis and eventually meiosis. In short, all the organisms made of complex cells — green plants, animals, and fungi — may have a collection of different microbial ancestors. Our most recent common ancestor was probably a flagellated microbe that possibly had become flagellated by acquiring surface spirochetes. (We are testing the spirochete hypothesis now, here at Caltech.) Some of the flagellated forms adopted photosynthesis and some of them didn't, just as some of the mollusks and some of the worms acquired photosynthesis and most didn't. Those that did found it was a good thing to stay in the same place and photosynthesize. Eventually these evolved into complex plants. Some that didn't acquire photosynthesis went on to evolve into animals. Basically, if you remove the photosynthetic plastids from plant cells, what is left over is very similar to animal cells. Both types have evolved from flagellated ancestors.

So we started with extremely simple bacterial microorganisms. They evolved in many, many ways. But they were always tiny. They formed communities, such as those dominated by bacteria and by the blue-green algae that first "polluted" the atmosphere with oxygen. These tiny microbes can sense each other. They are sensitive to light, to chemicals. In that sense they can smell and see. They have formed many kinds of very complicated partnerships; formation of microbial communities led to great laminated rock structures that geologists can find today. But the individual organisms stayed small. Their activities are represented in the microbial fossil record during the huge Precambrian stretch of time — from 3500 to 600 million years ago. Subsequent to their origin and diversification, after there was the production of quantities of breathable oxygen, a really different kind of cell evolved. The complex cells probably resulted from partnerships among different bacterial types of ancestors. Once complex cells evolved, they provided a unit component from which even more structurally complex organisms could be formed — namely, the fungi, animals, and plants.

When one looks back into the fossil record, it may seem that there was a time when there weren't any organisms, but now we know that though there weren't any animals and plants — large organisms — there were all kinds of microorganisms. Fossil evidence for microbial activities extends back, as far as we know, to some of the oldest sedimentary rocks that have not been subsequently heated or broken up.

The origin of life is an extremely mysterious event; it probably happened early on the surface of the earth — between 4500 and 3500 million years ago. But that early origin was followed by much evolutionary diversification on the microbial level. Microbial evolution, including the formation of partnerships by symbiosis, must have preceded the origins of animals and plants by at least 2000 million years. □

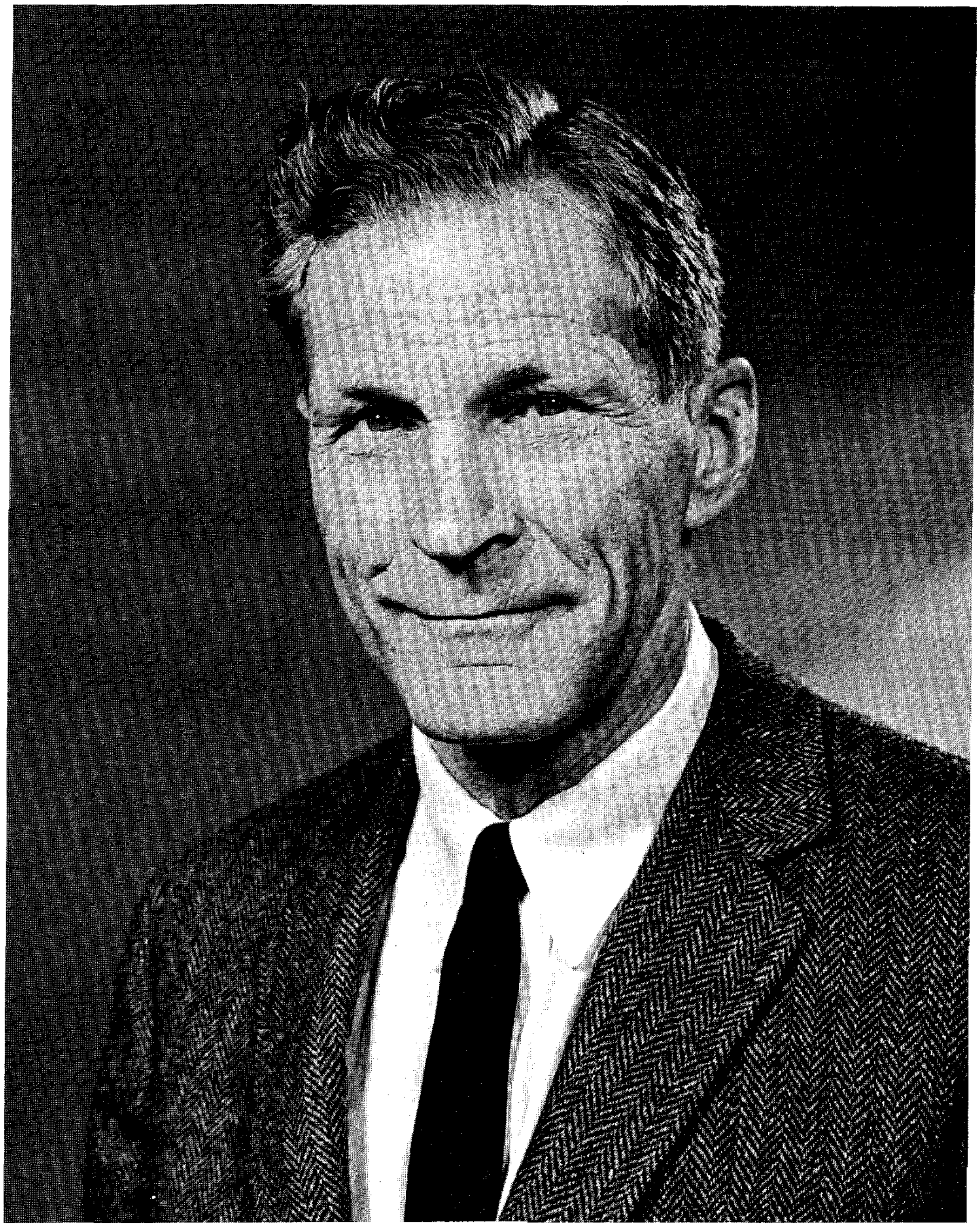
Retiring This Year



Max Delbruck

Albert Billings Ruddock Professor of Biology

Max Delbruck retires this June from his named professorship — only to accept a newly created position to honor retiring professors of unusual distinction: Board of Trustees Professor Emeritus. Delbruck, who shared the Nobel Prize in physiology and medicine in 1969, was the youngest of seven children in a distinguished German family of scholars and public servants. He began his career as an astronomer, but shifted to theoretical physics during his graduate study. In 1932 his interest turned to biology, and he came to study genetics at Caltech in 1937. During World War II he taught physics and researched in biology at Vanderbilt University in Nashville, Tennessee. George Beadle became chairman of Caltech's biology division in 1946, and he brought Delbruck here in 1947. Known as one of the founders of molecular biology, Delbruck used bacteriophage as a model organism to study genetics. In his current research he is using the fungus *Phycomyces* to study how sense organs work at the molecular level.



Alan R. Sweezy
Professor of Economics

Alan Sweezy becomes professor emeritus this month after 27 years on the faculty of Caltech. He is a native of New York City and an admirer and summer resident of New England, and before coming to the Institute taught at Harvard and Williams. Since his graduate school days at Harvard, he has been a student and interpreter of Keynesian economics, and in recent years has become particularly concerned with the economic and social implications of population. He has given a course on population problems for several years and has been associate director of Caltech's population program since it began. Not content to rest on academic laurels, he has also been active in off-campus organizations that deal with family planning and population growth. For three years he was chairman of the board of the Planned Parenthood Federation of America, and he is currently a member of the board of the local chapter and a member of Zero Population Growth.

Retiring This Year

. . . continued

Olga Taussky Todd
Professor of Mathematics

Olga Todd becomes professor emeritus on July 1, but she has already been honored this year — on her birthday (above). It was an occasion that brought forth special issues of two mathematics journals, a symposium attended by more than 40 distinguished colleagues, and a book with 62 papers on mathematics dedicated to her. It was all no more than fitting for so outstanding a mathematician. A native of Czechoslovakia, she taught in several European universities before coming to the United States in 1947. After ten years with the Bureau of Standards she came to Caltech. Her main contributions are in algebraic number theory (class field theory) and matrix theory, and she has greatly strengthened this work at the Institute. She has been in demand as an editor of professional journals and as a speaker. She has also contributed to a number of books and has published more than 160 papers, including one which earned for her the prestigious Ford Award from the American Mathematical Association. Another deep interest is that of teaching and training her graduate students. She is a corresponding member of the Austrian Academy of Sciences, and in 1963 was named a "Woman of the Year" by the Los Angeles *Times*.

Why Don't We Have A National Energy Policy?

by JOHN M. TEEM

DURING THE WINTER of 1973-74 the Organization of Petroleum Exporting Countries (OPEC) gave us both an economic and a political shock — a sudden price increase and an embargo on oil exports by its Arab member countries. The embargo was intended to discourage U.S. and other aid to Israel in the conflict then raging, and it ended within a few months, but today imported oil costs about four times as much, and domestic oil costs twice as much, as it did four years ago.

Government policy makers had good reason to worry about the effect of this energy crisis on the national economy. This double jolt disrupted only 4 percent of our total energy supply (plus the price increases), but it produced a reduction of about 5 percent in the real gross national product, unemployment increases of about 1.5 percent, and an increase in the inflationary rate of almost 6 percent — all within about a year.

These events suddenly made energy policy a much-talked-about topic, and many Americans began to recognize that we had some kind of energy problem. Today, we are still talking, and the national debate has, perhaps, become more intense since President Carter proposed his broadly ranging and complex energy policy to the Congress.

At about the time of this first "energy crisis" period I was involved in a task force in Washington, through which the federal government was making its first major effort to pull together a national plan for energy research and development. It brought together people from all the federal agencies involved in any kind of energy research — coal, solar, nuclear, or whatever. That planning exercise had started in July, before the embargo, but one key element seemed to be missing.

It was obvious to most of us that any national energy research plan should evolve in the context of an overall national energy policy. How else could we identify the priorities to be put on different technologies? How else could we identify what was missing? At that time, however, no one apparently could supply us with such a comprehensive description of our national policy for energy. But after the Arab embargo, the answer came quickly from the highest offices in the land: "Energy Independence" was to be our national energy policy.

It was clear to many people at that time — and has become increasingly so in the three years since — that it just wasn't that simple. We couldn't increase our domestic energy supplies fast enough, nor were we apparently willing to pay the costs of reducing our energy demands. I'm talking here not just about the cost of government expenditures. More expensive were the social, economic, and political costs of increasing our fuel prices sufficiently to bring the demand down enough — and help to increase our domestic supplies sufficiently — to make us independent of imported oil within a 10-year period. Today we import more OPEC oil than we did in 1973, and our annual national oil bill for imports has risen from about $4 billion to approximately $35 billion, so the costs of inaction were not negligible either.

A Short Look Backward

This energy problem has been around for a long time. Someone recently gave me a Presidential letter sent to the Congress on February 19, 1939. It served to introduce a report on energy matters.

> To the Congress:
>
> This report . . . suggests policies, investigations, and legislation necessary to carry forward a broad national program for the prudent utilization and conservation of the nation's energy resources. Our energy resources are not inexhaustible, yet we are permitting waste in their use and production. In some instances, to achieve

> apparent economies today, future generations will be forced to carry the burden of unnecessarily high costs.
>
> In the past the federal government and the states have undertaken various measures to conserve these resources. In general, however, each of those efforts has been directed toward the problems in a single field. It is time now to take a larger view: to recognize . . . that each of our resources of energy affects the others.
>
> It is difficult in the long run to envision a national coal policy or a national petroleum policy . . . without . . . a national policy directed toward all of these energy producers. . . . Such a broader and more integrated policy cannot be evolved overnight. . . .
>
> Clearly, there must be adequate and continued planning . . . which will reflect the best technical experience available, as well as give full consideration to both regional and group interests.
>
> The widening interest and responsibility on the part of the federal government for the . . . wise use of the nation's energy resources raise many perplexing questions of policy. . . . This report sets forth a useful frame of reference for legislative programs . . . (and advances) specific recommendations for solution of the most pressing problems.
>
> (Signed) Franklin D. Roosevelt

This message could have served as an introduction to President Carter's energy message to the Congress on April 20, 1977! It has been almost 40 years since President Roosevelt pointed out that later generations — and that was *us* he was speaking about — would have to pay the price in energy costs and shortages for the lack of integrated, carefully designed policies that take a long-range view of the problems. To an even greater extent, perhaps, it is the present younger generation, and the generations to follow, who are really being "ripped off" by our current policies.

The "pressing problems" that President Roosevelt mentioned are even more pressing today. The natural gas shortages back east this winter put between one and two million people out of work, and showed even those of us from Missouri that the coupling between energy and our economy is very strong.

Why is it, if energy is so very important to each of us, we haven't yet been able to agree on a comprehensive national energy policy?

A Long Look Forward

The difficult part of energy policy formation has been in trying to make sense out of the whole — as President Roosevelt pointed out. In seeking to understand this dilemma during my brief time as a Fairchild Scholar on the Caltech campus, I have discovered that energy policy is, indeed, a complex subject. Hoping to provide some perspective for understanding President Carter's energy proposals, and the process by which these will be considered, adopted, or modified, I have tried to answer three basic questions:

- What is involved in formulating and adopting a comprehensive national energy policy?
- What are the principal dimensions of the energy dilemma and some of the issues involved?
- What are the key objectives that national energy policies try to achieve and what are some of the conflicts between them?

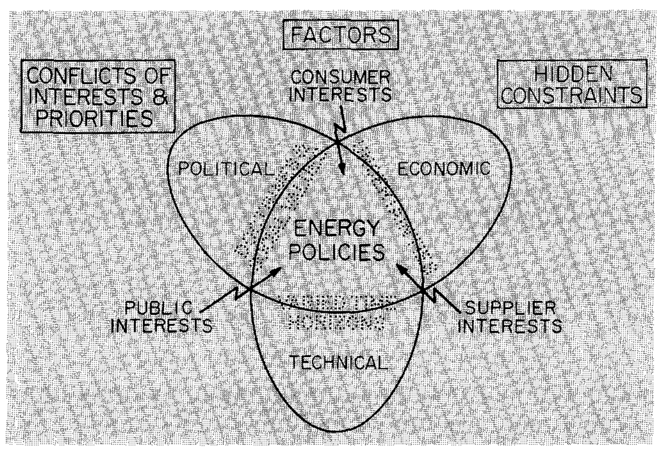
The diagram below shows some of the factors involved in formulating a national energy policy. It also helps identify the kinds of interactions that are involved in establishing (that is, getting agreement on) the "best" national energy policy.

All comprehensive energy policies, I think, have component elements or *factors,* which are political, economic, and technical in nature. Any national energy policy must include some aspects of each of these elements, and the energy policy domain thus falls where such factors overlap.

The process of evolving an energy policy requires resolution of many *conflicts of interests and priorities.*

It is also important to recognize that such conflict resolution takes place, and that energy policies are formulated within the context of a number of often hidden *constraints.*

There are, for example, differing political viewpoints on the worth of various social values — such as environmental conservation, or preventing the poor from suffering disproportionately from the economic



impacts of energy pricing policies, and even differing basic attitudes toward big or little business. There are also quite different doctrines within the political spectrum on what are the best national economic policies and on what is an appropriate role for government in energy affairs. Such doctrines can color the approach used to formulate energy policies. There is another, often unrecognized, doctrine that pervades many attitudes toward energy policy — that science and technology can accomplish *anything,* if we but unleash a "Manhattan Project" or "Apollo" type of effort.

Energy policy formulation and establishment may also be constrained by various uncertainties, both economic and technical. History has shown that it is often difficult, for example, to anticipate fully the total impact a particular energy regulatory or tax policy may have on the whole energy economy. The Federal Energy Administration's oil price and the Federal Power Commission's gas price regulations may be good examples. Other uncertainties concern what will happen outside our own country. What will be the effect on energy policy if OPEC suddenly lowers oil prices?

Poorly Meshed Time-Horizons

Finally, and I think most important in understanding why we don't have a coherent energy policy, is recognition that the energy policy domain is characterized by widely differing time-horizons among its economic, political, and technical components. The focus in the political sector, for instance, is often on the immediate or near-term. Congressmen and presidents are responsive to voters — at least every two, four, or six years — and their vision is often distorted when they try to look too far ahead.

The time scale or lead time for making any significant change in energy technologies is much longer. Fifteen to 20 years is not unusual in order to progress from a new technical concept through the research, development, and demonstration process to first commercialization. It is often 15 to 20 years after that before a new technology can become a significant (say, 10 to 20 percent) factor in the nation's total energy supply.

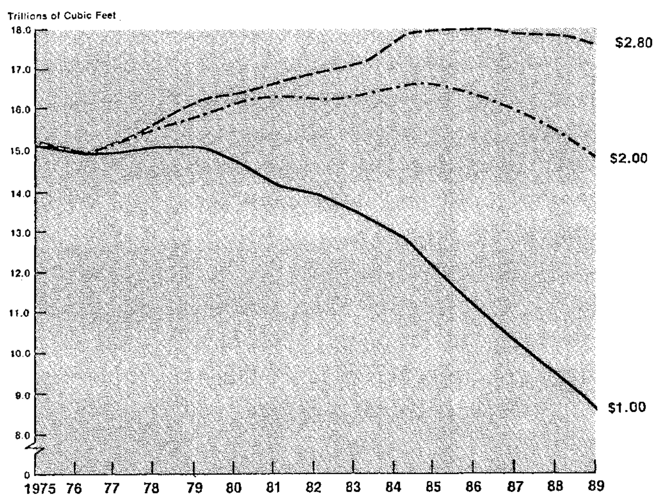
In the economic domain, time-horizons can be either intermediate or rather short. There is a longer time-horizon associated with economic return on investments; perhaps 6 to 10 years is a characteristic pay-back time used as a criterion for product-development decisions by equipment manufacturers. Investment time-horizons are somewhat longer for utility plant decisions; the associated discount rate is lower.

Another economic time-horizon constraining energy policies is the relatively long time — at least in comparison with some other basic commodity markets such as those for food or steel products — that it takes to see any significant expansion of fossil fuel supplies in response to energy price movements. This is well illustrated in the chart below. Here are plotted the FEA's projections of natural gas production under three assumed levels of controlled prices, assuming such prices were fixed in 1976 and maintained in constant dollars over a 15-year period. Note that there is relatively little increase in gas supply forecast (nationwide, under 5 percent) for 3 years after the price rise, and that the major impact on supply (roughly, a 50-100 percent increase) comes only after 10-15 years. Economists say that energy supply, as this illustrates, is relatively *inelastic* to short-term price movements, but that it becomes more *elastic* to longer term ones.

The same observation can probably be made about the demand for many energy sources — that it is inelastic in the short term, but grows more elastic over time. Gasoline is possibly a relevant example; its usage fell only slightly in response to the 1974 price increases. Over a longer period of time many analysts believe that gasoline demand will decrease in response to higher prices.

In summary, many of these time scales — political, economic, and technological — do not mesh well. This mismatch of time-horizons has, I believe, been an inhibiting factor in our establishing any coherent, overall national energy policy.

PROJECTED NATURAL GAS PRODUCTION



NOTE: These quantities include gas used for repressurization of wells; excludes tight gas.

The FEA's projections of natural gas production under three assumed levels of controlled prices. They presuppose that the prices were fixed in 1976 and are maintained in constant dollars over a 15-year period. (The quantities include gas used for repressurization of wells, but exclude tight gas.)

Credibility — Who and What Should We Believe?

I also sense that public attitudes toward our energy problems may be inhibiting our reaching agreement on an overall policy. Rather than apathy, our hang-up may be the problem of credibility — or rather, the lack of it. Many of us just don't know who or what to believe.

I suspect that a significant body of the American people tend to think that all this energy hassle is just a plot by the energy suppliers to get prices up — to gouge the consumers. The actions of OPEC may have lent some credence to such a view. In the minds of some of the public there lurks the suspicion that our energy dilemma is, at least in part, the result of a conspiracy on the part of our domestic energy industry and/or a gullible government. This credibility issue probably underlies the proposal to establish an Energy Information Administration within the new Cabinet-level Department of Energy to make independent assessments of oil and gas reserves, among other things. It may also stimulate, in part, the policy debate on whether or not there should be vertical or horizontal divestiture of portions of the energy companies.

In my judgment, there is no such conspiracy, and we desperately need to achieve better public understanding of the chronic nature of our energy dilemma. Only then can we hope to achieve some broad consensus on a national policy that will provide us some future relief.

Contrasting Approaches to Policy Formation

There are two different approaches to formulating energy policy. The first focuses on the technological means of filling expected gaps between energy supply and demand in the future, and says what the government will do to prevent or remove them. It tries to define how much and what kinds of energy will be available in the future.

The second approach looks at the market and the regulatory processes that maximize or impede the efficient economic use of energy, and focuses more on the impact of governmental policies that affect the operation of markets between suppliers and consumers of energy.

Any comprehensive national energy policy has to take both viewpoints into account, to some degree, and attempt to resolve any conflicts between them.

The first, or "gap-filling," approach is based on the doctrine that central planning can anticipate potential energy problems and solve them. It can do this through coordinated efforts directed either at developing new resources or at methods that will reduce the demand. *The first thing one does when using this approach is to* attempt to forecast what future energy supply and demands are likely to be, nationwide, and thus identify the potential gaps between them. An energy policy is then formulated in terms of a set of priorities among supply technologies — for coal, oil, nuclear, solar, and so on — and among methods of using energy more efficiently. Because of the close relationship between energy and the environment, public safety, and national security, such a policy must also consider what the allowable constraints or trade-offs among such factors will be and adjust these priorities accordingly. Finally, to complete the policy formulation, the role that government should play in encouraging development and commercialization of new supplies or for demand-reducing energy conservation should be identified, in order to meet the schedule implied by the supply-demand gap that the policy aims to fill.

The second, market-oriented approach, is based upon a different doctrine. Many economists feel that we will never have the *wisdom* necessary to allocate resources among the many diverse elements of the energy economy from a centralized, governmental perspective — at least not in the most economically efficient way. They believe that the free marketplace provides the best means for making such resource allocations efficiently.

So this approach focuses on identifying the constraints, incentives and dis-incentives that affect the efficient operation of energy markets, and then asks how governmental actions potentially affect these. The basic approach here is to minimize any constraints on market operation. However, this approach also tries to identify all the public interests affected by the energy economy and then seeks to determine to what degree governmental regulation of energy-related activities may be required to insure them.

The issues involved in this approach are often questions of regulation versus deregulation and how to achieve fairness among the money transfers between consumers (of various income levels) and suppliers. But the basic approach used in this method of policy formulation is to leave the balance between supply and demand to the marketplace and pricing mechanisms.

The Multiple Dimensions of Our Energy Dilemma

Certain aspects of these two approaches to energy policy formulation can be illustrated while considering the principal dimensions of our national energy dilemma and some of the issues involved:

1. Are we really running out of oil and gas — and if so, when?
2. What can we expect from other energy sources and new technologies?
3. How will future energy usage be related to economic growth?
4. What can we expect from conservation?
5. Can we keep energy costs low by regulating prices — and what is the relative impact of increasing energy costs on families of different income levels?

1. **When will we run out of oil and gas?** Domestic natural gas supplies are falling. Gas production peaked during 1970-72, at about 22 trillion cubic feet annually. Even with the increased discoveries and production that might follow a price increase, the best we can probably hope for is that domestic gas supplies might rise again to near the historical peak rate for the next 15 years or so before falling again. In part this supply will come from the Alaskan North Slope, providing new pipelines can be built to bring it down to the lower 48 states.

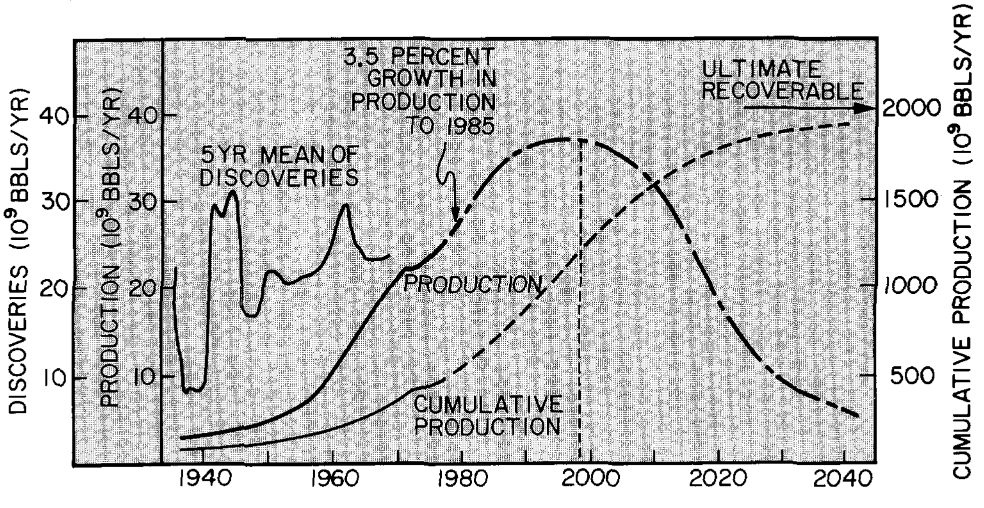
Domestic oil production also peaked in 1970 and has been falling ever since. The outlook for increasing domestic oil production in the future is similar to the situation for natural gas. Some new production, including that due to enhanced recovery from existing fields, can be expected under the stimulus of increased prices. But even with the arrival of Alaskan North Slope oil this summer and possible future discoveries located off the continental shelves, it is unlikely that domestic oil production can be maintained much above current, or perhaps historical, peak rates (about 3.6-4.0 billion barrels per year) for more than 15-20 years. Proven domestic oil reserves are now about 35 billion barrels, and the total estimated remaining U.S. recoverable resources — including undiscovered oil — amounts to about 135 billion barrels. Included in this latter estimate is about 40 billion barrels of potential oil production using advanced, so-called tertiary, recovery techniques. However, the FEA has recently estimated that, for such recovery techniques to become economic, domestic oil prices will probably have to increase by as much as a factor of two over current prices — i.e., to higher than we now pay for imported oil.

Domestic supplies of oil and gas are thus rapidly declining and, at most, can be expected to remain constant at levels less than our current consumption. So where are our petro-fuels coming from? Obviously, we are making up the gap now through imports from around the world. The world's resources amount to about 2,000 billion barrels of petroleum that is economically recoverable, and over half of that is located in Asia. Natural gas and condensable liquids increase our total petro-fuels bank to the equivalent of 5000 billion barrels of oil. Even this large supply of petro-fuels will be used up some day. What we do not know is exactly when this will happen. One possible answer to this question is shown for oil in the diagram below. Most analyses of this sort show that as early as 1990 — only a little over a decade from now — we will begin to find it very difficult to get oil from overseas.

Thus we can recognize the first dimension of our energy dilemma:

continued on page 32

Source: C. Wilson, MIT



WORLD OIL:

Production,

Cumulative Production,

Discoveries

Arie Jan Haagen-Smit

1900-1977

A Tribute by James Bonner

ARIE JAN HAAGEN-SMIT was a very special person. He did so many things so well that it is a privilege to celebrate his life on this occasion.

Arie — or Haagy, as we all knew him at the laboratory — was born in 1900 in the city of Utrecht in Holland. His father was the chief chemist of the Royal Mint of the kingdom of the Netherlands, and Arie's first chemistry lesson consisted of playing hide-and-seek among the piles of gold and silver bricks. He also watched his father dissolve coins and analyze them for their gold, silver, or copper content, a process that did not arouse Arie's interest in chemistry.

In high school Arie became enthusiastic about mathematics. He learned calculus by self-study and found physics fascinating. Arie also found languages fascinating and rewarding. In addition to English he studied French, German, Latin, and Greek. According to him his only poor grade in high school was in his native Dutch.

During his high school days his athletic skills developed too. As soon as the canal ice melted in the spring, he would begin rowing up and down the canals. He also sailed on Holland's lakes, and he was a champion boxer. Thanks to that rowing and boxing, his biceps were the largest to be found in the entire division of biology faculty — at least, up to about 1960. From that time on, Arie, having joined the establishment because of his work on air pollution, always wore a coat, so I couldn't check on the status of his biceps any more.

In 1918 Arie entered the University of Utrecht and chose chemistry as his major. He might have become a mathematician or physicist except that he was counseled by the university officials that there were no positions in Holland in these fields.

When it came time for graduate school, Arie again chose Utrecht and organic chemistry. The Professor of Chemistry at that time was P. Van Romburgh, a natural products chemist, who soon had Arie isolating a dermatitis-inducing agent from the outer layers of the fruit of the cashew nut.

Van Romburgh retired in 1926 and was succeeded by the young Leopold Ruzicka, who came fresh from Zurich. Ruzicka, the young giant of European organic chemistry, was interested at that time in the isoprenoids and in particular in the isolation, structure, and synthesis of the sesquiterpenes. His work with Ruzicka conferred on Arie a lifelong interest in the chemistry of the terpenes.

Arie received his PhD in 1929 and stayed on at Utrecht as a Chief Assistant in organic chemistry. In this position he was able to do his own individual research on natural products, but he also was obliged to supervise undergraduate laboratory courses.

In 1933 Ruzicka was succeeded at Utrecht by the German, Fritz Kogl, and Arie stayed on as his Chief Assistant. Utrecht, at that time, was the world center of the invention of a plant hormone, the so-called growth substance. Having one and subsequently two students from Utrecht, Caltech was basically a substation in plant growth hormone studies, the only such center in the U.S. A biological assay for the plant growth substance had been developed by Frits Went during the time that he was a graduate student at Utrecht and before he came to Caltech. Arie (and perhaps Kogl) set out to isolate the active principle, the plant growth substance. He isolated the material called heteroauxin, now called auxin, in 1934. The substance was indole 3 acetic acid. Its isolation laid the cornerstone of our knowledge of plant growth regulation.

It has always impressed me that Arie claimed no special credit for such a great discovery. Neither did he claim credit for another even larger discovery made in the summer of 1935. Frits Went, who was then a faculty member at Caltech, spent that summer in Utrecht, where he worked with Arie. They found that substances chemically similar to indole 3 acetic acid, such as α-naphthalene acetic acid — substances never found in nature — can completely mimic the action of indole acetic acid in the control of plant growth. From this discovery (not patented by the discoverers, of course) grew the whole field of chemical control of plant growth, the invention of 2,4-D as a weed killer, the idea of selective herbicides, the whole field of agricultural chemicals.

The Caltech plant hormone center included Kenneth Thimann and Frits Went. Thimann left Caltech in 1935 to establish a competing center at Harvard, and he persuaded Arie to come there for the 1936-37 academic year. This was the period when the Harvard chemistry faculty could not decide whether or not there was really such a thing as biochemistry. Thimann had a PhD in biochemistry himself, but I am sure there was some doubt about appointing more biochemists. In any case, it was relatively easy for Frits Went and Thomas Hunt Morgan, the chairman of the division of biology at Caltech, to persuade the Haagen-Smits to come to Caltech in 1937. Haagy was appointed an associate professor of bio-organic chemistry. The family rapidly took root in Pasadena, and here Arie and Zus raised their children: Jan, Maria, Margaret, and Johanna (Maria Van Pelt, Margaret Scott, and Johanna Demens).

Arie quickly established a research program; he and I collaborated on the isolation and structure determination of the plant wound hormone, which we named traumatic acid. Haagy investigated the terpenes of the turpentines of most species of pine. He also investigated the nature of the oils of desert plants, thus giving him an excuse for desert camping trips. And he worked on the flavoring materials of natural products. Haagy's complete microchemical analytical laboratory in Kerckhoff served not only Arie and his group at Caltech, but to a considerable degree it became a national facility for microanalytical chemistry, particularly during World War II when Americans were cut off from previously used resources in Germany.

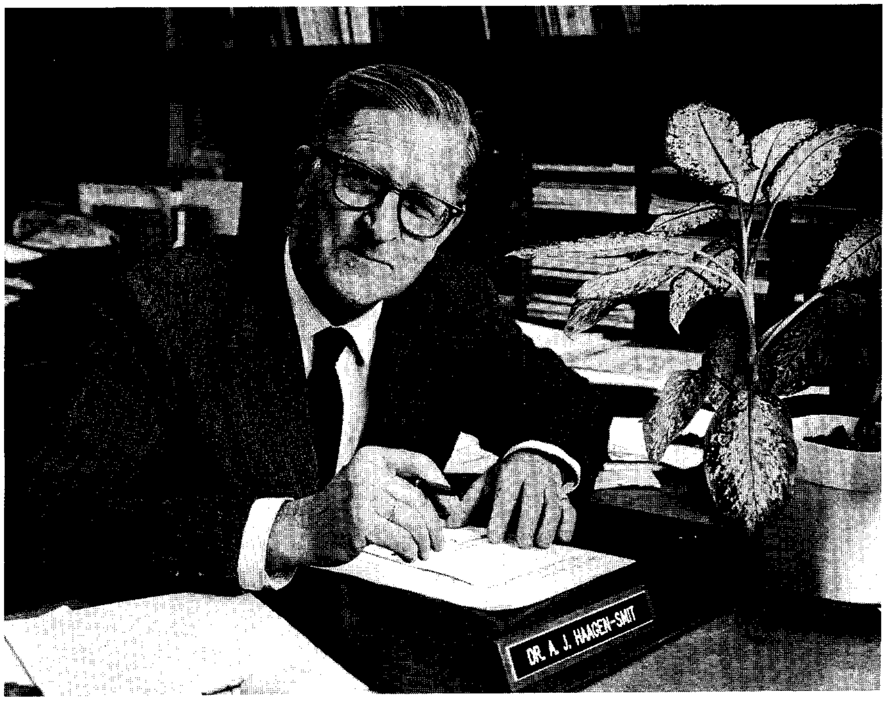
Haagy was good with students; one of them told me several years after he left Caltech that his notes on the course, Chemistry of Natural Products, contained more meat than those of any other class he had taken here.

Arie's students produced papers, and these papers produce an anecdote. My brother David got his PhD with Haagen-Smit and subsequently became a professor at Yale University. He once told me, "As a graduate student I used to be so annoyed when Haagy automatically put his name on my papers. Now, in the light of my greater experience, I realize the wisdom of his policy."

Arie shared completely the academic burdens of his colleagues. In addition he served for six years as the first executive officer for the division of biology, and I remember he had so much work to do that each evening, instead of a briefcase, he took home a suitcase full of papers, which he brought back in the morning full of resolved work.

Smog was born in 1943 at the Shell Butadiene Plant in South Los Angeles, and soon Arie and his colleague, Dr. C. Bradley, retired chemical director of Uniroyal, became completely occupied with the study of the chemical nature of smog and its source. I want to recall just three vignettes from these years.

The first is from perhaps 1946, when Haagy and Bradley were measuring oxidant levels in the ambient air. To do this they sucked air through short pieces of bent rubber tubing. The shorter the time it takes for the rubber tubing under tension to crack, the higher the air oxidant level. This turned out to be a measure of the ozone concentration in air. With such simple tools Arie established the nature and sources of smog. It was one man against an establishment that at first insisted that petroleum and automobiles could not possibly be the source of smog — but as we all know, Haagy won and won totally.



Another memory comes from quite a few years ago when I saw Haagen-Smit in the hall smiling to himself, and I asked him what was so funny. He said, "Today I had three Ford vice presidents in my office. Last year I would have had to go to Detroit to see them."

Still later, when he was chairman of the Air Resources Board, he was responsible for certifying that each car manufacturer had filed a compliance with the California Regulations Certificate. Volkswagen failed to get their compliance certificate in on time. Haagy was exultant! "I'm sorry it wasn't General Motors," he said, "but it was Volkswagen, and I shut down all their sales in California for one week until they complied. That's *real* power."

Once we discussed all of the facets of smog research and control that he had worked on, and he concluded that he had covered the field pretty well — scientific, legal, political, the works. "But, he said, "I might have done more in city planning."

Friendliness and friendship, good humor and a sense of humor, characterized every action of Arie Jan Haagen-Smit. They made him the ideal colleague and friend. We all rejoice that his work became so publicly appreciated during his lifetime, that so many honors were bestowed upon him in recent years. He deserved those honors, and I think he really liked them. Arie is the example, very rare, of the true scientist, who takes a problem and solves it not only scientifically but also societally. Whatever he did he did superbly. Sad as we all are that Arie is now gone, we can rejoice in his long and productive life — a life that I believe was happy and satisfying to him.

Arie Haagen-Smit died on March 18 of lung cancer, and a memorial service for him was held on campus on May 5. This tribute is adapted from the remarks made on that occasion by James Bonner, professor of biology.

William Noble Lacey

1890-1977

A Tribute by Ernest Swift

WILLIAM N. LACEY, one of the pioneering members of the Institute faculty and professor of chemical engineering emeritus since 1962, died March 26 in San Diego. His association with the Institute extended over 60 years.

Lacey came to what was then Throop College of Technology in 1916, and during the following years, in close cooperation with Arthur A. Noyes, he helped in formulating the general policies for chemistry and chemical engineering. He was largely responsible for bringing the program in chemical engineering from the original single senior required course to one of high national ranking. Its subsequent growth in recognition can be attributed in large measure to his policies and leadership during this period.

Lacey was born in San Diego in 1890, did his undergraduate plus one year of graduate work in chemical engineering at Stanford, and obtained his doctorate in physical chemistry at Berkeley where he worked with G. N. Lewis, one of the outstanding chemists of that era. He spent one year with the Giant Powder Company in San Francisco, and then in early 1916, upon the recommendation of Lewis, he accepted an invitation from A. A. Noyes to move to MIT as a research associate in chemistry.

Although Noyes was professor of physical chemistry at MIT, he had been persuaded in 1913 by George E. Hale, a former student of his, to spend a part of each year in Pasadena. By 1916 Noyes had decided to join with Hale in his plans for transforming the fledgling Throop College into the MIT of the West Coast.

Lacey must have become part of these plans, because later in that year he accepted an appointment as instructor in industrial chemistry at Throop. I have always thought that Lacey was a cautious and deliberate person, and have often wondered what visions of the future Noyes must have pictured for him. What would cause him to leave a prestigious institution, such as MIT, and move to one that had only recently emerged from being essentially a trade school; one whose campus consisted of one permanent building situated in the midst of weed patches and neglected orange trees; and finally, one where chemistry and chemical engineering had to share the second story of this one building?

Lacey must have had some apprehensions on noting in the January 1916 catalog that he would be joining only two other professors, Stuart Bates and Howard Lucas, in handling a chemistry and chemical engineering curriculum that listed class and laboratory courses in inorganic, organic, and theoretical chemistry; quantitative, technical, and food analysis; plus classwork in chemical engineering, industrial chemistry, and petroleum technology. By 1919 when the disruptions of World War I were past, James Bell, James Ellis, and Roscoe Dickinson had been added to the group; but for many years Lacey taught courses in industrial chemistry, chemical engineering, and even technical analysis.

It is surprising that in spite of this teaching load he was able to begin to do some research and also to engage in various consulting activities. He established and for several years directed the research laboratory of the Riverside Cement Company. Also for several years he traveled back and forth on weekends over the rough desert roads to Trona Lake to direct research for the American Potash and Chemical Corporation on the chemistry involved in the crystallization of their various products from the lake brine.

During the early twenties he contributed his engineering experience to a biochemical project being carried out in the basement of Gates Laboratory by Gordon Alles and Albert Raymond (then graduate students) for the commercial production of insulin. This work also resulted in a publication announcing the first preparation of crystalline insulin. It is significant that some 40 years later Alles and Raymond were instrumental in establishing the W. N. Lacey Fund. Contributions to this fund have made possible the very successful W. N. Lacey Lectures, which each year bring to the Institute internationally known chemical engineers for lectures and discussions.

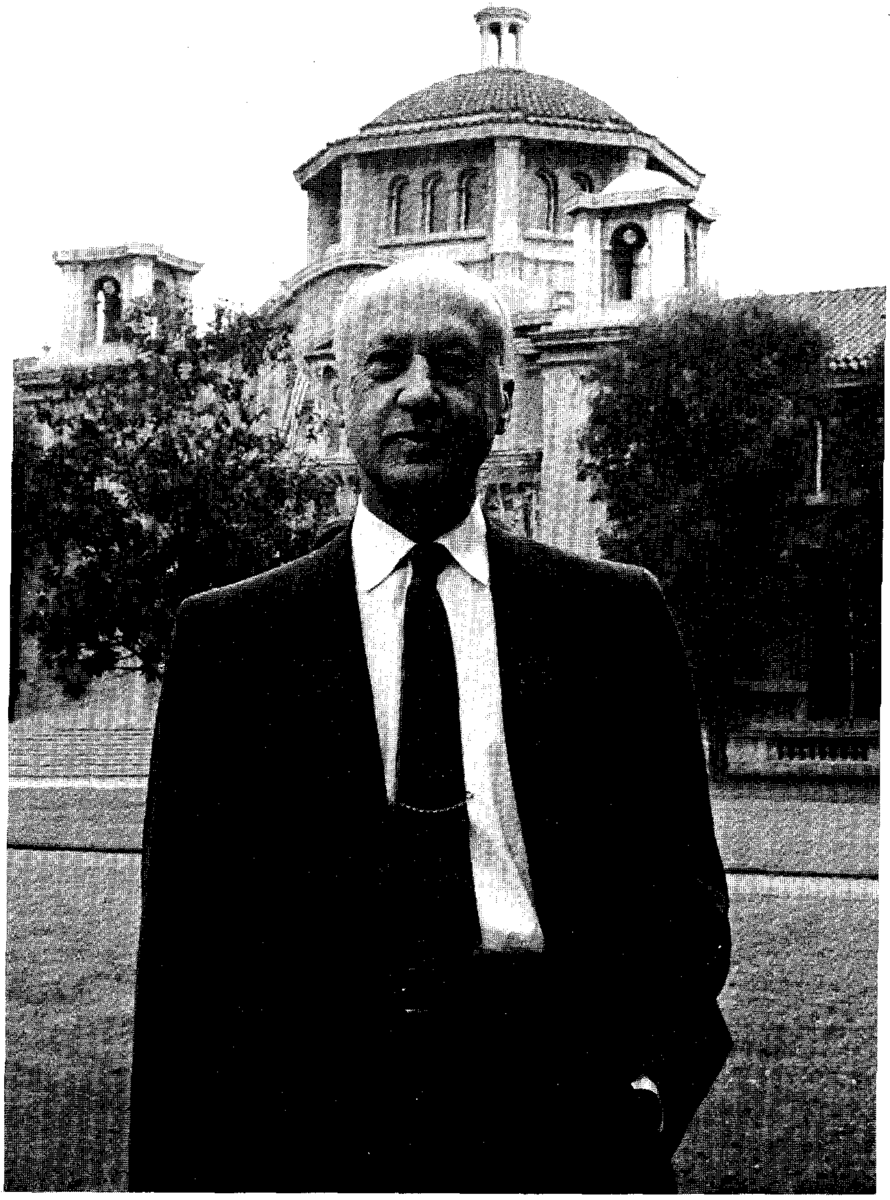
In 1927 he initiated a pioneering series of studies on the fundamental properties and behavior of hydrocarbons at various pressures and temperatures. He was later joined in this work by Bruce Sage. Aided by support from the American Petroleum Institute the studies extended over 40 years and have been of great value to the oil and gas industries, and subsequently to the petrochemical industry.

This project brought wide recognition to the Institute and many honors to Lacey. Among these were the Lucas Medal of the American Institute of Mining and Metallurgical Engineers (1947), the Hanlon Award of the Natural Gasoline Association of America (1946), the Certificate of Appreciation of the American Petroleum Institute (1952), and the Founders Award of the American Institute of Chemical Engineers (1968).

As the staff in chemical engineering was gradually enlarged, Lacey's instructional duties became lighter, and he was persuaded to serve as dean of graduate studies from 1946 to 1956. He was so conscientious toward the duties of this office that he was loath to delegate to his staff any duties that might affect the graduate students. For example, he read every word of every thesis submitted for his approval. Many proud authors of theses were chagrined when their prized efforts were returned for scientific or literary improvement, but most of them came to appreciate the value of his comments. He also served as interim dean of the faculty in 1961-62.

Lacey was active in various professional societies. He was a member of the American Chemical Society and was chairman and a counselor of the Southern California Section; a member of the American Institute of Chemical Engineers and the first chairman of the Southern California Section; and a member of the American Society for Engineering Education. He found time to author or co-author six text books and over 140 scientific papers. He was active in both World Wars, serving as a first lieutenant in the ordinance corps from 1917 to 1919, and as supervisor for a rocket development project for the Navy from 1940 to 1945. He was awarded the Presidential Certificate of Merit for this work.

Lacey's professional and research accomplishments brought him recognition and honor, but I believe he would have cherished most the respect and affection universally accredited him by both colleagues and students. His consideration for others was well known. I have never forgotten a small but typical example that occurred shortly after my arrival at the Institute in May of 1919 as a lowly graduate student. Lacey had reached the quarter finals of a faculty-graduate student tennis tournament. Learning that I played tennis, he thought it would be nice to involve this newcomer, so — disregarding tournament rules — he arranged for me to be drawn into his quarter-final bracket and thus to participate in the tournament.



Looking back over the years, I cannot recall an instance in which he appeared to lose his temper or even to show impatience with others. This is not to say that he did not have firm opinions or that he was not quite adamant in defending a position about which he had strong convictions. I first realized this when serving with him shortly after World War II on a faculty committee to formulate an Institute patent policy. The war research projects had produced numerous patentable results, and the administration recognized that royalties from these patents could represent much needed financial support. To my surprise this chemical engineer was uncompromising in his opposition. He argued that in spite of the short-range financial advantages such a policy was not to the best interest of the general public or the Institute. In spite of strong initial opposition his view finally prevailed and the present policy resulted.

On concluding this tribute I think I cannot do better than to quote from a statement by Lee DuBridge. It was given in 1963 at a standing-room-only dinner in the Athenaeum to honor Lacey upon his retirement. Dr. DuBridge said: "The Caltech star would be several magnitudes fainter than it is today if it were not for Will Lacey's devoted and distinguished service."

Ernest Swift is professor of analytical chemistry emeritus.

Energy Policy
. . . continued

By 2000, or earlier, we may have difficulty obtaining either domestic or imported petroleum and natural gas, except at very high prices. What we get then may well come from the Soviet Union or China – if they will sell it to us.

2. **What can we expect from other energy sources and new technology?** Obviously, if oil and gas are being used up, we must shift to coal or some other alternative. What about coal resources? The total world's supply of oil and gas is less than half of the total U.S. coal supply. The problem is to get the coal out of the ground safely and use it without fouling our environment. We also have relatively large quantities of oil shale, but there is some question about the environmental and economic viability of oil-shale production, at least at current world oil prices.

Geothermal energy, using currently developing hydrothermal technology, is a new resource. Liquid-dominated hydrothermal resources could provide an amount of energy equivalent to about a quarter of our current oil and gas supply. Getting access to the geopressurized fluids of the Gulf Coast and the western hot rock resources would give us a supply of energy larger by 50 percent than the potential for all our oil and gas. The question is whether these geothermal resources can be made technically exploitable.

If our current supplies of uranium are burned in light-water reactors like those operating today, they would provide us with a total amount of energy about equal to that of all of our oil and gas. If breeder reactors were used, the potential from this uranium is larger than the sum of all other non-renewable resources. But breeder reactors involve plutonium, with all its potential for proliferation of nuclear weapons.

The energy available from solar energy or nuclear fusion — if it becomes practical — is essentially infinite and inexhaustible.

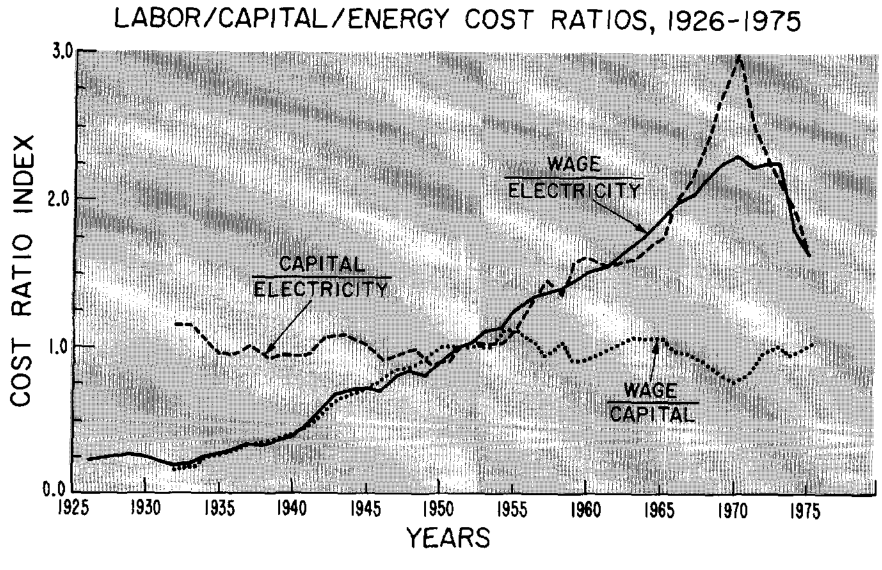
So there appear to be a lot of alternatives, but can they be developed quickly enough — and at what price?

A recent ERDA analysis tries to answer the question of what is the maximum impact on the energy supply that can be hoped for from these new technologies. This analysis indicates that by 1985 the maximum impact from improvements to existing coal-related technologies might add about 4 percent to the supply that is expected to be needed then. Improvements in light-water reactors could perhaps add an additional 5 percent, and enhanced oil and gas recovery might add 2 percent to our supply. Synthetic fuels, solar, and geothermal resources would provide less than 1 percent of our energy supplies by 1985.

By the year 2000 the situation could be somewhat more hopeful. The maximum impact from improving our currently existing technologies, primarily coal and nuclear, might be as much as 30 percent of our expected supply and needs by that date. Advances in coal combustion and for light-water reactors would each account for about 10 percent. Synthetic fuels would provide maybe as much as 6 percentage points in this estimate.

Other new energy sources might supply as much as 18 percent by 2000. In order of relative contribution, this increment would come from solar, geothermal, oil shale, and the nuclear breeder reactor. However, energy from new technologies would not necessarily be additional to that from improvements in existing coal and nuclear technologies, because there will be trade-offs among these various technologies. Hence, we must conclude that no one technology can fill the gap, and even with all of them at their maximum impact, we may not have enough. Thus is revealed the second dimension of our energy dilemma:

It will be difficult to achieve the potential benefits of new energy source technologies — perhaps somewhat lower energy costs than those extrapolated for petroleum-based technologies



In the American economy there has long been a substitution of energy for labor in order to increase productivity. The economic basis for this is shown in this diagram, which plots the ratio of the relative costs of labor, capital, and energy (in the form of electricity) over the past 50 years. The solid curve — which plots the cost ratio of labor to energy — and the dashed curve — which plots the ratio of capital costs to those for energy — have been rising. With energy becoming progressively less costly than either capital or labor, it has been substituted for them. Note, however, that since 1972 energy costs have been rising relative to capital and labor, and so these curves are falling.
Source: B. M. Hannon, U. of Illinois

and a substantial level of "gap filling" new energy supply — within the time horizon of the anticipated oil shortage.

3. **How will future energy usage be related to energy growth?** Energy has not only become a pervasive factor in our economy, it may even be the weakest leg of a three-legged stool on which our economy rests. The other two legs are capital and the labor force. In recent years this three-legged stool has been tilted.

Between 1950 and the early 1970's, energy became progressively less costly relative to either capital or labor. The consequence of this was a persistent and continuous substitution of energy for both capital and labor, with the result that the growth in our energy consumption per person has increasingly outrun the growth in our total gross national product per person. However, in the last few years, the relative costs of energy have been increasing, which suggests the third dimension of our energy dilemma:

The cheap energy that has fueled our economic growth of the past 30 years, and that of the other developed nations, is coming to an end. We do not know whether we can turn down, significantly, our historic non-linear growth in per capita energy usage (with respect to per capita GNP growth) without producing economic chaos or requiring significant changes in our style of life.

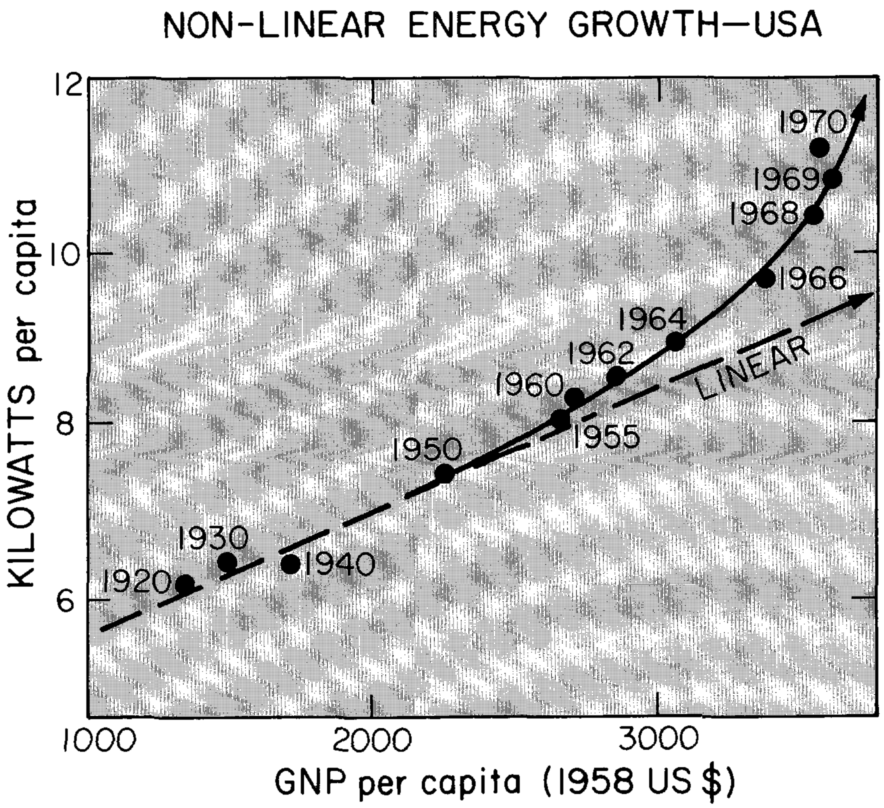
4. **What can we expect from conservation?** Can we use our energy more efficiently? Can we achieve significant energy conservation without sacrificing either our standard of living or our industrial output? These are related questions.

In the industrial area there is probably some chance for improvement, as comparisons with the experience of other countries indicate. But industrial usage of energy may be so closely related to economic growth and expansion of our labor force that too much "conservation" could be costly. Nevertheless, perhaps we can reduce our industrial demand by 25-30 percent.

In the residential sector the situation for substituting capital for energy is even more hopeful. We can add some insulation to existing buildings; better yet, we can replace old buildings with new ones and use insulation even more effectively in the construction. We can make more innovative design improvements, including perhaps designing to keep the sun's energy out in the summer but allowing it to come in in the winter. These progressively larger capital investments lead to progressively smaller energy usage, and total costs over the life of a building of providing a given level of comfort can usually be minimized in this way. Perhaps even lower fuel consumption can also be achieved, at the expense of somewhat higher total life-cycle costs, by adding active solar energy heating and cooling to the building. Generally, we can identify an optimum relative use of energy and capital (or labor) in providing building comfort, and this is usually at an energy-usage level below current practice. Furthermore, as fossil fuel costs for building heating and cooling increase, the optimum life-cycle cost will occur at even lower energy consumption. Thus, detailed studies have shown that levels of energy conservation in buildings may reach 30-35 percent and be cost-efficient without sacrificing comfort.

Per capita usage of energy for transportation is also relatively high in this country. Such usage can probably be reduced eventually by 30 percent or more, but this will require a significant replacement of our motor fleet with more fuel-efficient vehicles and perhaps greater investment in mass transit systems. The losses we now incur in the generation of electricity and in its transmission can also be reduced, perhaps by 5 percent.

ERDA has estimated that the total



The growth in our energy consumption per person has increasingly outrun the growth in our total gross national product per person from 1950 until the early 1970's, as is shown in this chart of the actual growth (solid curve) in relation to what would have constituted linear growth (dashed line).

reduction in the demand for primary fuels by 1985 could be as much as 14 percent from such technological improvements in the efficiency of energy usage. This is about what we expect to be able to add to the supply through improved source technologies. By the year 2000, however, the energy demand reduction through more efficient technologies may be as much as 24 percent of the then expected demand, without such conservation measures. This is somewhat less than the percentage improvement in energy supply from new technologies.

What will motivate consumers to change their current patterns to make these savings possible? What will motivate them to make the necessary capital investments required to reduce energy usage by such amounts? Well, the market or process-oriented energy policy analysts tell us that the best motivation we can give for conserving energy is a price increase, although some longer term cost benefits of energy-use reduction may exist even at current energy prices. However, our national experience to date is that relatively little conservation has yet occurred voluntarily. That raises the fourth dimension of our energy dilemma:

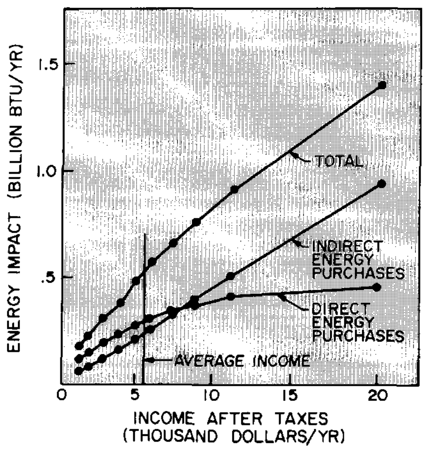
Any significant level of energy conservation probably requires comparably significant increases in the price we must pay for energy.

This observation also raises the other related energy policy issues:

5. **Can we keep energy costs low by regulating prices, and what is the relative impact of increased energy prices on families of different income levels?**

Keeping energy costs low through regulating the price of energy might appear to be an appropriate action, but it is a simplistic one that is not easy to apply equitably. If the price of natural gas, for example, is regulated to be significantly lower than that for other roughly equivalent forms of energy, an artificial demand for it is created, along with a concomitant disincentive to develop new supplies. This has occurred.

Source: B. M. Hannon, U. of Illinois



This chart plots the per-family consumption of energy versus family income in the period 1961-63. It shows in billions of Btu's both direct energy purchases, such as for heating, cooking, and gasoline (i.e. the curve that flattens out), and also the indirect purchases of energy included in the production of other consumer goods and services. Since 1963 family consumption of energy has gone up, perhaps by 35-40 percent. Income has also increased, due to both real gains and inflation. Thus, a recent average family income had gone from $5,500 shown here to about $10,500 per year.

On the other hand, if energy prices rise higher, there is a disproportionate impact on lower income members of society. Adjusting the data in the figure above to current levels of income and energy consumption, we find that a median income family (now about $10,500 per year) spends about 22 percent of its total income on energy — 16 percent of it for direct energy purchases. Such a family today uses about 750 million Btu's per year. but a low-income family, with an income of, say, $5,000 per year, must spend 28 percent of its total income for energy, although it uses only 420 MBtu. Of this, 22 percent is used for direct energy purchases. A high-income family now making about $38,000 per year uses about 1960 MBtu, and spends only 14 percent of its income for energy, roughly equally divided between direct and indirect costs.

If both direct and indirect energy costs were to increase by $1 per MBtu, such families' energy costs would change as follows:

The low-income family would pay an additional $420 per year, so that its total energy costs would now represent 36 percent of its income, 27 percent of it for direct energy purchases. The median income family would pay an additional $750 per year, which would mean that its total energy purchases would represent about 30 percent of its income, with 20 percent of that being for direct energy costs. The high-income family would pay an additional $1960 for energy annually, and its total energy budget would now be about 19 percent of its income, with only 8 percent of this being for direct energy purchases.

Thus we see that the poor bear, disproportionately, the costs of any price increase for energy — particularly those involved in direct energy purchases. This fact provides a rationale for some sort of income redistribution policy to equalize the relative costs of energy price increases among different income groups. There are several possible solutions, among which are a negative income tax associated with energy use, or a tax on gasoline. These could be the source of income transfers to make the costs of energy price increases more equitable. This brings us to the fifth dimension of the energy dilemma:

Formulation of an energy policy that involves regulating or increasing the price of energy also requires assessing the true costs – who will bear them, what social costs will be associated, and how to share the costs more equitably.

Resolving Conflicting Policy Goals

These multiple dimensions of our energy dilemma suggest or imply a number of broad national objectives that we might hope to achieve through any overall national energy policy:

- Ensure security of supply against foreign disruption.
- Ensure efficient economic use of alternative resources and adequate future supplies.

- Constrain environmental impact to conserve our natural environment.
- Keep energy costs low to minimize economic disruption.

The first emphasizes our need to be protected against any sudden, externally produced disruption to our fossil energy supply in the near term. One way to minimize the impact of potential future oil embargoes is to develop a substantial oil stockpile.

The second highlights our need to ensure that we will have the energy that is necessary for our economic survival over the longer run. But to do this we need to help by reducing our energy appetites somewhat through using our energy supplies more efficiently. We also want to diversify our sources of energy as soon as possible, reducing the relative dependence on oil and gas. We probably have at most only about 25 years before we are going to be unable to get — at any price — anywhere near the amount of petro-fuels we now use.

The third objective emphasizes our intent to conserve our natural environment, but at what cost? We clearly have no desire to return to the "smoky 1920's" nor to let technology lead us into more profound long-term environmental problems, such as those that could arise from improper attention to storing nuclear wastes. So far, our national policy seems to allow little compromise with this objective.

Finally, we must recognize that our economy runs on energy and that there are significant social costs for energy price inflation, particularly if such inflation occurs rapidly. We want to avoid these, or at least to make adjustments equitably and as slowly as possible, considering the needs of our citizens at all economic levels.

Perhaps we can all agree that these form an attractive set of national energy policy objectives, but the critical question is: Can we achieve them all simultaneously? It seems to me that the main reason why we are having so much trouble in agreeing on an energy policy is that, in trying to focus our priorities on one or possibly two of these four objectives, we often find ourselves in trouble with one or more of the others.

Too often we have tried to substitute energy slogans for carefully thought out energy policies. Remember "Energy Independence"? Perhaps throughout the past 20 or 30 years the energy slogan that has most nearly characterized our policy has been "Low Cost Energy, Adequate for All!" "Zero Energy Growth" is another slogan that has surfaced in recent years. And we all remember the various technological "fixes" that have been promised us. There was "Atoms for Peace" when we believed, naively, that nuclear energy would be our panacea. Now it's "Coal and Conservation" or, maybe, "The Solar Solution — Inexhaustible Energy Plus a Clean Environment!" Perhaps you have your own favorite energy slogan.

Each of these slogans may have been intended to focus our attention on one or another of the four objectives listed above. They sound good and simple. But such slogans, taken one at a time, *don't make a viable energy policy.* The real issue of energy policy is — can we achieve all of these goals together? We must face the probability that we cannot afford to give them all equal priority, because there are some fundamental conflicts among these worthy objectives. Hence, I believe my answer to this fundamental question is — Probably not.

I doubt that we will ever have a simple but coherent overall policy statement that will summarize everything beautifully. It will take a concerned and informed public and perceptive national leadership to work out all of these conflicts. Our energy policy must evolve over the next few years through a series of interrelated and thoughtful changes in the way we currently do business in this arena.

Two "Laws" of Energy Policy

I want to summarize with a slightly tongue-in-cheek suggestion of two "fundamental policy laws" or guidelines which I suggest for putting energy policy suggestions in perspective and for evaluating future proposals. It seems to me that President Carter's proposals are, at least, consistent with them. These are my "laws" of energy policy, perhaps not so profound as the laws of thermodynamics, but at least as easy to remember.

First in energy matters—
THE SIMPLE SOLUTION
IS NEVER THAT SIMPLE

Second—
WHATEVER THE SOLUTION,
IT'S GOING TO BE (TOO) COSTLY
AND SLOW

Perhaps a word or two needs to be said in defense of the second law. Most energy systems, whether they are intended to provide new sources of energy or to utilize energy supplies more effectively, demand large amounts of capital. This means that even if we resolve our energy policy debate soon and establish an effective and coherent national policy, it is going to take a long time before we complete the adjustment to our changing energy situation. It also may forecast, I'm afraid, a capital crunch as we try to find the capital resources to make the major new investments required, along with our energy crunch.

It is also true, I forecast, that our energy is going to cost us more in the future. One source of this rise is the costly trade-offs that must be made between energy and environment, or among energy, capital, and labor within our economy. Not the least inexpensive will be the social costs of income redistributions between energy consumers and suppliers that the rising monetary costs of energy imply — but which are politically difficult to swallow. (President Carter's proposed use of energy taxes and rebates seems aimed at minimizing such social costs.)

Whether our energy solution will be *too* costly or not, will depend upon the wisdom we bring to making these energy policy trade-offs and upon whether or not we, as a nation of special interests, can agree on a policy solution before it is too late to implement it. □

Sue Dahlberg sheds light on semiconductors...

gaining new knowledge to help improve the nationwide telecommunications network.

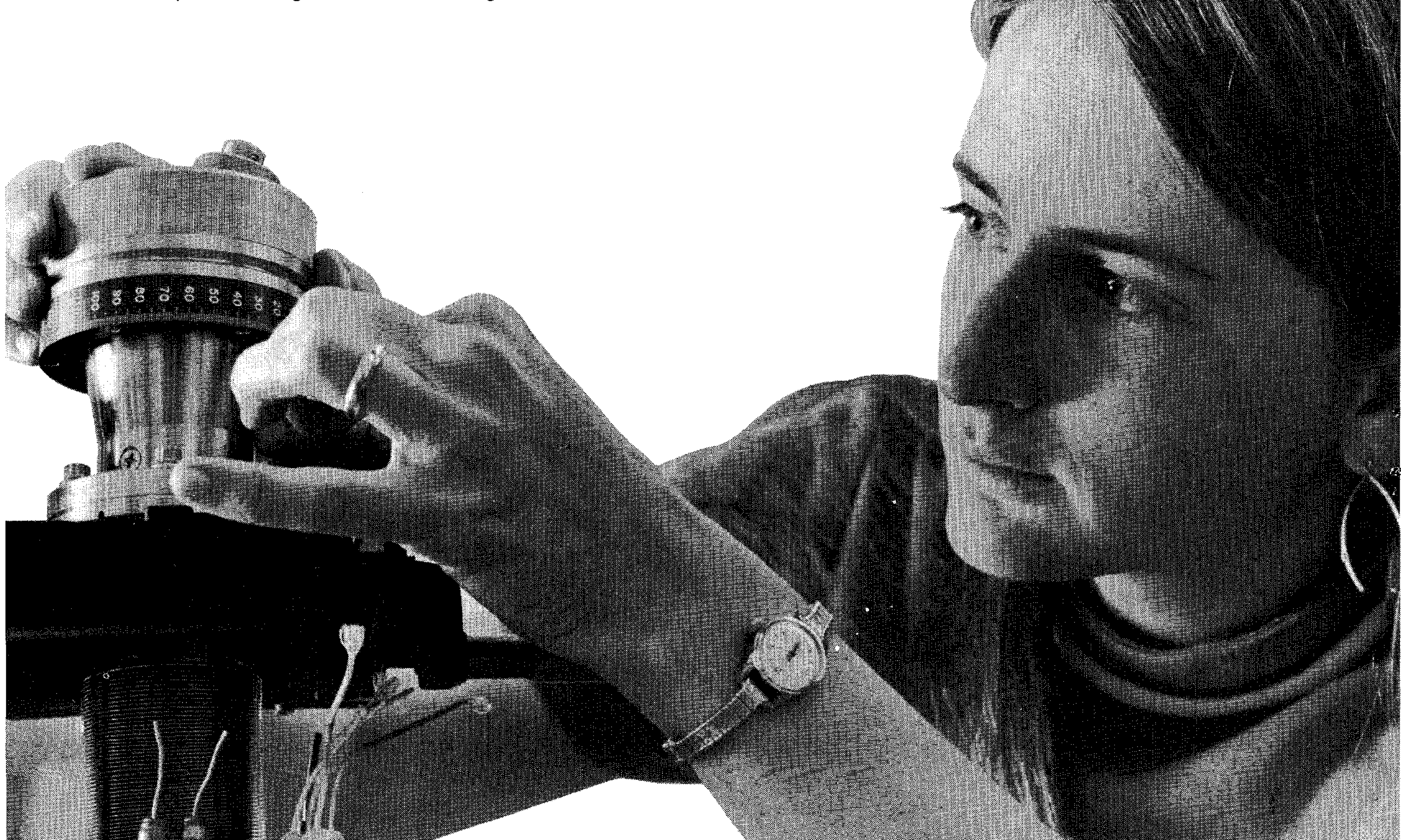
Sue is studying how crystal and thin-film semiconductors interact with light. Using special high-vacuum equipment and an electron gun built to her specifications, she has been bombarding such materials as gallium phosphide and gallium arsenide with electrons. Then she examines the change in electrical current as the surface reacts to light. Data from these experiments are used to analyze the behavior of semiconductors under development at several Bell Labs and Western Electric facilities.

Sue's research today may yield important practical benefits tomorrow, such as cheaper, more efficient solar cells, or improved light-emitting diodes, lasers and detectors for lightwave communications — a new technology in which phone calls and other information can be carried as pulses of light over hair-thin glass fibers.

A native of Arlington, Va., Sue came to Bell Labs in 1974 with a BS from Brown, and MS and PhD degrees from Cornell — all in chemistry. She is one of many Bell Labs people helping the Bell System meet the telecommunications needs of the future.

Bell Labs

From Science: Service



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College__________ Major__________ Graduation date__________
High School__________ Graduation date__________

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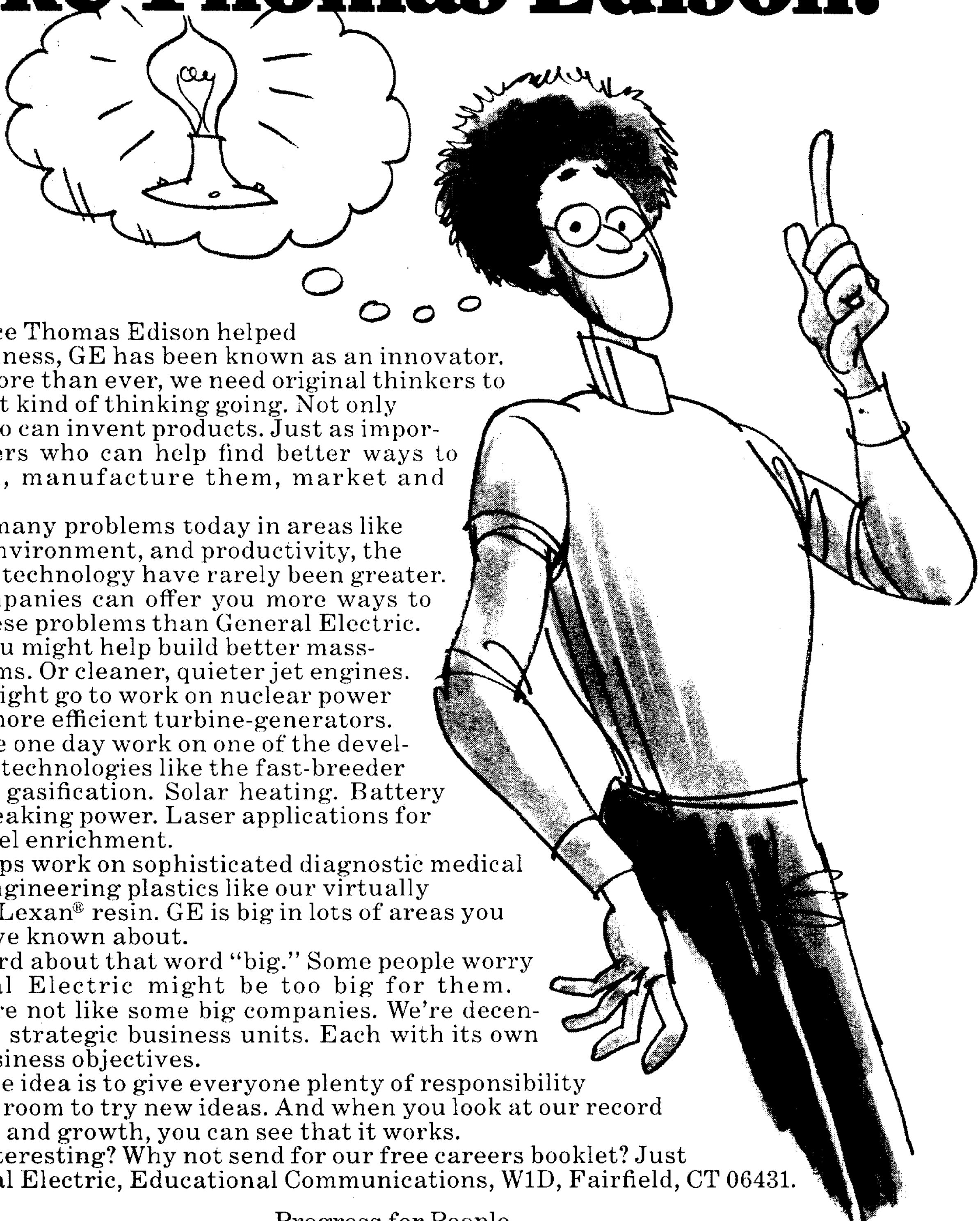

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