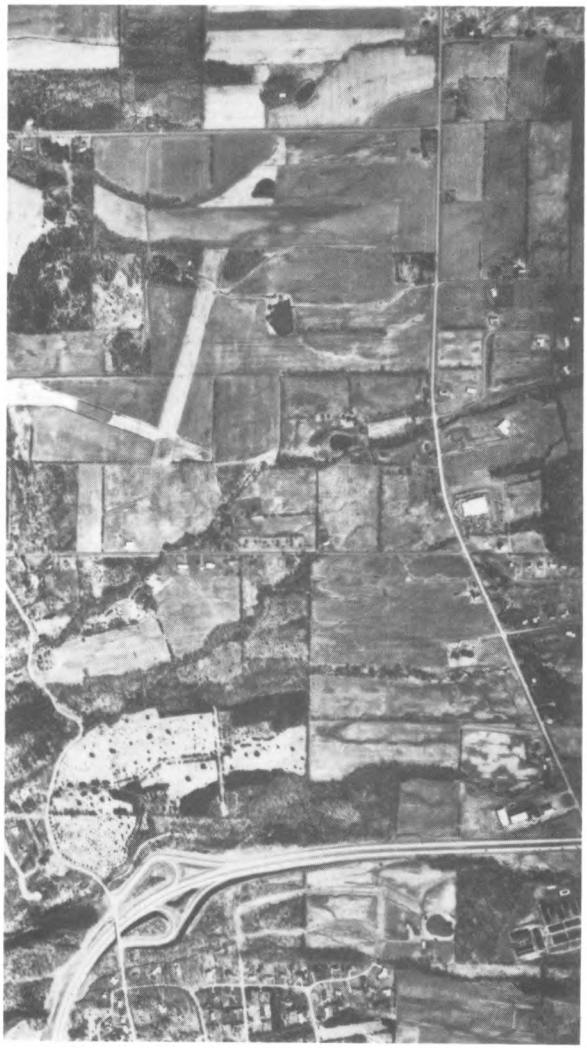
VISIONARY PATHWAYS



c. 1968

THE PAST AND FUTURE OF AGRICULTURAL BIOTECHNOLOGY

Some time ago, at about the same time that I was invited to speak at this meeting, I read an article about the invention of agriculture. It was a report on the work of a team of archaeologists at Yale, who believe they have pinpointed the origin of agriculture in time and space: about 10,000 years ago, at the north end of the Dead Sea. This area had already been identified as the location of an unusually advanced civilization. People had been gathering grain there for a long time. But then they made the transition—and this must be one of the great transitions in the entire course of human evolution—to planting grain and cultivating it.

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The interesting part of the story is why and how they did this. According to the Yale archaeologists, the civilization—which they call the Nataufian—was an unusually stable one for the time. The people were no longer merely nomadic hunters and gatherers. They had well-built houses and a sophisticated social structure. They knew how to harvest wild wheat and barley with flint sickles, and they processed the grains with stone mortars and pestles. They supplemented their grain diet with meat from deer and other wild animals.

Then the climate changed, as climates do. Summers in the Jordan Valley region became hotter and more arid. Some of the water sources dried up, and people began to congregate around the larger lakes. Summer droughts damaged game habitat and shortened the growing season. So there were food shortages, and migrations of displaced people; all the classic symptoms of a civilization on the verge of collapse.

But this civilization did not collapse. The crisis also presented an opportunity. Although the transformed climate was tough on the perennial plants, it favored the annual species of wild grains and legumes—the ones that completed their life cycle in the late spring, left big seeds that could survive the summer drought and germinate at the beginning of the next winter growing season.

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Probably the Nataufians already understood the mechanics of this process, and it was a logical step to begin to help it along—make it more dependable and productive—by saving seeds in the summer and planting them at the start of the wet season. And so began the ancient rhythms of agriculture, with times to sow and times to reap.

Agriculture was probably invented many times, by different people and in different places. But I found this article fascinating and revealing in many ways; it tells us something about where we all came from and if we look closely, it also can tell us something about where we are going.

The beginning of plant sowing and harvesting was also the beginning of plant breeding. The archaeologists believe it was easier for people to harvest certain grain plants—mutants with larger seeds, with tougher connections between seed and stalk that made the seeds less likely to scatter when people gathered the stalks and carried them to storage areas. In as few as 22 years, according to one hypothesis, the cultivated fields may have been taken over by the mutant varieties. So when the course of evolution changed for the human species, it changed for other species as well.

Agriculture then spread northward into Turkey, and eventually into Mesopotamia. As it did, it led to ongoing waves of change. Landraces of cultivated crops evolved. People cleared out weeds and altered animal habitat. Eventually they invented irrgation, which launched another round of effects on soil and water systems—and probably on the local climate.

About a thousand years later—at least according to the source I am citing here—people started domesticating animals. And of course that brought its own series of environmental and evolutionary consequences as people got into selective breeding, and battled predators, and altered ecosystems. Some of the ecosystem changes were deliberate—such as when people cleared trees to create savannas for grazing animals. Some were accidental—such as what resulted when people began to move herds of animals outside of their original habitats. If you have ever watched a grazing herd of sheep or goats, you know what I mean about ecological impacts.

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I am getting away from the Nataufians here, and I will return to them in a minute. But first, let us pull back the camera and take a quick look at what is generally known about the links between the development of human civilization and impacts on what we might call nature. We see homo sapiens emerging

as a distinct species and migrating all around the globe. Why? Because human beings have a superior ability to adapt to a variety of ecosystems. How do we adapt? We adapt by inventing new techniques of survival, such as agriculture and we adapt by modifying ecosystems to suit our needs. Every living thing, even the humblest lichen on a rock, modifies its environment. But no species comes anywhere close to homo sapiens in terms of environmental impacts. We are, as Isaac Asimov once put it, the environmental modifiers par excellence.

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Human beings moved about the globe and moved plants and animals about the globe. Rice, corn and wheat became world citizens, and so did Holsteins and Herefords. The world changed.

A lot of those changes took place in prehistoric times and we do not know that much about them. The transformation of North America took place more recently, and it is very well documented. I started poking into this subject some years ago when I was writing a textbook on American government and discovered in my researches something that I had not understood before about our history—something that fascinated me so much I later wrote a book about it. The discovery, simply put, was that the American colonists not only established a new society and a new government here, but in the process rebuilt the continent into something more suitable to their purposes. They imported plants and animals. They battled native weeds and predators. They cleared forests. They changed waterways. They dredged harbors. They built canals. They laid out roads. The single item that intrigued me the most was that the Mayflower had not only human pilgrims aboard, but also pigs and sheep and cattle—and a few stowaways, like dandelions in the food larders and moths in the woolen clothes. So there are pigs, weeds and bugs whose ancestors came over on the Mayflower. And practically everybody contributed to this rebuilding effort in some way or another. It expressed a great social consensus about what needed to be done.

And when people went west, the wave of change rolled across the continent with them. We have American myths to commemorate Paul Bunyan clearing the native forests and Johnny Appleseed planting immigrant trees.

Here in California the ecological transformation proceeded with tremendous speed after the Gold Rush. Undoubtedly the Indians had made their own imprint before that—do not believe that stuff about Indians having no impact on nature—and so had the Spanish explorers. They accidentally brought in grass seeds that established themselves well here, and they also brought, as a food supply, snails whose descendants are at this very moment chewing at the

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vegetables in my backyard. Thousands of people came to California. Miners dug in the mountains and washed away tons of soil with hydraulic mining devices. They hunted game and put some native species, such as the California grizzly, on the road to extinction. People built towns and cities, cutting trees to build them. Herds of cattle and sheep were brought in to feed the fast-growing new population. So it went, and so it goes.

Now, the things I have mentioned here are just a few examples of what has been going on as long as there have been human beings on the earth. Wherever human beings live, the environment changes. As human populations grow and their technologies become more advanced, the changes happen more quickly.

We are living now in the midst of the fastest and farthest-reaching ecological change in human history. Populations growing and expanding into areas that used to be wilderness. Plants and animals moving about the planet. Species extinction and genetic erosion proceeding at exponential rates. Tropical forests being cut down. Aquifers being depleted. Pollutants being dumped into the rivers and the oceans.

You have no doubt noted that I started out talking about agriculture and am now talking about the environment. When did the subject change? It didn't.

Agriculture, civilization, environmental change and environmental problems are all part of the same process. Call it human evolution. For a long time, people developed agriculture and civilization without paying much attention to the environment part. The environment simply did not exist as a concept for ancient peoples—even people of a few decades ago—in the way it does for us today. Eighteenth-century political philosophers such as Montesquieu talked a lot about "climate," which meant roughly the same thing as "environment" but what they were mainly interested in was the question of how environment affected civilization, what kind of an environment was most likely to become the basis for an advanced society. They did not have much to say about the civilization affected environment. The news had not yet begun to come in.

In the middle of the last century, a great and original American scholar named George Perkins Marsh wrote a book entitled *Man and Nature,* or, *Physical Geography as Modified by Human Action.* It summarized a great number of separate papers and reports that had been written up to that time—Marsh read twenty languages—about the impacts of ordinary human actions such as farming, logging, fire, converting land to agriculture, modifying waterways, domesticating plants and animals. It was a blockbuster of a book. It made a profound

impression on many people, both in the United States and Europe, and in a way it is still making an impression. Marsh was not a back-to-nature man, he did not say that people should go back to being hunters and gatherers. He merely reported on the impacts—but because most people had never thought systematically about those impacts before, the news it brought was most unsettling. Marsh is generally regarded as the source and inspiration of the early conservation movement that eventually came to be associated with such people as Theodore Roosevelt and John Muir, and it would not be stretching things at all to call him the grandfather of the modern environmental movement.

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Nowadays just about everybody is an environmentalist, and everybody has his or her idea of what environmentalism is about. Some people say it is about preserving wilderness. Some people say it is about conversing resources. Some say it is about spirituality. Some say it is about Gaia. I submit that what environmentalism is basically about is feedback. It is about information. It is about the discovery, a fairly recent one, that what we call by various names such as human cultural evolution, civilization, or progress have impacts on nature. That is what gave rise to environmentalism to begin with, and that is what is going to produce a lot more of it, because both impacts and feedback are on a strong growth curve.

A lot is being written and said these days about the impacts, and I will merely summarize briefly. First, human population is growing at a rate that would have been utterly unthinkable to most people in Malthus' time—but probably not to Malthus. We add well over eighty million people to the world's total population every year. Every year—to put it another way— the world faces a situation that is significantly different, by over eighty million people, from any situation it has ever faced before. Many of the major environmental problems that I mentioned above are getting worse very rapidly. We are making some headway in a few areas, such as cleaning up some American waterways, but unfortunately most of the major environmental problems in the world are quite out of control.

Secondly, at the same time that our human numbers and our impacts on the environment are increasing, our science and technology of environmental information-gathering and information-processing is improving tremendously. People are putting together new information-gathering organizations such as the International Geosphere-Biosphere Program, using new technologies such as satellite monitoring. In many ways, getting much, much better at getting feedback. This, too, can be expected to continue to grow and develop and

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change the ways we act and think.

It is worth noting that the environment is almost entirely dependent for its importance as a political issue on abstract information. If you stop to think about it, you will notice immediately that most of what we worry about and argue about in relation to environmental deterioration has to do with data and interpretations of data, news reports, projections and scenarios of the future.

At the top of the list of these environment-information worries is the greenhouse effect. It may well be the most important crisis the human species has ever had to deal with, but where is it? You can not walk out your door and feel it or see it. All our concern is based on projections and scenarios. The late Professor Walter Orr Roberts of the University of Colorado, who was my main source of information when I started looking into the matter, summed it up concisely. He said the buildup of CO_2 and other greenhouse gases in the atmosphere is scientific consensus; there is not much controversy about it. But there is no such consensus about whether the buildup will lead to a global climate change or what that change will be, or whether it has begun. Roberts said that the 1980s were the hottest decade since the invention of the thermometer. He also said that the difference was within the range of what could be called normal fluctuation. We do not know.

Roberts was one of the first scientists who made a specialty of looking into the possibility of global climate change, and he thought we were in the early stages of a warming trend caused by the greenhouse effect. So you might class him among the pessimists, but he was fairly optimistic about our prospects for coping with it. He never tired of pointing out how adaptable human beings are.

It seems to me that if you put all the pieces together—not only the indicators of global warming but also the data and projections we have on such matters as population growth, species extinction, soil erosion, aquifer depletion and deforestation—it adds up to a strong reason for believing that global conditions are going to be quite different in the years and decades just ahead of us, even if we can not say precisely how they will be different.

Up to this point I have said nothing at all about biotechnology. But as we all know, it is moving rapidly also. Perhaps not as rapidly as some people expected, but there is no doubt that we are looking at a full-scale scientific and technological revolution. I am on record as having said and written that the Biological Revolution will turn out to be as momentous as the Industrial Revolution, and I have seen nothing to make me change my

mind about that. And I do not see any likelihood at all that that revolution will unfold separately from the large-scale global environmental and developmental concerns I have been summarizing here. We are entering a period of global crisis, and we are going to find it necessary to mobilize all of our resources—definitely including our scientific and technical know-how—to deal with it.

With that somewhat sobering thought in mind, let us go back to the Nataufians. The article I mentioned described their innovation as the result of a "convergence of accidents." Four seemingly separate elements happened to be present at the same time—genetic resources, technology, social organization and need.

The genetic resources were available wild grains. The technology was the Nataufian's knowledge of how to harvest and process grain. The social organization was essential. Had they been a more primitive nomadic society, they probably would not have been able to organize the labor and the distribution of food. And need. They were in a time of crisis and they knew they had to do something.

So they invented agriculture. Is it possible to compare our present situation to that of the Nataufians? Yes. It is always dangerous to make historical connections of this sort, especially over a span of ten thousand years, but it is even more dangerous to fail to learn from history.

We can construct a plausible scenario of the near-term future that is based on a convergence of the same four elements. Genetic resources, technology, social organization and need. Genetic resources that can be adapted to new uses. Technology—biotechnology—that makes it possible to do that. A social structure that supports research and development. And need—a crisis situation, such as global climate change combined with overpopulation and other environmental stresses, that makes improvisation necessary. A situation roughly comparable to that of the Nataufians. This time, the response is not the invention of agriculture, but a great range of more effective ways to utilize biomass to produce food, fiber and energy.

Some such future situation is quite likely to unfold. But we should note that each of the four necessary elements may not be up to the occasion. The loss of genetic resources, as you all know, has become a serious international issue in recent years. Our technology and social organization may not be ready. Even the matter of need is in some ways problematic.

The Nataufians were dealing with a situation that was already present. The

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need was visible and they saw it around them. If the scenario that I am suggesting here is to become a reality, in any way that makes it a success story and not a global tragedy of a scale we have never before seen, it will have to be based on a response to anticipated, rather than present need. The consequences of not being ready, not being able to respond to the situation in time, are likely to be disastrous. When Walt Roberts and I were discussing this, we talked about the fact that, up till now, human adaptability has been a matter of dealing with environmental conditions that already existed. The human species has so far has not shown much ability to anticipate.

So there is serious doubt as to whether the "social organization" part of the scenario is really up to the challenge. Our political system is not famous for long-range planning. Our economic institutions are mainly keyed to need expressed in terms of market demand—either already existing or likely to exist soon enough to justify capital investment.

Another thing that makes us different from the Nataufians is that we know about environmental impacts. We do not know how to predict them too well, but we have every reason to believe that any large-scale transformation of agriculture such as the one I just suggested would also have many secondary and tertiary environmental impacts. And this concern about environmental impacts has a lot to do with how we make progress in science and technology.

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Biotechnology is unique in having evolved within the environmental era. The work that produced the first successful recombinant DNA took place in the early 1970s, and the public started hearing about it a year or two after the first Earth Day and the United Nations Stockholm conference—events that mark the beginning of the modern environmental movement. Much of what environmentalists have to deal with involves the results of technology—cleaning up the effects of the Industrial Revolution that people either did not know about or swept under the rug—and so it is hardly surprising that there is a strong anti-technological bias to the environmental movement.

I doubt that environmentalist concerns about biotechnology are likely to diminish or disappear. They will be around for several reasons. One reason is that some people have made a career out of frightening people about biotechnology and would be lost without it. Another is that some people have made a religion out of being frightened and are no more interested in letting go of their scenarios of biotechnology on the rampage than right-wing true believers are interested in letting go of their scenarios of global communism on the march.

And a third reason is that there are excellent scientific reasons for being concerned about adverse ecological impacts from genetically modified plants or animals or microorganisms. I expect and hope that organizations represented here, such as the Environmental Defense Fund and the National Wildlife Federation and the Sierra Club will continue to demand adequate risk assessment and regulation. So I do not think a get-out-of-the-way-and-let-us-save-the-world argument is going to prove to be very persuasive with environmentalists—especially if your idea of saving the world turns out to be developing herbicide-tolerant crops.

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And on the other hand, a lot of people are more interested in biotechnolog's ability to deliver than they are in the possible adverse consequences. We have seen, in the case of AIDS, tremendous pressure put on the scientific -industrial establishments to come through with a vaccine or a cure. Many of you are probably familiar with the book *And The Band Played On,* which is a powerful and angry indictment of the medical-research establishment for failing to move more vigorously against AIDS. If the kind of global environmental crisis that I have described begins to become inescapably obvious and not just a matter of academic debate, you can expect to hear a great clamor to mobilize science and technology to deal with it. Environmentalists are suspicious of technological fixes, but the general public has no such reservations. Technological fixes will do fine. They will not only be tolerated, they will be demanded.

This means that agricultural biotechnology will find itself in the exciting but uncomfortable position of being pushed and pulled in different directions at the same time—asked to solve the world's problems while simultaneously being accused of getting ready to cause perhaps worse problems.

Some years ago, in his book entitled *Broken Code: The Exploitation of DNA,* Marc Lappé said that biotechnology occupies a "special moral position." I think he was quite right. And it is not entirely pleasant to be in a special moral position. It means that people ask a lot of you, and hold you accountable in different ways.

You are in a special moral position, you who are in the process of creating agricultural biotechnology. Rather, I should say we are in it—all of us who are in some way taking part in the dialog in whatever role, whether as scientist or industrialist or critic or regulator. If in the future somebody writes some book like *The Band Played On* about agricultural biotechnology's failure to anticipate and respond to the world's needs in a time of ecological and developmental crisis. I

You are in a special moral position...

do not think the anti-biotechnology crusaders are going to come out of it looking any better than the alleged mad scientists.

How to respond to this moral challenge? There are many things that need to be done—and many things that people are already doing. For environmentalists, it means dropping the "Great Satan" view of biotechnology and putting our risk-assessment and regulatory concerns in the context of a policy that actively supports research and development. The Ecological Society of America did this in its 1989 paper on the environmental use of genetically engineered organisms. The World Resources Institute did this in an excellent recent report entitled *Transforming Technology,* which explored, among other things, the compatibility between biotechnology and "alternative" or "sustainable" agriculture.

A lot of people in the environmental community have bought into a polarizing and, I think, foolishly oversimplified idea that the world is either going to move toward a future of "alternative" or "sustainable" agriculture that is easy on the environment and helpful to the disadvantaged, or toward a mechanized and expensive high-tech agriculture that is resource-wasteful, polluting and of benefit only to big-time agribusiness. Personally, I think we are going to find agriculture becoming as pluralistic as the rest of society, with a vast range of techniques and no clear either-or. The World Resources Institute report speaks to this when it describes high-tech agriculture that is resource-thrifty and ecologically sound. "Farmers of the next decade may grow genetically engineered disease-resistant soybeans on one conservation-tilled field while monitoring real-time soil moisture data from a nearby insect-resistant cornfield and analyzing feed requirements for their cattle by computer."

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There are many ways that biotechnology can contribute to the needs of small farmers in economically disadvantaged areas. But if that comes about it will be because people in agricultural science and industry direct more of your energies toward environmental concerns and Third World development—even toward projected needs—as well as toward the commercial possibilities in Western developed countries. This is the challenge to the other side, and there are many ways to meet it. *Pro bono* research, for example. New courses and research programs and even special institutes in the universities. More support for federal agencies such as the Agency for International Development and for international initiatives such as the U.N.'s International Centre for Genetic Engineering and Biotechnology, which the U.S. government has studiously and deliberately neglected.

There are a lot of ways that environmental and public interest groups and universities and biotechnology industries can work together—even while we continue to argue about the safety of bromoxynil or the impacts of genetically modified microorganisms—to advance the general human and ecological well-being we all claim to be concerned about.

There are a lot of ways that environmental and public interest groups and universities and biotechnology industries can work together.

Perhaps I am overstating the urgency of the whole situation, maybe it really is not—and is not about to become—as serious as I have indicated. So let me sketch out some alternative futures.

In closing, I will briefly describe three scenarios of change that I constructed for a conference of planning officials in Hawaii two years ago. You can pick the one that seems most plausible to you.

The first scenario I called "Business as Usual." In this history of the future, instabilities resulting from environmental disturbances, population growth and the needs of developing countries are minimal. Assumptions about economic growth, international development and human progress remain essentially the same as they were during the post-World War II era.

In the second scenario, entitled, "Disturbance and Adaptation," there are serious global environmental challenges, including warming as a result of the greenhouse effect and they are met by a range of reasonably successful responses—including responses based on advance planning. There are costs and changes, but we rise to the occasion.

The third scenario I call "Chaos and Conflict." It shows environmental changes too great or too rapid to be handled, with consequent breakdown of social and political order. One likely result would be new terrorist or revolutionary movements, as environmental concern escalates into environmental fanaticism.

Fill in these outlines with whatever information you have, and take your choice of which you believe is the most likely. Most of my remarks have been based on my own expectation that the future will be somewhere in the margins between the second and the third scenario, between the "Disturbance and Adaptation" future and the "Chaos and Conflict." In fact, as I see it, that is where we are already. I often quote as my favorite futurist the ex-Kansas City Royals reliever Dan Quisenberry, who once said, "The future is just like the present, only longer."

Now I realize that there are all kinds of pressures and demands on all of you—what we might call real-world considerations—that make it impossible

for you to be completely preoccupied with the sort of concerns I have been talking about here. I understand that, and I am not here to ask you to quit your jobs or drop your present research programs, or ignore the interests of your stockholders. All I want to say is that the world I have been talking about—the one with 5.4 billion people on it, with eroding soil and depleted aquifers and disappearing forests and polluted water and a climate that may well change significantly in our lifetime—that is the real world and it can neither be ignored nor separated from all of the other things we do.

Sol suggest that we look for ways to show we know that and to find ways to make that awareness a visible and integral part of our work—whatever our part in the Biological Revolution may be. And I think that if we do, we may be able to cut through some of the conflict that has held us back and that biotechnology will progress and flourish and be seen in the future as one of humanity's great accomplishments—as I sincerely hope it will.