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Microorganisms, the Environment, and Private Research and Development

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Suppose that there were no microorganisms. Suppose that the Earth was populated only by the multicellular macroorganisms which—somehow—were chemically degraded, upon dying, to keep the life cycle going. We would still be interested in trying to explain the life processes and in applying this knowledge to solving problems of food, clothing, health, shelter, and pollution. Given this scenario, if someone were to announce the invention of a machine, only one cubic micron in size, which performs the fundamental biochemical reactions of life, his discovery would out-strip the transistor, electronic chips, or the laser in importance. Even before the Nobel laureation ceremonies had been conducted, scientists and engineers would be busily elaborating the findings and putting them to work to solve many problems in the areas mentioned above.

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Yet, in our real world, we already have just such a marvelous invention. Not only do these tiny machines perform the range of biochemical reactions, but, miraculously, they reproduce themselves and are readily grown and maintained in myriad quantities. Furthermore, their rates of activity are easily controlled, they operate under a wide variety of environmental conditions, they have ingenious feedback mechanisms for coping with sudden changes in their environment, and they can be stored indefinitely if desired. Where, then, is the plethora of their practical application to solving man's problems?

It is true that microorganisms have been put to important uses, but, unlike the physicists and electronic engineers, the biologists and bioengineers are not exploiting the potential of their devices. Perhaps this is because of the "NIH theory" (Not Invented Here), which dims their enthusiasm. But, for whatever reason, this is a condition which should not and cannot continue.

Obviously, the bioengineer is at a disadvantage compared to the electronic engineer in that, because the former did not invent his marvelous little machine, he cannot fully understand or control it. Considerable fundamental research by the biologist is required to attain such insight. As we all know, fundamental research does not fare well in today's nearsighted philosophy of research priorities. Here, however, the microbiologist is better off than many of his scientific colleagues, because it is hard to imagine fundamental discoveries in microbiology which cannot quickly be applied to

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problem solving. However, a reason frequently cited for favoring a physical or chemical approach over a biological one in solving a particular problem is that "biological vagaries" make the biological processes less dependable. And, indeed, all of us have been frustrated with the experience of setting up "replicate" microbial experiments and observing disparate results. But, unless one wishes to yield his faith in science, such "vagaries" are the result of real differences and are testimony to our poor understanding of the machine we did not invent. Any fundamental research improving our knowledge in this area cannot but have direct application to removing the vagaries.

It is because of the almost immediate transition possible from discovery to application in the field of microbiology that the traditional interface between university or institutional and private research is less distinct than in most other areas of science. This is desirable, in that the more closely research and development are coupled, the quicker will be the practical "payout." Thus, the role of private research and development seems to be very large in the forthcoming "biological era," an "era" which is now hard upon us.

Food products and beverages constitute the oldest application of microorganisms to meeting man's needs. But these products today are mostly the result of art, not science. This is not to say that we are dissatisfied with the wonderful breads, cheeses, wines, and beers we now enjoy. Rather, science should now build on this microbiological art to bring us new foods and condiments. In the 1950's, there was much talk concerning the imminent use of algae for human and animal food and dietary supplements. In the 1960's, attention was focused on the production of edible bacteria from hydrocarbon substrates. In the latter decade, considerable progress was also made in tissue culture techniques utilizing unicellular inocula. The ability to grow complete vegetables from such inocula was demonstrated. Here the development extends microbiological techniques into the macrobiological world, in that the unicells develop into large organisms. In either event, the techniques are largely microbiological and may eventually lead to culture production of only the edible tissues of plants. In most of these areas, the remaining problems to be solved are more technological than scientific, indicating that some forceful development work could result in improved and new industrial applications of microbiology. The projected world food situation argues strongly for a concerted effort.

One of our national problems is sewage disposal. For about a century now, microorganisms have been haphazardly applied to achieve the biodegradation of domestic wastes. The microorganisms used are those present in the influent sewage, and little is done toward deliberate selection from among these organisms or toward the control of their environmental conditions. At best, the microorganisms operate under conditions which permit an efficiency of only several percent. Nonetheless, they do a remarkable job and are the mainstay in providing the sewage treatment currently given to our waste waters. Relatively minor research and development efforts could probably effect significant improvements in the amounts of sewage which can be treated and the effectiveness of treatment.

Not only can microorganisms rapidly consume large quantities of organics, but they can also remove eutrifying nutrients from waste water to combat uncontrolled algal growth in our lakes and estuaries resulting from sewage pollution. However, because the necessary microbiological research and development have not been undertaken, chemical methods are the only ones now being widely considered for such processes. The chemical methods are more costly and frequently result in added pollution of our streams with the chemicals themselves. However, the chemical engineers and chemists have been more aggressive in this area than the biologists and bioengineers.

The environmental problem complementary to that of sewage disposal is the provision of safe drinking water. In the past, the treatment of drinking water has been limited to physical and chemical methods. However, as man has been forced into ever-tightening environmental cycles, biologically treated sewage has already been used as the total or partial source of raw water for processing into potable water. Thus, the process of sewage treatment becomes inseparable from that of the production of potable water. Microbial engineering, therefore, will play an increasing role in water production.

Some effort has been devoted to utilizing microorganisms to desalt seawater. Studies have shown that "sodium pumps," operating through cellular membranes, can attain efficiencies closer to the thermodynamic minimum required for removing salt from seawater than can purely physical or chemical processes. To date, however, very little has been done to harness these cellular mechanisms of sodium ion transport. The need for fresh water for domestic, industrial, and agricultural purposes is increasing at such a rapid rate that considerable effort should be expended to understand the ion transport mechanisms for the development of synthetic analogues or for the direct application of microorganisms toward this end.

In addition to pollution of our hydrosphere, we are faced with overwhelming pollution of our atmosphere. An important aspect of the air pollution is the sulfur content of fossil fuels which, upon burning, release noxious sulfur oxides to the atmosphere. Microbial techniques offer promise for removing sulfur from fossil fuels and, possibly, economically recovering sulfuric acid. In essence, this would involve harnessing microbial processes which oxidize the sulfur in coal deposits and give rise, in that instance, to acid mine-drainage problems. Microorganisms may also be useful in removing air pollutants from stack exhausts or in synthesizing more manageable, or even useful, products out of such pollutants. Recent research concerning the ability of vegetating seeds to remove a wide variety of pollutants from the atmosphere raises the possibility of a similar role for microorganisms. Just as the high surface-to-volume ratio of microorganisms makes them useful for treating sewage, the same characteristics may lend them advantages in cleaning up polluted air bubbled through aqueous cultures. Nitrogen-fixing bacteria offer elegant testimony to the ability of microorganisms, infinitesimal as they are individually, to handle almost infinite volumes of gas collectively.

Another major environmental task for microorganisms may be imminent in the area of solid waste disposal. The composting art has developed to the point where appropriate research and development might make cellulose reactors feasible for disposal of solid wastes from farms, animals, municipalities, and industries. Such applications could extend to reprocessing as well as final disposal of cellulose products, one of the major components of solid wastes.

The demonstrated ability of microorganisms to concentrate large amounts of inorganic and organic chemicals from sewage, water, air, and soil raises the possibility of a new technology based on bioaccumulation. Specific molecules might be concentrated for purposes of pollution control or industrial production through the use of microorganisms. The organisms might be harvested and processed for recovery of the product, or they might be removed from the mother liquor, induced to yield the product in more concentrated form, and be returned for another uptake cycle.

The fields of antibiotics and chemotherapy already represent a major microbial industry. Discovery of active agents has been empirical and has plateaued in recent years. However, as relationships between structure of the agents and their metabolic functions are correlated, and their mechanisms of action become better understood, additional major discoveries in preventive and clinical chemotherapy will occur. Concomitant developments in microbiological control will make possible the directed synthesis of the desired compounds.

In addition to processing pollutants or producing food and chemotherapeutic agents, microbial techniques have yet another highly important role to play—that of achieving microbial quality control of materials consumed or contacted by humans. Methods for monitoring microbial quality of sewage, water, foods, and drugs have been of historic rather than protective value. Thus, the quality of the water we swim in or drink is not known until after the fact. The same is true of many consumables where it is impracticable to retain the products until the time-consuming microbiological tests can be made. With standard microbiological detection methods, 24 to 48 hours or more are generally required before a product can be pronounced safe for consumption. New and much faster techniques already exist, but they have yet to be applied to the problems. Appropriate bioengineering development could immediately improve the public health protection afforded drinking water, swimming pools, beverages, frozen foods, prepared foods, drugs, and cosmetics. Many of these techniques have been developed under support from the National Aeronautics and Space Administration in its project to detect extraterrestrial life. Similarily, the space program has sponsored the development of numerous contamination control methods for consumables and products which come in contact with humans. The techniques are also applicable to the control of habitable space to reduce the spread of infection. In the manufacture of some products, application of these techniques is already in effect, but broader, more significant applications in the field of public health lie in the immediate future.

In addition to the use of whole microorganisms, cellular components will play important roles in solving environmental problems. Some of the applications of research and development in this area would include the use of immobilized enzymes for the promotion of specific biochemical reactions or sequences of reactions. Large-scale syntheses of complex commercial preparations or the destruction of pollutants in water, sewage, or air may be achieved in this fashion. Immobilized enzymes will also find use in the continuous assaying of wastes or products for specific compounds. Such techniques will be applicable to product quality control, pollution control, and public health measures, in addition to the clinical medicine assay techniques currently employed.

Some of the most perplexing mysteries of the cell which, when completely elucidated, will have far-reaching application are those of the structure and function of membranes. The synthesis of artificial membranes which function analogously to natural membranes will be applied to production problems of separation and treatment. Sewage processing, potable water production, saline water conversion, and the manufacture of pharmaceuticals will benefit. Ion-specific membranes not found in nature will be synthesized. Prior to these developments, considerable application of natural membranes may be anticipated.

Intact, isolated chloroplasts and mitochondria, when these can be maintained in pure "culture," will constitute highly concentrated "metabolic reactors" and will be useful in combatting water and air pollution. These organelles may also be efficient producers of food or dietary supplements. Being highly responsive to their environment, they might also serve as sensors for feedback and control of industrial processes.

The use of real or analogue nucleic acids and proteins for information storage in computers is not beyond the realm of speculation. The ultra-miniaturization which these polymers might provide may be offset, however, by their relatively slow switching speeds compared to electronic devices.

In terms of ultimate developments, genetic engineering looms most prominently. Manipulation of the genetic code through transduction, microsurgery, gene pooling, or complete synthesis and introduction of nucleic acids will make possible the creation of microorganisms for specific tasks. Microorganisms highly efficient for the production of food, a wide variety of products, energy storage, and waste treatment will be developed. The techniques learned will permit the creation of new forms of macroorganisms designed for specific tasks. By-products along the way may include intensive development of bionics and biomachines, in which parts of living organisms and parts of machines are grafted together to achieve special functions. Meanwhile, it is not impossible that the discovery of extraterrestrial life may make useful microorganisms directly available to use or may yield knowledge to hasten the development of genetic engineering.

Undoubtedly, much of the preceding sketchy crystal-balling will prove inaccurate. However, one thing is certain. The error lies chiefly in conservatism rather than fancy. Man's actual progress in science and technology outstrips his predictive imagination.

Fantastic progress in physics and chemistry will continue, but biologists, and microbiologists in particular, are about to have their inning. And they are in the unique position of having what is tantamount to the ultimate machine already invented for them. Despite this headstart, however, they have not been as aggressive as the physicists and electronic engineers in exploiting the respective inventions available to them. This will soon change!

Because of the close coupling of research and development in microbiological areas of environmental control, private industry has a unique opportunity to play a major role in the "biological revolution" that this change will bring about. This augurs well for the solution of environmental problems, because small, private organizations have been shown to produce an inordinately high proportion of creative ideas and inventions. Furthermore, the resources and organizational size required for research and development in microbiology permit small groups to do significant work. This favorable position for private endeavor in no way mitigates the roles that must be played by Governmental, university, and institutional laboratories. It is to be hoped that proper programming and coordination of the public and private spheres of effort will place man in control of his environment in time to avert the various catastrophes so frequently predicted. If we are successful, much of the credit will undoubtedly go to biologists who harnessed that immortal "invention," the microorganism.