INTRODUCTION

Biotechnology is the most recent step in humankind's long endeavor to use nature's own processes to advance the human condition. The word itself joins knowledge to practice, science to technology. We might have used it to describe the emergence of agriculture, or of pharmacology, or even the training of athletes—activities that have grown from ancient roots into exotic and very contemporary forms. In each case, accumulating knowledge of nature has suggested ways of making life safer, healthier, and more productive. While biotechnology is a relatively new word with narrower connotations, it is good to keep in mind its link to the past, especially when speaking of its benefits for cultures separated from the traditions of modern science.

Biotechnology begins with the study of plants and animals, intricate and beautiful even in their smallest features. Great artists have struggled to capture the details of birds, flowers, and insects that underlie their wonderful variety. Each advance in our ability to see things at a smaller scale has brought new wonders into view, new patterns and behaviors that explain the mysteries of the larger parts. During the past quarter-century, these advances have brought us to one of nature's major milestones: We can now "see" the elemental atoms of which all normal matter is constructed. Below this level is a yawning gap to the dense kernels of atomic nuclei, a hundred thousand times smaller than the smallest atom, where a new world—an equally beautiful but lifeless world—is being explored by physicists.

Life, in other words, can be surveyed today for the first time in history throughout its entire spectrum, from the smallest to the largest scales. The tools that made this possible draw heavily from other fields of science and require large investments that normally only governments can make. The insights revealed by these tools, however, can be analyzed and exploited with relatively modest resources. That is just as well because small-scale nature is stunningly complex. We are nowhere near understanding all that we can see, and even with powerful new tools, exploring the terrain of life will consume the energies of entire communities of scientists. The territory is vast, and the mapping and developing of it are international enterprises.

This vastness of the universe of living things extends not only in numbers of species and types of organisms and the varieties of chemicals that make them function, but also to the processes of life. From the numerous systems of chemical reactions, material transport, information flow, and mechanical support at the smallest scale to the functions of organs and the behavior of organisms at the largest, the sheer volume of information required to understand even simple life-forms is staggering. It is not enough to see these things. To comprehend them requires storing a huge amount of information, retrieving it efficiently, and processing it to test ideas about causes and effects. Biology can only now produce its own technology because the technology of information has matured in our era.

Seeing small with X-ray diffraction, magnetic resonance, and electron microscopes, and *thinking big* with fast computers, gigantic databases, and wide-band transfer, are two of three ingredients that permit a "bio" technology. The third ingredient is the ability to make things happen at the smallest scale. The means of doing so are varied, and they often recruit life's own processes to execute our direction. This is an old idea, not unlike the use of bees for pollination. Today we use bacteria and viruses to carry out our microscopic husbandry. But we also use lasers and tiny probes and activated molecules whose effectiveness we learned from laborious experiment. The manipulation of matter at this scale is part of what nanotechnology is all about, and it is no accident that nanotechnology, information technology, and biotechnology are growing up together. They are convergent technologies, and they feed each other in a complex ecology of discovery, innovation, and increased human effectiveness.

Biotechnology is the application of the three ingredients to accomplish human goals. Our aim is not simply to understand disease, but to cure it; not only to consume whatever edible we find, but to make it safer, more nutritious; not just to harvest nature's random products for our manufactures, but to make them stronger, safer, and more adapted to our needs. Nature's complexity, once a barrier to these aims, is now revealed to us as a rich source of opportunities to achieve them. How we seize these opportunities for the good of humankind is what we call biotechnology. ■

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