Living Machines: Biological Technology and Pollution Control

We tend to identify "biotechnology" with genetic engineering, and especially with transgenics—borrowing a gene from one organism and stitching it into the genome of another. Back in the '90s, genetic engineers pulled off stunts like creating a rabbit that glowed in the dark using a gene from a bioluminescent jellyfish.

But because of all the hype, it's easy to forget that humble bacteria and other microorganisms are themselves miracles of evolution's own engineering, developed and refined over billions of years. Every bacterial cell is a tiny machine of incredible complexity and adaptability. It's likely that the first bacteria evolved at the bottom of the ocean, exploiting thermal energy from volcanic vents in fissures at the junction of tectonic plates.

And they're still there, as well as all through the earth's crust, living in environments as extreme as Antarctic permafrost and the superheated water of geysers. They manage to extract not only the carbon, hydrogen, and oxygen that are the building blocks of all life from these environments, but also other chemicals they need that they have made part of their metabolism—compounds of sulfur, iron, nitrogen, and more. They can do things on the nanoscale that human technologies do far less efficiently on a scale thousands of times larger. And all this is possible because of how fast they reproduce, and so how well they adapt. It even turns out that bacteria have been doing their own transgenics all this time, borrowing genes and sections of genes from each other as part of their adaptive ingenuity.

These capacities of bacteria have created enormous problems in contemporary medicine, as over-use of antibiotics has led to the selective breeding of multiple-resistant bacterial strains like MRSA. But the very same capacities give bacteria—and other microorganisms like yeasts and fungi—enormous potential in pollution control. Microorganisms can be used not only to convert harmful industrial by-products into harmless substances, or even into useful ones, but also as replacements for toxic chemicals used in production. So can substances like enzymes that the organisms produce and that can be synthesized independently.

Volatile organic compounds (VOCs) and other common compounds like hydrogen sulfide emitted as outgases by a variety of industrial processes create problems of both odor and toxicity. Nonbiological techniques for reducing these emissions include condensation, activated carbon adsorption, absorption/scrubbing, and incineration. These methods, however, all have their own major drawbacks. The pollutants are removed from the effluent, but must still be recovered (or, in the case of incineration, generate greenhouse gases in combustion); other problems include high chemical, operating, and equipment costs.

Several biologically based techniques for VOC and odorous compound removal offer major improvements over older methods. Collectively known as bioreactors, these techniques include *biofilters*, *biotrickling filters*, and *bioscrubbers*. Biofilters pump the effluent gas through loosely packed material coated with bacteria that break the pollutants down. Originally, ordinary peat, compost, soil, or chicken manure were used, but more efficient media for the microorganisms, with better surface-to-volume ratios and other improvements, have since been developed. Biofilter reactors can be arranged in series, with each filter chamber removing a different pollutant. Biotrickling filters are essentially similar but function vertically rather than horizontally, which requires a smaller footprint than basic filter reactors. A variation on trickle filtering, a well-established technique in sewage treatment, biotrickling uses a tower in which effluent solution trickles down through layers of microorganism-coated material that extract the pollutants. Bioscrubbers, as their name implies, are a bioactive version of wet scrubbing, another well-established technology for the reduction of pollutants in outgases. The bioscrubber solves two problems with biotrickling: it improves the absorption of pollutants into the liquid, and it lengthens the time the microbes have in which to consume the pollutants. It does this by collecting the discharge effluent in a storage sump before being recycled back to the bioscrubber.

It's worth emphasizing that the bacteria used in bioreactors are not for the most part genetically engineered but are naturally occurring. Biofiltration, in other words, exploits the existing "technology" the bacteria use in their own metabolism. Bottom line: The more we learn from and imitate living systems, the cleaner and safer we can make industry, and the less harmful impact on the environment.