BIOLOGICAL SYSTEMS

Cleaning with Bacteria

An early example of biotechnology at ORNL was the 1972 demonstration by Chet Francis that garden soil bacteria in bioreactors could remove nitrates and trace metals from industrial waste effluents. ORNL built a pilot bioreactor to treat nitrate wastes at the uranium enrichment plant in Portsmouth, Ohio. The Oak Ridge Y-12 National Security Complex used Francis' design for a full-scale plant to treat nitric acid wastes. Bioremediation has continued at these sites using recombinant and natural bacteria to treat wastes underground.

In 1997 lysimeter experiments, ORNL used a genetically engineered microorganism to detect soil contaminants; its controlled release into the environment at a Department of Energy site was the first to be approved by government agencies.

In the 1960s Howard Adler and associates were studying the effects of radiation on *Escherichia coli*. Some radiation-damaged bacteria died except, mysteriously, when they were grown in the presence of other bacteria. The eventual explanation was an enzyme-containing membrane fraction from those other bacteria, which removed oxygen from the media, allowing the damaged *E. coli* bacteria to recover.

Adler and Jim Copeland developed a technique for extracting and freezing these membrane fragments and using them to remove oxygen from liquid media that support the growth of anaerobic bacteria (which die in oxygen). Their technique is useful for early detection of diseases caused by anaerobic bacteria, such as gangrene and tetanus, as well as production of chemicals like butanol. In 1987 they formed Oxyrase, a company that continues to sell diagnostic media to hospital pathology and research labs in North and South America, Asia, and Europe.

ORNL and other DOE national laboratories, working with Applied Carbo-Chemicals (ACC), developed a fermentation process using a novel microorganism that converts corn sugar to succinic acid, needed in the manufacture of de-icers, food additives, solvents, and ultimately plastics. ORNL's Nhuan Nghiem and Brian Davison developed the fermentation process in a bioreactor. ACC recently demonstrated this soon-to-be commercialized process with a 100,000-liter fermentation.—*Brian Davison*

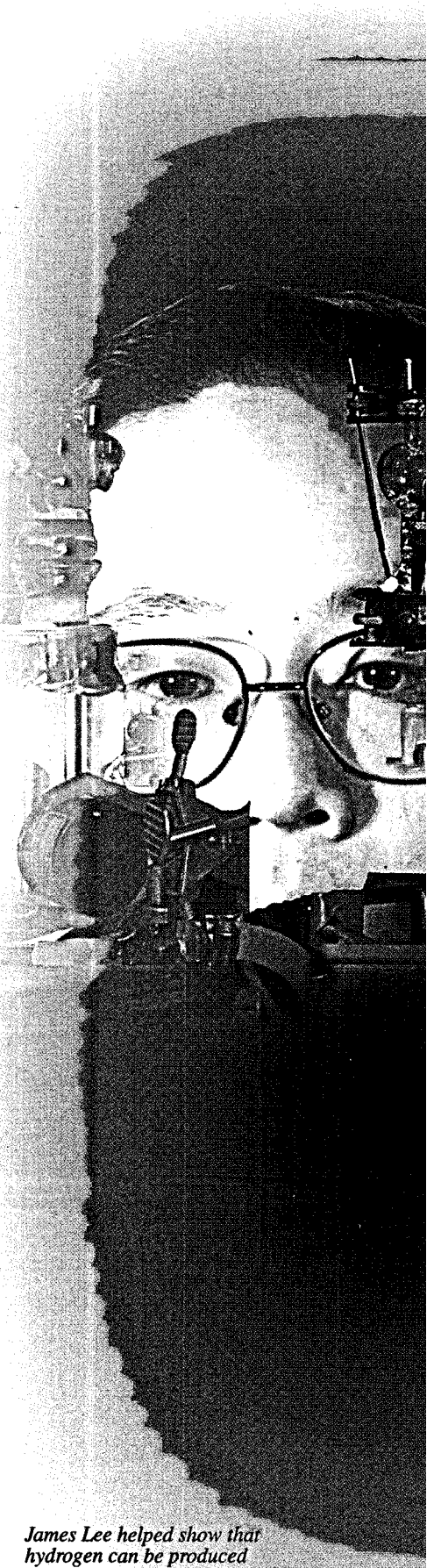
Finding the Light

Several ORNL biologists interested in studying green plant cells and radiation focused on photosynthesis. In this process, plants synthesize carbohydrates (tissues) from airborne carbon dioxide and water, using light as an energy source.

William Arnold and Robert Emerson identified the photosynthetic unit in pioneering studies that led to Arnold's 1966 discovery of delayed light, an internationally recognized fundamental discovery in photosynthesis. (Arnold also is known for coining the term "nuclear fission," used universally to describe the process of splitting atomic nuclei.) Roderick Clayton provided evidence for the electronic nature of the first step of photosynthesis.

In the 1970s and 1980s Robert Pearlstein developed theoretical models that described the migration of light energy in the chlorophyll antenna lattice of green plants and bacteria. Later in the 1980s Elias Greenbaum and his ORNL colleagues Perry Eubanks, Jim Thompson, Mark Reeves, and Ginger Tevault used photosynthesis in spinach and later algae to split water molecules to produce oxygen and the energy-rich gas, hydrogen. In 1985 Greenbaum demonstrated direct electrical contact of photosynthetic electrons with platinum metal nanoparticles; this work was featured on the cover of *Science* magazine. In 1995, Greenbaum, working in collaboration with Ida Lee and James Lee, discovered the diode properties of isolated Photosystem I reaction centers. In 2000, the continuation of this work led to the first measurement of photovoltages of isolated photosynthetic reaction centers.

In 2002 Greenbaum and his associates at ORNL and the University of Southern California investigated the use of photosynthetic reaction centers for restoring sight to the legally blind. ORNL has had only a handful of photosynthesis researchers, but they all have made noteworthy contributions to this field.



James Lee helped show that hydrogen can be produced photosynthetically by algae in illuminated water.