

quantities and, hence, reduce cost. Also, in pharmaceutical manufacture the desire to make chirally pure compounds is leading to new opportunities. Chirality is important in a product; in a racemic mixture one enantiomer is often therapeutically useful while the other may cause side effects and add no therapeutic value. The ability of enzymes to recognize chiral isomers and react with only one of them can be a key component in pharmaceutical synthesis. Processes that depend on a mixture of chemical and enzymatic synthesis are being developed for a new generation of pharmaceuticals.

Technological advances have facilitated the use of enzymes over an increasingly broad range of process conditions. Enzymes from organisms that grow in unusual environments (e.g., deep ocean, salt lakes, and hot springs) are increasingly available for study and potential use. New enzymes and better control of reaction conditions allow the use of enzymes in the presence of high concentrations of organics, in high-salt aqueous environments, or at extreme temperatures, pH, or pressures. As we couple new insights into the relationship of enzyme structure to biological function with recombinant DNA technology, we are able to produce enzymes that are human designed or manipulated (see Section 14.9 on protein engineering). We no longer need to depend solely on natural sources for enzymes.

While there are many reasons to be optimistic about increasing use of enzymes, the number of enzymes made at high volume for industrial purposes evolves more slowly. In 1996 the U.S. sales of industrial enzymes were \$372 million, and sales are projected to grow to \$686 million by 2006. The products made in enzyme processes are worth billions of dollars. Table 3.5 provides a breakdown of projected enzyme sales by industrial sector. Table 3.6 lists some industrially important enzymes.

Proteases hydrolyze proteins into smaller peptide units and constitute a large and industrially important group of enzymes. Proteases constitute about 60% of the total enzyme market. Industrial proteases are obtained from bacteria (*Bacillus*), molds (*Aspergillus*, *Rhizopus*, and *Mucor*), animal pancreas, and plants. Most of the industrial proteases are endoproteases. Proteases are used in food processing, such as cheese making (rennet), baking, meat tenderization (papain, trypsin), and brewing (trypsin, pepsin); in detergents for the hydrolysis of protein stains (subtilisin Carlsberg); and in tanning and the medical treatment of wounds.

TABLE 3.5. Industrial Enzyme Market*

Application	1996 Sales (U.S. \$ in millions)	2006 Projected Sales (U.S. \$ in millions)
Food	170	214
Detergent	160	414
Textiles	27	32
Leather	11	13
Paper & Pulp	1	5
Other	3	8
TOTAL	372	686

*Data from C. Wrotnowski, *Genetic & Engineering News*, pp. 14 and 30, Feb. 1, 1997.