BIOTECHNOLOGY IN INDUSTRY

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PREFACE

This book examines selected industrial applications of biotechnology in detail, and surveys research and development (R&D) in process design and equipment. Commercial-scale processes are described in three generic application areas: (1) proteins and chemicals from pulp and paper industry wastes, (2) single-cell protein (SCP) for human consumption from organic waste materials, and (3) high-fructose corn syrups using immobilized enzyme technology. In addition to technical, product and cost information, each process is evaluated in terms of potential improvement or modernization. A survey of unit operations (defined as process steps resulting in chemical, biological or physical changes) provides a basis for evaluating future R&D trends such as continuous operation, enzyme and cell immobilization, and reduced energy requirements for fermentation and product separation.

Biotechnology involves a wide range of industrial applications of biological processes and materials. Throughout history, fermentation has been used in producing and processing foods and alcoholic beverages. It was not until the 19th century, however, that the role of microorganisms in fermentation processes was demonstrated. Although the post-World War II growth of petroleum-based processes displaced some applications, fermentation has remained an important component of the food and pharmaceutical industries.

Today biotechnology is undergoing a resurgence in a wide range of industries. A combination of factors has led to this renewed interest in biological processes, including:

- the opportunity to replace petroleum-based feedstocks with low-cost organic substrates;
- lower operating temperatures and pressures; and
- reduced environmental hazard.

In addition, recent developments in molecular genetics (e.g., recombinant DNA technology) and process design (e.g., continuous reaction, use of immobilized enzymes) may form the basis for the growth of new markets

through the introduction of new and better products and the improvement of process economics for existing products.

The MITRE Corporation has been studying the growth of biotechnology in industry. This book, the second in a series of studies sponsored by Electricité de France, examines in detail the following three process areas:

- proteins and chemicals from pulp and paper industry wastes;
- single-cell protein (SCP) for human consumption from organic waste materials; and
- high-fructose corn syrups (HFCS) using immobilized enzymes.

The first book on this subject preceding this study was *Biotechnology and Energy Use* presented by the authors and published by Ann Arbor Science in 1981.

Information is presented on current, commercial-scale facilities, as well as potential future improvements likely to result from research and development. To provide a basis for evaluating these and other processes, biotechnology is defined in terms of a set of "unit operations," and recent technical developments are surveyed.

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CHAPTER 1

INTRODUCTION

BACKGROUND AND PURPOSE

The use of biological processes and materials for industrial purposes dates back thousands of years. The Babylonians and Sumerians, as early as 6000 B.C., used yeast to produce alcohol in the form of beer. By about 4000 B.C., the Egyptians were using the carbon dioxide produced by brewer's yeast to leaven bread. Over the centuries, fermentation processes were developed for production of various food products, such as vinegar, pickles and cheeses. It was not until the seventeenth century, however, that the existence of microorganisms was recognized, and another 200 years before Pasteur demonstrated in the 1870s that the products of fermentation were created by these microorganisms. The following 100 years saw the emergence of biochemistry, the development of industrial processes to produce solvents such as acetone and butanol, and the discovery of penicillin and other antibiotics. Although some fermentation processes were displaced after World War II by processes based on petroleum, fermentation has remained an important component of the food and pharmaceutical industries.

From this rich historical context, a new term, "biotechnology," has emerged to describe modern applications of biology (principally microbiology) in industry. Although much of the current excitement over biotechnology centers on recombinant DNA (a powerful tool for genetic engineering), this is only one factor contributing to modern biotechnology. Research is accelerating on both the biological elements (e.g., enzyme immobilization, new strains and fermentation kinetics) and the engineering elements (e.g., pretreatment of feedstocks, reactor design and product separation).

The advantages in using any microbial process in industry can be traced to a fundamental characteristic shared by all microorganisms: small

size and correspondingly high surface-to-volume ratio. This facilitates rapid transport of nutrients into the cell, thereby supporting a high metabolic rate. The commonly used analogy is highly appropriate: each cell operates as a miniature chemical factory. The diversity of microbial life is also an advantageous characteristic from an industrial use standpoint. Microorganisms can be found that exist under the widest possible range of conditions and that metabolize a variety of substrates. This makes it possible to design industrial fermentation processes that rely on inexpensive nutrients and operate under ambient conditions.

Aside from improved understanding of the biological and engineering principles, other, external factors have led to the recent emergence of biotechnology. These include:

- opportunities to use low-cost organic substrates (e.g., forestry residues or agricultural wastes) in favor of petroleum-based feedstocks;
- reduced energy consumption and increased safety due to lower operating temperatures and pressures; and
- reduced environmental hazard.

The above incentives, combined with new technological developments, have led to a consensus that biotechnology will be the most dynamic area of industrial innovation in the 1980s, analogous to the emergence of microelectronics in the 1960s. World markets for biotechnology products are projected to be on the order of hundreds of billions of dollars by the end of the century.

This book provides an evaluation of current commercial-scale processes and the new generation of technologies anticipated over the coming decade. More specifically, detailed process descriptions are provided in three generic application areas:

1. proteins and chemicals from pulp and paper industry wastes;
2. single-cell protein (SCP) for human consumption from organic waste materials; and
3. high-fructose corn syrups (HFCS) using immobilized enzyme technology.

Commercial facilities are operating or under construction for each of these applications. To adequately appreciate the new generation of technologies emerging from research and development, biotechnology is defined in terms of a set of unit operations, and representative examples are provided of state-of-the-art technology available at each process step.

SCOPE AND APPROACH

Detailed process descriptions for the three application areas stated above are based on the leading commercial facilities in North America. Unlike our earlier reference (*Biotechnology and Energy Use*, Clerman et al., Ann

Arbor Science Publishers, Inc., Ann Arbor, MI 1981), the descriptions are an in-depth examination of current state-of-the-art rather than a survey of research and development. The four processes selected are identified in Table 1-1 along with the general application areas they represent.

Information on the processes was obtained from the following sources:

- scientific and technical literature,
- patents,
- process, product and equipment brochures, and
- experts in industry and academia.

Because of the commercial potentials of these processes, there was some difficulty in obtaining detailed information. These proprietary restrictions varied as indicated in Table 1.1. Data on the HFCS process were the most closely protected, due to the highly competitive nature of this industry. Information was available on the demonstration plant for the Waterloo process for SCP production; however, descriptions of commercial facilities currently under construction in North America and Europe were held proprietary. To provide the best possible descriptions within the above constraints, we defined hypothetical plants closely modeled after actual commercial facilities and determined operating ranges, wherever possible, in lieu of precise figures. Even with this approach, some gaps remained that could not be filled by literature searches or consultation with experts.

ORGANIZATION OF THIS BOOK

Chapters 2 through 5 contain process descriptions. Each description is organized into the following general subsections:

- Evolution of Technology,
- Process Description,
- Product Uses,
- Cost Estimation, and
- Evaluation.

The content of most of these chapters is self-evident. The evaluation section is reserved for an assessment of the process in its current configuration and suggestions where improvement or modernization may be possible. In some cases, the suggested modifications are technologies covered in the unit operations survey (Chapter 7).

The unit operations survey was based on information obtained from the literature and organized in a format that can be supplemented and updated as necessary. More details regarding the scope of the unit operations survey and the approach taken are provided in Chapter 6, with detailed descriptions provided in Chapter 7. Chapter 8 offers a summary of the book and materials presented.