Chapter 8

Training and Personnel Needs in Biotechnology

"Most of our technology walks out every night in tennis shoes."

Robert Swanson
Genentech

"The key to educating a biotechnologist is flexibility in specialized aspects of a program that is firmly based in science and engineering."

David Pramer
Rutgers University

"The biotechnology revolution . . . has changed in *fundamental* ways how biologists and chemists regard their disciplines and therefore how those disciplines may properly be taught ."

Budget Change Proposal
California State University
Center for Biotechnology Education and Research

CONTENTS

Box

Figures

Tables

Chapter 8
Training and Personnel Needs in Biotechnology

INTRODUCTION

The continued commercialization of biotechnology in the United States depends on trained scientific and technical personnel. High-technology firms consistently rank quality of education and the availability of a skilled work force among the most crucial elements for success (16,30), and access to educational facilities is often pivotal in decisions about where to locate biotechnology firms (30).

Biotechnology is not one discipline but the interaction of several disciplines to apply scientific and engineering principles to the processing of materials by biological agents to provide goods and services (37). Thus, currently practicing "biotechnologists" were not trained as such, but were trained in such fields as molecular biology, genetics, biochemistry, microbiology, botany, plant pathology, virology, biochemical engineering, fermentation technology, and others. Much of the training for biotechnology continues to be in these and related areas.

Biotechnology personnel needs will change as the industry continues to grow and mature. The shift in emphasis from research and development (R&D) to production, for example, requires more bioprocess engineers and more technicians. Applications in new industrial sectors will also change personnel requirements. While the pharmaceutical industry is currently the predominant user of biotechnology, agriculture is also a significant user and other industrial sectors are increasingly applying biotechnology. Future personnel needs in biotechnology will depend on the R&D needs, the products that are produced, and the extent to which biotechnology is integrated into various industries. While most industry analysts and academics agree that the number of biotechnology personnel needed will continue to grow in the next 5 to 10 years, opinions vary on the specific types of jobs that will be available and the type of training required for these jobs. U.S. colleges and universities have responded to the perceived personnel needs in biotechnology with a variety of new training and educational programs.

SIZE AND FUTURE GROWTH OF COMMERCIAL BIOTECHNOLOGY

Few analysts expect biotechnology to generate a large number of new jobs, but its applications are growing rapidly and its personnel needs are often for specific, highly trained individuals. OTA estimates the total personnel working in biotechnology for dedicated biotechnology companies **(DBCs) and large, diversified companies to be about 35,900, of whom 18,600 are scientists and engineers.** While this indicates at least a five-fold increase in employment since 1983, the total numbers are low when compared with other high-technology sectors. Computer and data processing services, for example, employed almost 600)000 workers in 1986 (58).

A range of figures has been published on biotechnology employment in the past 5 years (table 8-l). A 1982 report estimated the total U.S. private sector employment in "synthetic genetics" to be 3)278) with an annual growth rate of 54 percent (26). Using data from a 1983 OTA/National Academy of Sciences survey, OTA estimated employment in U.S. biotechnology R&D work force to be 5,000 (72). Using data from a similar survey conducted in 1985, the Institute of Medicine (IOM) estimated that 12,000 scientists were employed in the biotechnology industry that year (39). A 1986 report estimates that 15)959 scientists and technicians are working in biotechnology (62). The

Table 8-1.–Estimates of Employment in Biotechnology, 1982-87

Year	Source of Estimate	Estimated Number Employed	Employment Sectors
1982	Feldman & O'Malley[a]	3,278 (total employees)	Private sector
1983	Office of Technology Assessment[b]	5,000 (R&D employees)	Biotechnology companies (based on total of 219)
1985	Institute of Medicine[c]	12,000 (scientists only)	Biotechnology companies (based on total of 282)
1985	National Science Foundation[d]	7,000 (scientists and engineers)	Biotechnology companies and large corporations
1986	Center for Occupational Research and Development[f]	15,959 (scientists and technicians)	Biotechnology companies, (based on total of 242)
1986	National Science Foundation[d]	8,000 (scientists and engineers)	Biotechnology companies and large corporations
1987	U.S. Department of Commerce[g]	25,000 (overall employment)	Dedicated biotechnology companies (based on a total of 300)
1987	Office of Technology Assessment[h]	13,221 (scientists and technicians) 24,347 (overall employment)	Dedicated biotechnology companies (based on total of 296)
1987	Office of Technology Assessment[i]	5,360 (scientists and technicians)[i] 11,600 (overall employment)	Diversified companies (based on total of 53)
1987	Office of Technology Assessment	18,581 (scientists and technicians) 35,947 (total biotech employees)	Diversified and dedicated biotechnolo-ogv companies

[a]M. Feldman and-E, p, O, Malley, *The Biotechnology Industry in Ca//forn/a*, contract paper prepared for the California Commission on Industrial Innovation, Sacramento, CA, August 19S2.
[b]U.S. Congress, Office of Technology Assessment, *Commercial Biotechnology: An International Analysis*, OTA-BA-218 (Elmsford, NY: Pergamon Press, Inc., January 1984).
Constitute of Medicine, Committee on National Needs for Biomedical and Behavioral Research personnel, National Academy of Sciences, *Personnel Needs and Training for Biomedical and* Behavioral Research *(1985* Report) (Washington, DC: National Academy Press, 19S5).
[d]National Science Foundation, *Biotechnology Research* and Development *Activities* in *Industry*, Surveys of Science Resources a Series, Special Report, (NSF 86-311) (Washington, DC: 1987).
[e]Ninety-four firms were estimated to represent two-thirds of the industry's activity.
[f]B.F. Rinard, *Education for Biotechnology* (Waco, TX: The Center of Occupational Research and Development, 1986).
[g]U.S. Department of Commerce, International Trade Administration, *1988* U.S. *Industrial Outlook* (Washington, DC: Government Printing Office, January 1988),
[h]U.S. congress, Office of Technology Assessment, Survey of Dedicated Biotechnology Companies, 1987.
[i]U.S. Congress, Office of Technology Assessment, Survey of Diversified Corporations in Biotechnology, 1987.

National Science Foundation (NSF), however, estimated that only 8,000 scientists and engineers worked primarily in biotechnology as of January of 1986 (56), A reason for the difference is that NSF has assumed fewer companies are performing the bulk of biotechnology R&D than the other estimates, and NSF considered only personnel involved in R&D, not production (18,56). The U.S. Department of Commerce recently estimated that 25,000 people worked for dedicated biotechnology companies (76). This estimate is very close to OTA's estimate, derived from a survey of dedicated biotechnology.

Current Survey Results

In the spring of 1987, OTA surveyed dedicated biotechnology companies (DBCs). Firms were divided into small (1 to 20 employees), medium (21 to 100 employees), and large (101 to 1,000 employees). The numbers of small and medium firms were nearly even at 112 and 121, respectively. Only 56 companies employ 101 to 1,000 people. (See ch. 5.) The average company had 86 employees, and the median response was 30. private companies averaged 40 employees, while public and subsidiary companies were approximately equal in size with an average of approximately 165 employees. Companies working in human therapeutics, plant agriculture, and human diagnostics tended to be the largest in the industry, averaging 120 employees. Specialty chemicals and reagents companies tended to be smaller, with 30 to 45 employees. Chapter 5 discusses other sectoral differences of commercial biotechnology.

The OTA survey of DBCs found that 135 companies employed a total 11,597 people, of whom 6,297 or 54 percent were scientific and technical personnel. Extrapolating these figures to the total of 296 biotechnology firms identified for the survey gives a total employment figure of 24)347) of which 13,221 would be scientific and technical personnel.[1] A second OTA survey covered 53 diversified corporations involved in biotechnology research and development. The survey showed these 53 companies, including large chemical, pharmaceutical, and agricultural companies (see ch. 5), employed 11,600 in biotechnology, of whom 5,360 were scientists and engineers with advanced degrees. OTA estimates that the current number of scientists and engineers employed in biotechnology is at least 15,000 to 21,000, with an additional 15,000 to 19,000 nontechnical personnel working for biotechnology companies. These ranges are probably slightly lower than the actual total, as not all large corporations involved in biotechnology could be identified and surveyed, and more dedicated biotechnology companies have been identified since the 296 were surveyed (see ch. 5 and apps. A and B).

The future rate of growth of employment in biotechnology will depend on the success of companies in introducing products and services based on biotechnology, the expansion of biotechnology applications in new fields such as waste management and the extraction industries, and investor confidence in biotechnology. Companies contacted for a survey for the Industrial Biotechnology Association (IBA) expected their staffs to grow an average of 44 percent from July 1, 1987 to June 30, 1989 (38). If companies grew at their hoped for rates, the biotechnology work force would number almost 58,000 by June 1989 (70). Companies responding to the OTA survey also reported high levels of employment growth, averaging 27.4 percent over the next 5 years. In 1983, companies expected to increase their staffs by 42 percent during the next 18 months. They actually increased their staffs by 20 percent (39). While companies can be expected to be optimistic, growth in biotechnology employment is indicated. According to analysts with the Bureau of Labor Statistics, the overall number of life scientists is expected to grow 21 percent or 30,000 jobs between 1986 and the year 2000, largely because of increasing applications of genetics research (67).

Personnel Needs in Biotechnology

Personnel needs in biotechnology are changing with the maturation of the industry. Each stage of development requires different activities and skills. Early stages mainly require research scientists and supporting laboratory technicians. As potential commercial products are developed, bioprocess scale-up engineers, cell culture and fermentation specialists, separation and purification specialists, analytical chemists, clinical scientists, regulatory affairs experts, and financial analysts are required. When full-scale production is underway, technicians at a variety of levels and quality control specialists are needed, as well as marketing managers and other business specialists.

This changing mix of personnel at biotechnology companies is becoming evident. Production and quality control positions are being added to the R&D jobs that have been the mainstay of employment. The current trend is toward hiring technicians rather than Ph.D. level researchers (47). opportunities for biologists and biochemists at the master's and bachelor's level (38) and perhaps even with 2-year associate of applied science degrees (62) will increase. Currently, according to data from OTA's survey of DBCs, Ph.D. scientists represent 14 percent of company personnel and 28 percent of scientific personnel. This demonstrates a continuing decline in Ph.D.s as a percentage of the scientific work force in biotechnology. Data from OTA's 1983 survey showed that 43 percent of R&D personnel held Ph.D.s., while the Institute of Medicine reports that 38 percent of the scientists employed in biotechnology firms held Ph.D.s in 1985 (39).

Biotechnology firms are also shifting somewhat from researchers to managers and marketers (17). Many scientist/founders of the dedicated biotechnology companies have been replaced by managers geared to getting products to markets rather than out of the laboratory (3).

Different sectors of the biotechnology industry also have differing personnel needs. The educational requirements for a position in plant genetic

[1] The overall mean number of employees per biotechnology company *(85.9)* times the number of companies (296) gives a slightly higher number (25,426) than given here. However, the presence of a few large companies probably skews the average too high. OTA instead multiplied the number of small companies (112) times the average number of employees (11.1), the number of medium companies (121) times the average number of employees (55.3), the number of large companies (56) times the average number of employees (267), and the number of unclassified companies (17) times the overall average number of employees (85.9) to arrive at the figure of 24,347. See ch. 5 for a description of the biotechnology industry.

engineering are very different from those for a position in developing monoclinal antibody test kits. The research scientists involved must know different biological systems, and the technicians involved must be familiar with different lab procedures and equipment.

Scientific personnel needs in biotechnology involve a variety of disciplines, including molecular biology, genetics, microbiology, biochemistry, immunology, and several engineering disciplines. Positions within these disciplines range from Research Director to Technician, and qualifications range from a Ph.D. with substantial experience to a bachelor's degree or, possibly, less (box 8-A).

Box 8-A.—Scientific Positions in Biotechnology Companies

Companies engaged in biotechnology-related research and development vary in the positions they offer, the education and experience required for similar positions, and the responsibilities of staff at particular job levels. The job categories described below are intended to give a general idea of the positions existing within the industry.

Scientific/Research Director: Senior manager responsible for multiple biotechnology research disciplines, such as molecular biology, fermentation, and cellular biology. This is the highest scientific level, and thus requires an exceptionally high degree of expertise and many years of research experience. Also of importance are organizational and interpersonal skills, as well as experience in the business community.

Department Director/Research Director: An individual who is responsible for and manages one biotechnological discipline. The position typically requires a Ph.D. degree, with several years of project management experience in a business setting. Organizational and interpersonal skills are important.

Section Manager/Group Leader: Chief scientist responsible for administering and directing the work of a scientific team involved in one specialized discipline or in a project covering several disciplines. Typical education and experience include a Ph.D., postdoctoral work, and teaching or research experience of at least 8 years since receipt of the Ph.D.

Principal Research Scientist: Head scientist responsible for supervising the work of scientists on several projects in one or more special disciplines. Typical education and experience include a Ph.D., postdoctoral work, and 5 to 8 years of teaching or research experience after receipt of the Ph.D.

Senior Scientist: Participating scientist responsible for supervising the work of other scientists on one or two complex projects. Is involved in departmental planning activities and may also participate in several other projects. Typical background includes a Ph.D. and 2 to 4 years of experience or an M.S. and 6 to 8 years of experience.

Research Scientist: Participating scientist in one or two projects, generally in one discipline. Assists in coordinating and assigning work. May be involved in day-to-day planning and in supervising staff. Is able to work independently. Typical education and experience include a Ph.D. and 1 year of experience or an M.S. and 3 to 5 years of experience.

Research Associate: Participating scientist who gives advanced technical assistance on one or more projects and provides limited supervision. May help coordinate project activities according to schedules set by supervisors. Background usually includes an M.S. and 1 to 3 years of experience or a B.S. and 3 to 5 years of experience.

Research Assistant: Individual who assists on a project under the direction of a senior or higher-level scientist. Typical education and experience include an M.S. and no related experience or a B.S. and 2 to 3 years of experience.

Research Technician: Person who assists on a project, usually by carrying out routine scientific work and conducting standardized tests under direct supervision. Typical background includes a B.S. with none to 2 years of experience.

SOURCE: Industrial Biotechnology Association, *Careers in Biotechnology*, Washington, DC, 1987.

Types of Jobs Available

Molecular biologists and immunologists constitute about a third of the research workers in biotechnology (82). Most molecular biologists have focused on animal and bacterial systems because this research is most applicable to human health (13) and most funding for molecular biology has come from the National Institutes of Health. Immunologists are heavily involved in the development of hybridomas to produce monoclinal antibodies, More recently, the employment of plant molecular biologists has been increasing with the redirection of agricultural research toward molecular biological techniques (see ch. 10).

Bioprocess engineers, biochemists, and microbiologists develop methods of producing biotechnology products in large quantities (13). The demand for these specialties will increase as products are readied for production (82).

Microbiologists study bacteria, yeast, and other micro-organisms and identify microbes with particular characteristics for industrial processes (13). Microbiologists also identify optimum growth conditions for micro-organisms and conditions for production of the substance of interest.

Cell culture specialists perform similar functions for plant and animal cells grown in tissue culture. Tissue culture is becoming increasingly important for the production of useful products, and expertise in tissue culture is an increasingly important skill.

Bioprocess engineers design systems to approximate conditions identified by the microbiologist. Bioprocess engineering is related to chemical engineering. One of the main tasks undertaken by bioprocess engineers is the design of fermentation vats (13) and various bioreactors (55) for the micro-organisms that will produce a given product. Biochemists are required for the next stage of production–the recovery, purification, and quality control of a given product. Many high-value products are extremely fragile, making purification a difficult and highly skilled task.

Available Personnel

For the most part, the available supply of life scientists adequately meets personnel needs (2, 45,48,56), though various observers have identified certain specific shortages in areas such as protein chemistry (6,8,20,64), x-ray crystallography **(32),** bioprocess engineering (34,35,36,39,42,61,81), cell culture (7,81), quality control (21,52), and other aspects of scale-up. Microbial ecologists are also seen as being in short supply (69,74). In general, companies see an ample supply of scientists trained in molecular biology, biochemistry, cell biology, and immunology, since these areas have traditionally been well-funded by the National Institutes of Health (48).

There are about 66,500 Ph.D.s in the biological sciences work force, representing about a quarter of the total of this work force. Master's degree holders represent another one-third of this total, with the rest holding bachelor's degrees (75). The number of bachelor's degrees awarded in the biological sciences peaked in 1976 at 59,000 and has declined since then. About 38,640 bachelor's degrees were awarded in 1984 (75).

In terms of general biological sciences, the work force is well supplied or oversupplied. During the 1980s, unemployment of recent graduates with bachelor's degrees in biosciences has been higher than for other science and engineering fields, except physics. The life sciences in general, and the biosciences in particular, have been oversupplied for several years, relative to demand (79).

potential Shortages

Shortages in certain emerging fields, such as protein engineering, are largely unavoidable, due both to the difficulty of predicting which fields will have the heaviest demands and the lag time required for educational institutions to gear up for new fields. The expense of new faculty and new equipment prevents institutions from rapidly moving into new areas. In areas with a shortage of researchers, a shortage of university instructors is usually also apparent (32,.50). For example, pharmaceutical companies are hiring x-ray crystallographers with expertise in biological molecules from academia at a rate that threatens to undercut both research and training of future crystallographers **(32).**

A shortage of microbial ecologists has resulted from the increased interest in the purposeful release of engineered organisms into the environment. Until recently, microbial ecology was a relatively obscure field that attracted less money and talent than more glamorous fields such as molecular biology. The Environmental Protection Agency (EPA) has identified ecological risk assessment, ecosystem structure and function, and ecological and toxicological effects as priority areas (77), but EPA does not fund many extramural research and training programs. The National Science Foundation also supports some research, and thus training, in microbial ecology (74).

Predicting future employment needs accurately requires information that is often unavailable. Such predictions are necessarily speculative. A survey of biotechnology firms in the San Diego area indicates that one-third of the bachelor's level employees hired during the next 5 years will work in recombinant DNA. Other areas of high anticipated need include DNA sequencing, separation chemistry, and animal tissue culture (8) (see table 8-2). Personnel specialists at a 1987 meeting of the Industrial Biotechnology Association also pointed to basic recombinant DNA techniques as their biggest training need (37).

A 1984 OTA report said that a potential shortage of highly trained bioprocess engineers in the United States "could be a bottleneck to the rapid commercialization of biotechnology in the United States" (72). **While no such shortage is evident almost 4 years later, biotechnology still has not been used to produce a large number of products and thus there is not yet a heavy demand for bioprocess engineers.** This is at least partly because biotechnology is still largely used to produce high-value, low-volume products. Producing high-volume, low-value products will require more engineering talent for successful scale-up (41). Some industry representatives fear a shortage of bioprocess engineers lies ahead as more products reach the final stage of commercialization (35,36). Shortages of bioprocess engineers have recently been predicted for the 1990s (61). However, most companies contacted by Genetic *Engineering News*, an industry trade journal, did not expect any personnel shortages to develop during the next 5 years (48). Some biotechnology company personnel managers have, however, reported difficulties hiring biochemical engineers at the B.S./M.S. level with cell culture or fermentation experience (38,29).

Table 8-2.—Anticipated Hiring of B.S.-Level Biotechnologists by San Diego Area Biotechnology Firms, 1987-92[a]

Area of work	Number expected to be hired	Percent of total
Recombinant DNA.	292	33%
DNA Sequencing	119	13
Animal Tissue Culture	118	13
Separation Chemistry	117	13
Hybridoma Technology.	84	9
Virology	52	6
Protein Synthesis	31	4
DNA Synthesis.	24	3
Plant Tissue Culture	19	2
Other (e.g., fermentation, animal model development and testing).	29	3
TOTAL	885	

[a]Data represent estimates for 27 organizations based on responses from 15. Numbers are cumulative for the 5-year period.

SOURCE: Sanford Bernstein, San Diego State University, February 1987.

Since 1984, protein chemistry has emerged as a strong need (6,8,20,21,64). The knowledge of making, purifying, and stabilizing proteins to their active form is required, especially in pharmaceutical applications. The need for immunologists has also increased, due to demand in both monoclinal antibody development and in AIDS research.

Whether or not shortages actually materialize will depend on how rapidly biotechnology products are commercialized and how and when universities and their students respond to predicted manpower needs. While a shortage of bioprocess engineers would be a serious bottleneck for the industry, the actual number needed will not be very large. Bioprocess engineering is not labor intensive, and it has been estimated that personnel requirements for bioprocessing, even after firms enter mass production, will be only 10 to 15 percent of the total biotechnology work force. Furthermore, technological advances, such as biosensors and computer-controlled continuous bioprocessing, could reduce labor intensity (46,72,78).

Potential projected personnel shortages might also be ameliorated by mobility among disciplines. For example, potential shortages of plant molecular biologists were identified several years ago (39,57,72). However, the field of plant molecular biology has been able to move ahead quite rapidly in the last few years due to the large pool of molecular biology postdoctoral fellows and

Photo credit: Calgene

Cell and tissue culture methods are used to regenerate plant cells containing foreign genes into whole plants.

trainees. While many of these scientists were trained in animal or bacterial systems, they were able to apply their skills and knowledge of molecular genetics to plant systems. The postdoctoral pool has thus served as a buffer, although there is still a strong need for biotechnologists with plant expertise (5).

No such postdoctoral pool exists for bioprocess engineering. The current soft market for petrochemical engineers creates a logical pool of potential bioprocess engineers, should shortages become acute. However, traditional chemical engineers have no understanding of living systems. As one engineering professor put it, “When you’ve spent your whole career with nonliving systems, you just don’t get an appreciation of living systems overnight” (14).

Experience in the pharmaceutical industry has shown that chemical engineers can be retrained in bioprocess engineering (72). However, some industrialists argue that large-scale fermentation and downstream bioprocess engineering for recombinant organisms are radically different from traditional biochemical engineering techniques and require special training. For example, recombinant organisms are often fragile and slow producers. Since slow producers are at greater risk of being overrun by contaminants, special techniques to maintain pure cultures are needed (61). In addition, pharmaceutical production is rapidly changing from bacteria and yeast fermentation to mammalian cell culture, which requires different expertise.

universities have responded with some increased emphasis on bioprocess engineering, although new biotechnology programs emphasize engineering less than genetic manipulation techniques (see “New Initiatives in Biotechnology Training,” below). College students appear to be highly responsive to market signals (73) and can thus be expected to seek out educational programs for various aspects of biotechnology to the extent that they perceive occupational rewards from careers in particular areas.

Belief is widespread that interdisciplinary training should be increased, although opinions vary on the specific disciplines that should be included (16,23,40,72). Industrialists have referred to the need for “life-science-oriented engineers and engineering-oriented life scientists” (61), as well as for chemical engineers with an understanding of biosynthesis and biologists with an appreciation for scale-up problems.

Different types of firms have different personnel needs. Generally, smaller firms have a higher percentage of Ph.D. scientists than do larger firms (24). Small firms are more likely to be concentrating on relatively basic research and development, and thus have more Ph.D. research scientists. Small firms are also less likely to be involved in large-scale production, and thus can be expected to have less need for technicians than larger companies. Some analysts have indicated that small companies are less able to afford on-the-job training and need someone who can get up to speed right away (68). Others have indicated the importance of a broad general education, adding that special skills and protocols must be learned on the job (15). The average firm size is increasing (table 8-3), indicating that more firms will need a variety of non-Ph.D. support personnel in both scientific and nonscientific areas.

Table 8.3.–Number of Scientific Employees per Biotechnology Firm, 1983=87

Year	Scientific and Technical Employees per firm	Ph.D.s per firm	Percent Ph.D.s in scientific work force	Source
1983	22.8	12	53	Office of Technology Assessment
1985	42.12	16	37	Institute of Medicine
1987	42.9	12	28	Office of Technology Assessment

SOURCE: Office of Technology Assessment, 1988.

EDUCATION AND TRAINING FOR BIOTECHNOLOGY

Many academics and industry observers believe that the best preparation for biotechnology is training in a traditional discipline, such as genetics or plant physiology, while learning some of the tools of biotechnology. Individuals trained in targeted disciplines can then work in interdisciplinary teams on specific problems. For example, David Pramer, director of the Waksman Institute of Microbiology at Rutgers University, wrote in 1983 that:

> . . . it would be unwise for universities to offer educational programs in biotechnology that are narrowly conceived or overly professional, and it is essential for university scientists within traditional academic disciplines not to abdicate a responsibility to educate biotechnologists . . .
>
> To continue to flourish, biotechnology must be nourished by a steady supply of individuals who also are well educated in traditional disciplines . . . Since biotechnology 5 years from now may be quite different from what it is today, the key to educating a biotechnologist is flexibility in specialized aspects of a program that is firmly based in science and engineering (60).

Many academics believe that new initiatives in training and education are required by the Nation's colleges and universities to meet the education and research needs of the emerging biotechnology industry. OTA identified 60 new initiatives in biotechnology training at 49 different U.S. colleges and universities. These programs are listed in appendix C. Forty-one of these programs responded to an OTA survey requesting information about curriculum, funding, age, number and type of students, and resources of the programs. Results of the survey give a good indication of how colleges and universities have responded specifically to new opportunities in biotechnology and should be representative of new initiatives in biotechnology on the Nation's campuses. No attempt was made to catalog the many traditional programs that also provide education and training related to biotechnology. The identified programs range from 2-year applied associate of science degrees to short courses in particular biotechnologies designed for professional scientists. Also included in the OTA list of new initiatives in biotechnology training and education are university-based biotechnology research centers. While these centers generally do not sponsor courses or grant degrees, they do enhance biotechnology education on their campuses through access to equipment, faculty development, and research opportunities for both graduates and undergraduates. These centers also provide a focal point for discussions of how best to educate and train new biotechnologists.

For the most part, university programs have been developed at the institutional level with little or no coordination or formal interaction among the program developers at different colleges and universities. Most do, however, have some form of interaction with industry. Only 7 of 41 programs said that they did not consult industry in establishing their programs. Consultations with industry included surveying local biotechnology companies and sending program proposals to industry representatives for comments. While it is generally too early to assess industry's satisfaction with graduates of these programs, most graduates have apparently had a relatively easy time finding employment in their fields.

Age of Programs

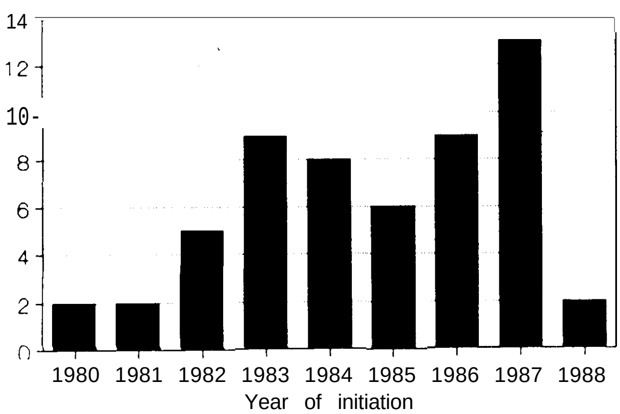
With the exception of programs in biochemical engineering, all of the programs identified are new: the oldest began in 1980. Of 56 programs for which the year of initiation is known, more than a third were begun since 1986 or are still in the planning stage (figure 8-l). Additional programs are probably in the planning stages and may be created in the next few years.

As figure 8-1 indicates, a large number of biotechnology programs were initiated in 1983. This would indicate a 2-year lag from the year when more biotechnology companies were founded, 1981 (see ch. 5). Two years is a relatively short time in which to develop curricula and approve programs, indicating that some institutions moved quickly into biotechnology (28) or at least to identify themselves with biotechnology.

There is no clear pattern of which degree level programs were founded first. In each year a mix of programs was initiated, aimed at a variety of educational levels. For the most part, community college programs are newer than bachelor's and master's programs.

At the doctoral level, most programs are in bioprocessing or biochemical engineering, except for the Iowa Biotechnology Training Program's Ph.D. in microbiology and immunology. Traditional Ph.D. programs in molecular biology, microbiology, biochemistry, and other fields relevant to biotechnology were not surveyed.

Figure 8-l. -University initiatives in Biotechnology Training[a]



aTh. total number of programs shown here is 56. Biochemical engineering programs are not included.

SOURCE: Office of Technology Assessment, 1966.

Curriculum Content

Recombinant DNA techniques formed the core of many of the programs. Of 32 programs that provided OTA with curriculum information, 26 reported coursework in recombinant DNA. No other specific skill or technology was mentioned by more than half of the programs. Courses or skills mentioned as requirements or electives by one-third to one-half of programs include tissue culturing, hybridoma technology, immunochemistry, bioprocess engineering, fermentation, and purification and separation sciences.

The extent to which training in bioprocess engineering is available is not clear. Only a few programs have in-depth faculty expertise; most expertise is scattered among chemical engineering

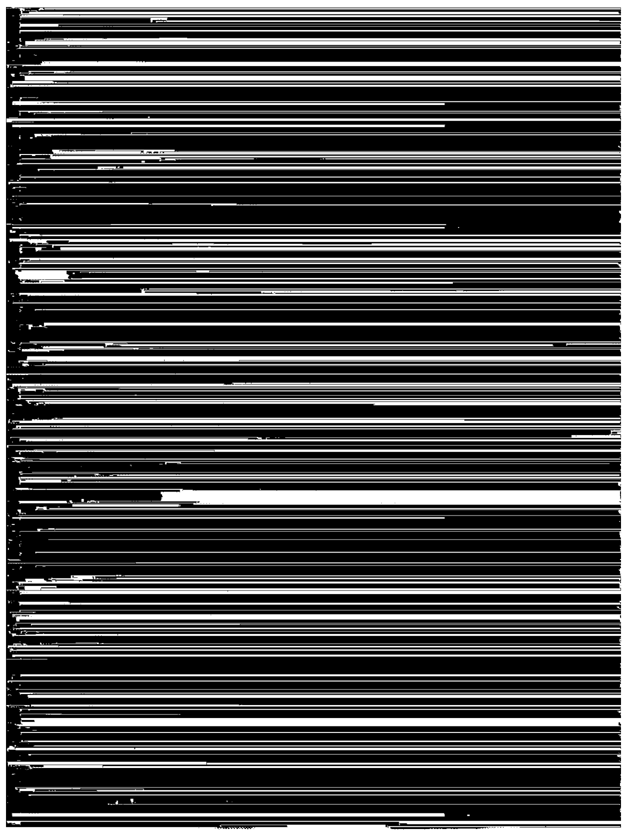


Photo *credit:* **Case** *Western Reserve University*

Two undergraduate students read a DNA sequence on an autoradiograph. Such opportunities were extremely rare at the undergraduate level several years ago, but are becoming increasingly common.

departments (14). According to the National Research Council, fewer than 20 U.S. colleges and universities have meaningful biochemical engineering programs (55). The American Council of Education reported in 1985a total of 58 doctoral engineering programs in biotechnology (33). While many of these programs were in departments of chemical engineering and so most likely relevant to OTA's definition of biotechnology, many others were in departments such as biomedical engineering, which have less relevance to industrial biotechnology.

The currently depressed market for chemical engineering graduates may make it difficult for departments to add faculty, courses, and equipment for bioprocess engineering. If departments have fewer students, they will have some difficulty securing the additional funds. Deciding which, if any, areas of traditional chemical engineering to reemphasize is problematic.

The vast majority of the undergraduate chemical engineering curriculum is mandated by the accreditation standards of the American Institute of Chemical Engineers and the Accreditation Board for Engineering and Technology. At the University of Iowa, for example, students interested in biochemical engineering are urged to use their limited electives for courses in biochemistry, microbiology, biochemical engineering, genetics, and biology. They have also integrated bioreactors, microbial kinetics, and enzyme reactions to illustrate concepts and techniques in traditional chemical engineering coursework (86).

All of the training programs are laboratory-intensive, except for some of the short courses and workshops. Academic program directors who had contacted industry representatives about their needs uniformly reported that industry needed technicians with hands-on laboratory experience and have designed their programs accordingly.

Many biotechnology academic programs reported that a shortage of protein chemists existed in the industry, or that industry needed technicians and bioprocess engineers with an understanding of protein chemistry. No course specifically in protein chemistry was evident in the curricula supplied to OTA, but nearly every program required courses in biochemistry, which would include protein chemistry. It is not clear the extent to which students will learn the solution properties of proteins, purification and sequencing methods, and protein synthesis within these programs. A course in protein chemistry was recommended in a model curriculum for a 2-year program for biotechnicians (see table 8-4). San Diego State University, however, will initiate a Certificate in Protein Engineering in the fall of 1988, which will include specific courses in protein engineering (22). The California State University at Los Angeles intends to offer a course in advanced protein chemistry (66).

Table 8-4.—Biotechnology Programs Offering Associate of Applied Science Degrees

Year of initiation	University	Program
1983	Monroe Community College	Biotechnology Program
1986	Central Community College	Biotechnology Program
1986	State University of New York, Alfred	Biotechnology Program
1986	Technical College of Alamance	Biotechnology
1987	Boston University/Metropolitan College	Biotechnology Laboratory Methods
1987	Madison Area Technical College	Biotechnology Laboratory Technician Program
1988	Becker Junior College	Biotechnician Program

SOURCE: Office of Technology Assessment, 1988.

Community College Laboratory Technician Programs

The need for biotechnicians with specialized but limited training has prompted several community colleges to institute or consider instituting biotechnology training programs. Early in the development of biotechnology, most work was done by highly educated, innovative thinkers, who often had to develop new procedures as their research progressed. As with all technologies, as biotechnology matured, more of the work has become routine and can be assigned to less highly trained technicians (9,62). Figure 8-2 gives a profile of skills

Figure 8-2.—Biotechnology Laboratory Technician

	DUTIES	TASKS								
a	COMMUNICATION	Follow and analyze protocol	2 Keep accurate records	3 Communicate subject matter professionally	4	5 Organize and present oral reports	6 Locate and review reference materials	7 Read current scientific journals	8 Maintain mathematical literacy	9 Maintain computer literacy
B	SAFETY	Identify first aid supplies, personnel and emergency protection areas	2 Maintain safe work area	3 Use appropriate safety procedures and guidelines	4 Label all materials	Store and dispose of hazardous materials	6 Monitor handling of radioisotopes and biohazards			
C	MEDIA PREPARATION	Practice aseptic techniques	2 Prepare glassware	3 Perform mathematical calculations	4 Make stock reagents	5 Monitor physical properties of a solution	Sterilize reagents	7	8 Maintain reagent integrity	
D	FERMENTATION	1 Identify and quantify microorganisms	2 Isolate and maintain pure cultures	3 Maintain and analyze fermentation materials	4 Maintain, analyze and troubleshoot fermentation equipment	5 Prepare seed inoculum	6 Control and monitor fermentation equipment	7 Harvest microorganisms	8 Recover effluent products	
E	TISSUE CULTURING	1 Isolate and characterize cell lines	2 Propagate animal tissue	3 Propagate plant tissue	4 Use cryogenic techniques	5 Perform tissue instrumentation	6 Propagate and harvest viruses	7 Generate monoclonal and polyclonal antibodies		
F	PRODUCT ANALYSIS	1 Evaluate all production materials	2 Evaluate biological characteristics	3 Perform instrumental analysis	4 Perform animal bioinstrumentation	5 Document product specifications	6 Perform statistical and data analyses	7 Maintain and troubleshoot analytical instruments	8 Meet government and/or company standards	
G	GENETIC ENGINEERING TECHNIQUES	Construct DNA library	2 Probe and analyze DNA library	3 Construct recombinant vectors	4 host cells	5 Perform mutagenic techniques	6 Apply selective pressures	7 Micromanipulate embryos		
H	NUCLEIC ACID ISOLATION AND ANALYSIS	1 Disrupt cells chemically	2 Ultra centrifuge nucleic acids	3 Analyze by restriction mapping	4 Run DNA gels	5 Perform Northern and Southern blots	6 Label nucleic acids	7 Sequence nucleic acids	8 Synthesize nucleic acids	9 Manage sequence database
I	PROTEIN PURIFICATION	1 Homogenize cells	2 Run protein gels	3 Perform Western blotting	4 Denature/renature proteins	5 Precipitate/solubilize proteins	6 Chromatograph proteins	7 Concentrate (filter and dialyze) proteins	8 Modify proteins	9 Perform enzyme activity assays

SOURCE: Madison Area Technical College, 1987.

required by biotechnicians. Two-year training programs may be appropriate for these technicians (62).

OTA has identified seven associate of applied sciences (AAS) programs in biotechnology, six taught at community or junior colleges and one taught at a state college (table 8-4). These programs are designed to fill the need for biotechnicians, (similar to the more established need of chemical technicians)," although students from these programs may go on to 4-year colleges. Six of the seven programs began since 1986, and the seventh began in 1983.

The need for biotechnicians at the AAS level is not well established, but several analysts expect it to surface soon (9,62) based on the precedent from other high-technology industries. A consortium of 2-year postsecondary schools commissioned a study in 1986 to assess the need for 2-year biotechnician training (62), Table 8-5 shows a model 2-year curriculum in biotechnology developed as part of this study.

The 1986 study included a survey of biotechnology companies and a Biotechnology Task Force on Education, consisting of industry and academic members. The study produced a number of significant findings, among them:

- technicians in biotechnology will be different from current technicians in other technology fields, most significantly in that they will require a broader and more interdisciplinary technical base;
- 77 percent of the biotechnology companies surveyed expected biotechnicians to have at least a bachelor's degree; however, since few 2-year programs currently exist, the industry has little experience for judging the quality of 2-year program graduates;
- based on the biotechnology industry's present level of employment of biotechnicians from 2-year training programs, about 200 graduates a year should be able to find placement from 1986 to 1995,
- 2-year programs should be initiated in areas with the largest markets for biotechnicians, which currently includes California, Massachusetts, New Jersey, New York, and Maryland. The need for biotechnicians exists in other parts of the country, however, and will expand as the industry expands.

Industry appears skeptical toward the 2-year programs thus far. Concerns include whether 2 years in college can provide the knowledge necessary to manage complex instrumentation and sensitive organisms (84) and that technicians without a theoretical understanding may not be able to adapt to the changing needs of rapidly evolving technology (84).

Industry representatives also give these reasons for skepticism: a current oversupply of B.S. and M.S. degreed biologists available for technician work; 2-year programs lack the breadth and depth of 4-year programs; and companies need the research background provided by B.S. and M.S. programs (62).

Some reasons for reluctance in hiring graduates of 2-year programs will dissipate as the dedicated biotechnology companies grow and mature. For example, small companies are more likely to require their employees to assume multiple duties, some of which will require more training than 2-year programs provide. As a company's overall

Table 8-5.—Proposed Two-Year Curriculum in Biotechnology

Year One	Year Two
Quarter 1	*Quarter 4*
Introduction to Biotechnology	Industrial Microbiology
Technical Math 1: Algebra/ Geometry	Computer Operations
Chemistry 1: Inorganic	Fundamentals of Instrumentation and Control
Molecular and Cell Biology I	Analytical Chemistry
Technical Communications I	Fluid Power Devices
Quarter 2	*Quarter 5*
Technical Math II: Statistics/ Precalculus	Applied Genetics
Applied Physics I	Instrumental Analysis
Molecular and Cell Biology II	Economics in Technology
Chemistry II: Organic	Biotech Internship or Project
Technical Communications II	Mechanical Devices and Systems
	Elective
Quarter 3	*Quarter 6*
Principles of Microbiology	Protein Chemistry
Biochemistry	Industrial Instrumentation
Applied Physics II	Industrial Relations
Electronics	Biotech Project or Internship
Elective	Technical Elective

SOURCE: B.F. Rinard, *Education for Biotechnology* (Waco, TX: Center for Occupational Research and Development, 1986), workload and staff increases, it can divide tasks by level of skill and maybe able to employ people full-time at the lower skill levels. Also, as work continues to shift from research and development to production, more of the tasks will become rou-, tine. Larger companies may also be able to afford more time for on-the-job training.

College and University Bachelor's Level Biotechnology Programs

At least 11 colleges and universities have instituted new bachelor's-level programs in biotechnology (table 8-6). Like the 2-year programs, these programs emphasize hands an laboratory experience, but include more theoretical science and humanities courses. Students are prepared either to go directly to work in industrial labs, or to enter master's or doctoral programs.

The Rochester Institute of Technology (RIT) instituted its biotechnology program in 1983 "to prepare graduates to work as biotechnologists in research programs and development and production facilities in academia, government, private industry, and other organizations" (28). Students also goon to M.S. and Ph.D. programs. In addition to courses in general biology, chemistry, biochemistry, and molecular biology, the program requires 25 courses related to biotechnology, including specific courses on analytical chemical separations, mammalian tissue culture, plant tissue culture, hybridoma techniques, plant physiology, genetic engineering, and an individual biotechnology senior research project. Students are also encouraged to work in a cooperative education program for four quarters, making the course of study a total of 5 years instead of 4. Employers in the cooperative education program have included government, industry, and academic labs.

Although it is among the oldest of the new initiatives in biotechnology education, the RIT program has only 45 graduates (as of spring 1988), due to the length of time required to complete the program.

Like many of the programs identified, the RIT program consulted with industry during program planning and implementation. RIT established a Biotechnology Advisory Council, consisting of representatives of 12 companies with interests in biotechnology. The head of the Department of Biology at RIT reports that council members "continue to be involved in curriculum review in light of the rapidly changing needs of the field, (and) in providing up-to-date information about their companies' particular interests and needs" (28).

Another program in New York State is the bachelor of science degree in recombinant gene technology offered by the State University of New York College at Fredonia. In addition to general courses in chemistry, biology, botany, and physics, the program requires courses in recombinant gene technology, genetics, and cell and subcellular biology. Initiated in 1983, the program had 43 stu-

Table 8-6.—Biotechnology Programs Offering Bachelor of Science Degrees

Year of initiation	University	Program
1980	State University of New York, Plattsburgh/W.H. Miner Agricultural Center	In Vitro Cell Biology and Biotechnology
1982	Worcester Polytechnic Institute	Biotechnology
1983	Cedar Crest College	Genetic Engineering
1983	Rochester Institute of Technology	Biotechnology
1983	State University of New York, Fredonia	Major in Recombinant Gene Technology
1984	Case Western Reserve University	Concentration in Biotechnology and Genetic Engineering
1986	California Polytechnic State University	Biochemical Engineering
1986	Cook College, Rutgers University	Biotechnology[a]
1986	North Dakota State University	Biotechnology Academic Program
1987	University of Kentucky	Biotechnology
1988	Ferris State College	Biotechnology Emphasis

[a]Curriculum is pending approval by the State Department of Higher Education

SOURCE: Off Ice of Technology Assessment, 1988.

dents enrolled in the spring of 1988. A total of 44 students had completed the program through 1986, with most going to work in academic or government laboratories.

The oldest bachelor's level biotechnology program identified by OTA is the In Vitro Cell Biology & Biotechnology Program, begun in 1980 by the State University of New York at Plattsburgh and the W.H. Miner Agricultural Center. The program includes both an approved major field of study at Plattsburgh leading to the bachelor of science degree and a self-contained semester of intensive training in techniques of biotechnology. One semester of the B.S. program consists of a 15-credit-hour course of lecture and laboratory work in tissue culture and biotechnology in residence at the Miner Institute. This course is also open to qualified students from other colleges and universities, and attracts both undergraduate and postbaccalaureate students.

The North Dakota State University at Fargo offers a bachelor of science degree in biotechnology in both its College of Agriculture and its College of Science and Mathematics. A minor in biotechnology is also available. In addition to traditional courses, North Dakota State offers courses in recombinant DNA, plant cell and tissue culture, animal cell culture, plant micropropagation, and process biochemistry. Having begun in 1986, the program has no graduates yet.

The University of Iowa offers B.S. as well as M.S. and Ph.D. degrees in chemical and material engineering with opportunities in biochemical engineering/biotechnology. The Iowa program prepares its B.S. students primarily for M.S. and Ph.D. programs.

Other existing or planned B.S. level programs in biotechnology include those at Cook College of Rutgers University, Ferris State College in Michigan, the University of Kentucky in Lexington, and Cedar Crest College in Allentown, Pennsylvania.

Certificate Programs

Certificate programs are offered to postbaccalaureate students who wish to learn specific techniques in biotechnology (table 8-7). Four universities in the California State University sys-

Photo credit: Rochester Institute of Technology

An undergraduate student majoring in biotechnology prepares DNA for restriction enzyme mapping.

tern offer certificates in biotechnology or related technologies to either undergraduate or postbaccalaureate students in the life sciences. Other universities offer certificates at the graduate level.

Two of the most established programs are at San Diego and San Francisco State Universities, both initiated in 1983. San Diego offers a certificate in recombinant DNA technology as well as an M.S. in molecular biology and a Ph.D. in molecular and cellular biology. The certificate program consists of 24 semester units of courses in radioisotope techniques, biochemistry, bacterial genetics, molecular biology, and recombinant DNA techniques. An internship in a university or industrial laboratory is also required. San Diego State Univer-

Table 8.7.—Programs Offering Certificates in Biotechnology

Year of initiation	University	Program
1980	W.H. Miner Agricultural Center	In Vitro Cell Biology and Biotechnology
1983	San Diego State University	Recombinant DNA Technology
1983	San Francisco State University	Genetic Engineering
1986	California State University at Hayward	Biotechnology
1986	Rutgers University	Biotechnology
1986	Tufts University	Training Program in Biotechnology Processing
1987	California State University at Los Angeles	Biotechnology
1988	San Diego State University	Protein Engineering
Planned	San Diego State University	Agricultural Biotechnology

SOURCE Off Ice of Technology Assessment, 1988

sity will offer a Certificate in Protein Engineering starting in Fall 1988, and plans to start offering a Certificate in Agricultural Biotechnology in Fall 1989 (22).

San Francisco State University offers a similar program. The Genetic Engineering Certificate Program is open to postbaccalaureate students ‘(who wish to become specifically competent in the concepts and laboratory skills of genetic engineering” (65). The 13 units required for the certificate may be used toward the 30 units required for the master’s of science in biology. About 50 people have completed the certificate program, and about three-fifths are working for biotechnology companies. The remainder are working in university laboratories or are pursuing graduate degrees.

California State University at Hayward initiated a certificate program in biotechnology in 1986. The program requires one academic year to complete 28 quarter units of work in cell biology, molecular cloning, immunochemistry, cell culture, radiation biology, and other electives. Developers of the Hayward program consulted biotechnology companies and identified industry needs in protein purification, immunochemistry, and cell culture.

California State University at Los Angeles started a l-year certificate program in biotechnology in the fall of 1987, which can be applied to a master’s degree program. The core of the program consists of four courses in gene manipulation. The program developers anticipate adding courses in hybridoma laboratory techniques, cell culture, and advanced protein chemistry. The program director visited four biotechnology companies and heard the following needs expressed: employees who bring their minds as well as their hands to a task; employees who have had research project experience of at least half-time intensity; and employees with expert theoretical backgrounds in protein chemistry (66).

A similar although shorter program is the Training Program in Biotechnology Processing offered by the Biotechnology Engineering Center of Tufts University. Tufts offers this 15-week summer program designed to train students in biotechnology processing, and to place them in positions as technicians in industry. Sponsored by Tufts and a consortium of biotechnology companies, the program received start-up funds from the Bay State Skills Corporation.

Rutgers University offers a certificate in biotechnology to its M.S. and Ph.D. students in the Departments of Microbiology and Chemical and Biochemical Engineering. In addition to the degree requirements of their programs, students in the certificate program must complete 15 credits from a list of courses in biotechnology, such as Chemistry of Microbial Products and Enzyme Engineering. For students in either the microbiology or the chemical and biochemical engineering program, at least six credits must be taken outside of the program in which the student is registered (59).

University Master’s Level Biotechnology Programs

Master’s degree programs in biotechnology are multidisciplinary and often interdepartmental (table 8-8). Almost all the programs preparing students for careers in bioprocessing are at the

Table 8-8.—Biotechnology Programs Offering Master of Science Degrees

Year of initiation	University	Program
1955	Massachusetts Institute of Technology	Biochemical Engineering
1970	Rutgers University	Biochemical Engineering
1980	State University of New York, Plattsburgh/Miner Institute	In Vitro Cell Biology and Biotechnology
1981	University of Maryland, Baltimore County	Applied Molecular Biology
1982	Worcester Polytechnic Institute	Biotechnology
1984	Case Western Reserve University	Concentration in Biotechnology and Genetic Engineering
1984	University of Minnesota	Microbial Engineering
1985	University of Iowa	Biochemical Engineering/Biotechnology
1985	University of Tennessee, Knoxville	Biotechnology
1986	California Polytechnic State University	Biochemical Engineering
1986	Tufts Biotechnology Engineering Center	Biotechnology Engineering
1987	Lehigh University	Applied Biological Sciences
1987	Old Dominion University	Biotechnology
1988	University of Illinois	Biological Engineering
Planned	San Diego State University	Biotechnology
Planned	University of South Florida	B.S/M.S. in Biotechnology

SOURCE: Office of Technology Assessment, 1988.

master's and doctoral levels, and several directors of these programs indicated that industry considered M.S. and Ph.D. degrees to be the entry level in bioprocessing (63)86). The need to combine process engineering with a basic understanding of molecular biology requires advanced training, according to some observers (27,71,86).

The University of Maryland, Baltimore County, has offered a master's degree in Applied Molecular Biology since 1981, with the first class graduating in 1984. The degree can be earned either in a 2-year postbaccalaureate program or as a 5-year B.S/M.S. program. Emphasizing hands-on laboratory skills, the program requires a summer research internship, A Ph.D. program in Molecular and Cellular Biology that will use the Applied Molecular Biology program as its core curriculum is under development.

Lehigh University in Bethlehem, Pennsylvania, is establishing an M.S. in applied biological science, which will provide students with hands an experience in genetics, biochemistry, and bioprocessing. While preparation for a Ph .D. program is the principal goal of the program, students will also be prepared to work for industry. The program is sponsored by the Biology, Chemistry, and Chemical Engineering departments.

The University of Minnesota offers a master's degree in microbial engineering, which will enable students to integrate the basic science of microbiology with technological applications of the capacities of micro-organisms, cultured cells, and parts thereof. The interdisciplinary program draws on faculty from more than nine departments of four colleges and institutes in the university. Begun in 1984, the first five students finished in 1987.

San Diego State University is in the process of establishing a different type of master's program, which will combine scientific instruction with corporate and legal instruction. The program will have tracks in biopharmaceutical toxicology/risk assessment, venture capital and entrepreneurial biotechnology business development, and regulation and biotechnology patent law (22).

Tufts University has a 5-year B.S./MS. program in chemical/biochemical engineering. The program includes all the courses required for certification as a chemical engineer plus courses in cell and microbe cultivation, biotechnology processing lab, applied enzymology, and biochemical engineering, Core courses are given in the early evening, making them accessible to people in industry.

Doctoral Programs

Traditional doctoral programs in biological, chemical, and engineering sciences produced the expertise that created today's commercial opportunities in biotechnology. Nonetheless, OTA did not attempt to evaluate or catalog these programs, as they are well developed and have mature professional societies and accreditation systems in place.

Academic opinion is divided about the desirability of creating new doctoral programs in biotechnology. Increasingly, biotechnology is viewed as comprising a set of tools that can be applied to a variety of disciplines. On the other hand, biotechnology increasingly requires interdisciplinary training or at least the ability to collaborate effectively across disciplines.

Several doctoral programs are making biotechnology an explicit component of their curricula and Ph.D.s in biotechnology are under consideration (table 8-9). Case Western Reserve University offers a Ph.D. in biology with a concentration in biotechnology and genetic engineering. At the University of Minnesota, a Ph.D. minor in Biological Process Engineering is under development. And the University of Maryland, Baltimore County, is developing a Ph.D. program in Molecular and Cellular Biology that will use courses in applied molecular biology as its core curriculum. Several universities offer Ph.D.s in biochemical engineering.

In many areas of the life sciences, biotechnology companies are well supplied with Ph.D. scientists (38). The greatest need at the Ph.D. level is biochemical and bioprocess engineering (55).

Short Courses in Biotechnology

Short courses in biotechnology, ranging from a couple of days to a couple of weeks, are a popular way for scientists of various backgrounds to learn a particular technique (table 8-10). Shorter workshops may be centered around lectures and demonstrations, and longer workshops will usually have hands -on laboratory components.

Begun in 1982, the Center for Advanced Biotechnology Training in Cell and Molecular Biology at the Catholic University of America in Washington, D.C., has one of the most established series of short courses. Participants are usually mature scientists seeking information and skills to assist them in research and, to a lesser extent, in teaching (53). The Center has trained about 1,200 scientists in areas such as immunochemistry, hybridoma / monoclinal antibody production, tissue culture, recombinant DNA methodology, protein sequencing, and separation techniques. Courses are funded entirely by tuition.

Rutgers University in New Jersey also offers a variety of short courses related to biotechnology. Demand from industry for these courses is high, with students coming to New Jersey from California and Europe to participate (60). Tufts University and Worcester Polytechnic Institute both offer short courses in bioprocessing for university-level instructors.

University Biotechnology Centers

University-based biotechnology research centers take many forms and have varied purposes. Examples of centers include the Center for Bioprocess Engineering at MIT, the Biotechnology Program at Cornell, the Center for Biotechnology at the State University of New York at Stony Brook, the University of Wisconsin Biotechnology Center, and the Penn State Biotechnology Institute. The Ohio State University is in the process of establishing a biotechnology center. (See ch. 4 for an extensive listing of biotechnology centers.)

Table 8.9.—Biotechnology Programs Offering Ph.D. Degrees

Year of initiation	University	Program
1955	Massachusetts Institute of Technology	Biochemical Engineering
1970	Rutgers University	Biochemical Engineering
1982	North Carolina State University	Minor in Biotechnology
1984	Case Western Reserve University	Concentration in Biotechnology and Genetic Engineering
1985	University of Iowa	Emphasis in Biochemistry/Biotechnology
1986	Tufts University	Biochemical/Chemical Engineering
1987	Lehigh University	Biochemical Engineering
Planned	University of Illinois, Urbana/Champaign	Biological Engineering
Planned	University of Minnesota	Minor in Biological Process Engineering

SOURCE: Office of Technology Assessment, 1988.

Table 8“10.—Biotechnoiogy Programs Offering Short Courses[a]

Year of initiation	University	Program
1982	Catholic University of America	Center for Advanced Training in Cell & Molecular Biology
1983	American Type Culture Collection	Workshops
1983	State University of New York, Stony Brook	Biotechnology
1984	Cook College of Rutgers University	Biotechnology
1985	University of Minnesota	Institute for Advanced Studies in Biological Process Technology
1986	Tufts University	Biotechnology Engineering Center

[a]Many institutions offer summer and other short courses in fields related to biotechnology This list is only representative of some Of the more established or better known programs.

SOURCE: Office of Technology Assessment, 1988.

Purposes of the centers frequently include conducting or sponsoring research, coordinating biotechnology research and training among the various university departments, providing a forum for multidisciplinary projects, and purchasing specialized equipment. Centers may also be involved with local biotechnology companies in technology transfer and economic development activities. Some centers sponsor short courses in laboratory techniques for both academic and industrial scientists.

Only two of the biotechnology centers contacted by OTA said their sole function was research. All the others reported that some portion of their mission (usually 10 to 35 percent) was for training and education.

Founded in 1981, the Program in Molecular Biology and Biotechnology at the University of North Carolina at Chapel Hill is one of the oldest programs of its kind. The program sponsors workshops and conferences designed to give researchers intensive hands-on experience in DNA technologies. The program also supports core facilities important for research and training in biotechnology and molecular biology. They state their primary purpose as “facilitating the diffusion of molecular technology throughout the biological community.” Together with the North Carolina Biotechnology Center, the program sponsors a university/industry cooperative research center in monoclinal lymphocyte technology (25).

The Center for Biotechnology at the State University of New York at Stony Brook supports “programs for research and education to stimulate a university/industry partnership and economic development” (49). Supported by more than 30 different biomedical departments, ranging from chemistry to medicine, the Center sponsors several activities related to training and education. The Center also sponsors a variety of seminars and conferences on biotechnology, including a workshop cosponsored by Cold Spring Harbor Laboratory in molecular biology for secondary school science teachers. The Center also provides financial support for SUNY students to work in biomedical laboratories.

The University of Wisconsin Biotechnology Center is involved in a variety of training functions. It has sponsored short courses in biocomputing and sequence analysis and workshops in agricultural biotechnology. The Center is also working with the Biochemistry and Chemical Engineering Departments to develop a Bioprocess and Metabolic Engineering Training Consortium (44).

The Michigan Biotechnology Institute has an institutional relationship with universities. Although it is a free-standing institute, it funds master’s, doctoral, and postdoctoral traineeships at Michigan State University, the University of Michigan, and Michigan Technological University.

Other Curricular Components of Biotechnology

New biotechnology is being incorporated into many traditional programs outside of the basic biological sciences, such as chemical engineering, pharmacy, and agriculture.

The University of California at Davis, for example, has no formal curriculum in biotechnology at the graduate or undergraduate level, but does have a Biotechnology Program of the College of

Agriculture and Environmental Sciences to facilitate research and education programs. Discipline-based majors, such as biochemistry, bacteriology, genetics, fermentation science, and engineering, are tailored by the student and his or her advisor with the necessary electives to prepare the student for a career in biotechnology. The Biotechnology program serves to enrich and extend existing strengths by reviewing curricula and assuring that relevant courses are offered frequently enough.

At San Jose State University, the concentration in biochemistry, begun in 1972, is being modified to reflect new requirements for biochemists. A course in recombinant DNA methods is now included in the chemistry curriculum, and other modifications are being considered, A member of the San Jose State University (SJSU) Department of Chemistry reflects a widely held opinion in saying she would "most like to see biotech methods to be incorporated into already established laboratory courses as opposed to having separate specialty courses. " SJSU organized a symposium with representatives of biotechnology firms to determine industry's needs and found that industry was looking for students who are well versed in basic, fundamental principles, and are capable of problem solving and independent thought more than students who are specialized in sophisticated techniques.

Photo credit: Case Western Reserve University

An undergraduate separates myosin and myosin-light-chains, using fast protein liquid chromatography, as part of an undergraduate biotechnology program.

Tufts University has added a course in "Frontiers in Biotechnology" to their chemical engineering curriculum. The course will give chemical engineers an overview of genetic engineering, biotechnology, and hybridoma production, with emphasis on laboratory techniques.

OTA has no figures on the number of universities that have added courses in recombinant DNA and other biotechnologies to traditional majors, but it is probably significant. Many of these courses are new offerings. Until recently, students would not have the opportunity to conduct experiments with recombinant DNA technology until graduate school. Now many of these courses have been introduced to undergraduates and, in some cases, high school students.

Retraining

Retraining has emerged as a significant need given the rapid development of new biotechniques and the large number of researchers who received their formal training before new techniques were widely integrated into biological research. Short courses described previously are a principal way of accomplishing this retraining. In addition, most biotechnology companies, at least the larger ones, provide training funds for their employees. Almost 9 out of 10 (88 percent) of the biotechnology companies surveyed reported that they provide educational assistance to their employees (38).

In addition, retraining is an integral part of many companies' day-today operations. Companies hold seminars, sponsor cross-department training, and establish systems to keep their research staffs abreast of current literature (43).

Retraining is also a principal motivation for companies to enter into collaborative arrangements with universities. These arrangements frequently allow company scientists to spend time in university laboratories, updating their skills (see ch. 7).

Biotechnology in Secondary Schools

Gradually, aspects of genetic engineering and other new biotechnology techniques have reached high school classrooms. Several programs such as the Cold Spring Harbor / SUNY Stony Brook workshop mentioned above, have been designed to teach recombinant DNA techniques to secondary school teachers. Over a dozen States are planning biotechnology educational programs for high schools (10).

The North Carolina Biotechnology Center has embarked on a 3-year Secondary Education Project to introduce biotechnology into the high school curriculum. The first group of high school biology teachers was brought to the center in July 1987 to conduct recombinant DNA experiments and to develop lesson plans and materials to teach the science, applications, and social issues of biotechnology. The University of Wisconsin Biotechnology Center also sponsors workshops for high school biology teachers.

Cold Spring Harbor Laboratory sponsors week-long workshops around the country to educate high school biology teachers in recombinant DNA technology. The 3-month project, conducted in 1987, had a goal of reaching 250 teachers. Twice as many teachers applied as could be accepted (19).

The California Sector of the Industrial Biotechnology Association also sponsors training in biotechnology for high school teachers at three centers in the State (1). California has also recently established a Blue Ribbon Biotechnology Curriculum Advisory Committee in order to strengthen the high school biology curriculum (4).

Biological Sciences Curriculum Study, a major publisher of textbooks and learning modules for high school students, is increasing its emphasis on biotechnology in its material. A module due out in spring 1988 covers ***Advances in Genetic Technologies*** and includes experiments in bacterial transformation and plant crown gall formation (51).

FUNDING OF TRAINING ACTIVITIES

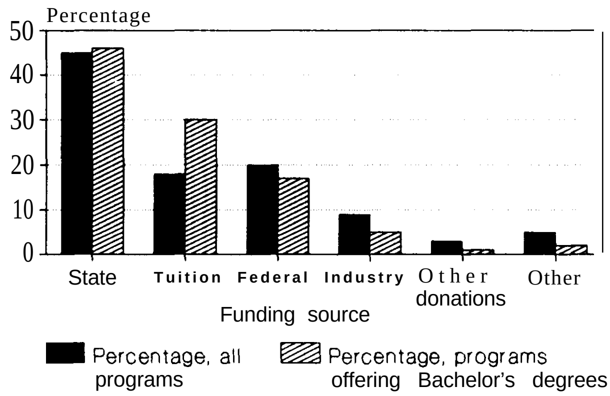
Traditionally, most Federal funding of biotechnology has been directed toward research at major universities. These funds, most of which come from NIH, indirectly support training, though mainly at the graduate and postdoctoral levels. Training at the undergraduate level is supported only to the extent that these funds "trickle down" in the form of making equipment available, providing teaching assistants, and enriching faculty members' abilities to teach subjects related to biotechnology,

States provide a significant amount of funding for education and training in biotechnology. About three-fourths of the programs identified by OTA are at State institutions, and States provide, on average, almost half of the funds for these programs. The Federal Government provides about 20 percent of the programs' funds (figure 8-3).

It is difficult and perhaps artificial to completely separate training funds from research funds, as the two activities are closely linked at U.S. universities. Nonetheless, funds are frequently allocated by State and Federal agencies with one or the other purpose in mind. Programs stressing education rather than research or vice versa have different needs, in degree if not kind, so it is useful to distinguish to the extent possible funds intended for education as opposed to funds intended for research.

As biotechnology education has permeated the undergraduate and even secondary school curriculum, sources of funds have become more diversified. Programs responding to OTA's survey reported that significant percentages of their

Figure 8-3.-Source of Funds for Biotechnology Training and Education Programs



SOURCE: Office of Technology Assessment, 1988.

funds came from State and industrial sources, as well as from student tuition. For the 36 programs reporting their sources of funds, State governments supplied the lion's share of support, providing almost half of the funds. Tuition provided the next largest share of funds, just below one-fifth, followed closely by the Federal Government. Industry-sponsored research provided almost 10 percent of program funds (figure 8-3).

The programs are costly due to expensive equipment and materials and generally intensive laboratory work. One State-subsidized program costs about $10,000 per student (84). Three-fourths of the programs (29 of 41) reported unmet needs for space or equipment.

Federal Funding

Most of the current cadre of Ph.D. biotechnologists in industry and academia were supported by Federal research or training grants when they were trained in the various disciplines that undergird biotechnology (5). However, few Federal funds are designated specifically for biotechnology training. Most agencies have no formal training program; any training in biotechnology is achieved through the usual grants mechanisms. Most direct Federal support to students goes to graduate students in the form of fellowships, traineeships, and research assistantships. However, Federal support for life sciences is strong, and in 1985, Federal funds were the primary source of support for almost 20 percent of the life science Ph.D.s, compared with less than 8 percent of other science and engineering fields (80). Of 35,980 full-time biological science graduate students, 10,532 received some Federal support in 1984 (80). In the life sciences, enrollment rises with increased Federal support, and drops when Federal support drops. A drop in support since 1980 already is reflected in a drop in the Ph.D.s awarded (80). Six Federal agencies contacted by OTA reported specific efforts in training for biotechnology (see ch. 3 for a full discussion of Federal funding).

National Institutes of Health

The National Institutes of Health is by far the largest Federal supplier of fellowships, traineeships, and training grants, providing 87 percent of the funds for these activities. NSF is a distant second with 9.2 percent of the total (80).

Predoctoral training occurs in many fields and many disciplines directly or indirectly related to biotechnology. Postdoctoral traineeships have been funded by the National Institutes of Health (NIH) at a level of $150 to $170 million per year in recent years. NIH estimates that $70 million in , training funds go to students working in areas either directly or indirectly related to biotechnology, mostly at the predoctoral level (83). Most of the funds come from the National Institute of General Medical Sciences (NIGMS). In addition, NIH supports 45 research associates in biotechnology for 1 to 3 years in an NIH laboratory. NIH officials report that the training dollar at NIH has shrunk from 18 percent of the research budget in 1971 to less than 5 percent of the research budget in fiscal year 1988. NIH supports a total of about 12,000 graduate students (80), about half of whom could be expected to be working in areas directly related to biotechnology.

At a 1985 meeting of the NIH Director's Advisory Committee, officials of the White House Office of Science and Technology Policy suggested that NIH support training in biotechnology in all disciplines, including the agricultural and physical sciences. It is not surprising that NIH responded negatively to this suggestion given the agency's strong tradition in the biomedical sciences. A consensus was reached, however, that in order for the United States to maintain a strong lead in biotechnology there must be increased research training in the basic disciplines of biotechnology—molecular genetics, biology, immunology, biochemistry, and virology.

NIH is currently collaborating with the National Science Foundation to support the Massachusetts Institute of Technology Biotechnology Center to enhance research training in bioprocess engineering (see box 3-A). In addition to the predoctoral and postdoctoral fellowships available through the National Research Service Awards Act, the NIH intramural program has recently established a research associateship and a biotechnology fellowship program through which about 40 people will be supported to receive research training in appropriate intramural biotechnology-related laboratories. The average cost is $18,000 to $36,000 a year per individual.

National Science Foundation

The National Science Foundation (NSF) sponsors competitive, peer-reviewed predoctoral fellowships, making 450-540 new 3-year awards each year from an annual appropriation of about $27 million; 25-35 percent of the awards are in the biological and biomedical sciences (55).

At the postdoctoral level, NSF funds about 20 fellows in each of two areas relevant to biotechnology-plant biology and environmental sciences –for a total of $2.2 million per year (55).

NSF also contributes to the Presidential Young Investigator awards, which support outstanding young faculty scientists at a base rate of $25,000 per year for 5 years. In the biological sciences, 25 recipients were named in 1984, 21 in 1985, and 10 in 1986 (55).

Other training funds within NSF are available through the award structure itself, rather than specialized fellowships. However, research grants are estimated to support only 0.3 trainees per grant, due to the small size of most NSF grants (85). NSF also supports biotechnology education through mechanisms such as the Biotechnology Process Engineering Center, which is an NSF Engineering Research Center at the Massachusetts Institute of Technology, and its support of Cold Spring Harbor Laboratories training and outreach programs. Other programs, such as Instrumentation and Laboratory Improvement and Undergraduate Faculty Enhancement, also support training efforts.

Department of Defense

The Office of Naval Research (ONR) supports fellowships run by the National Research Council at a level of about $400,000 annually. Approximately five of the fellowships are in fields related to biotechnology. In addition, many graduate students are supported on contract awards, but it is not clear how many of those are in fields related to biotechnology.

Department of Agriculture

The Food and Agriculture Sciences National Needs Graduate Fellowship Grants program of the Cooperative State Research Service (CSRS) supported 87 doctoral degree candidates in 16 institutions in fiscal year 1986, totaling approximately $1.5 million. Although figures are not available, $45 million in biotechnology research (see ch. 3) provides varying levels of support to a large number of graduate students and postdoctoral fellows. It is difficult to determine the extent to which either of these programs actually supports students working in areas relevant to biotechnology,

In 1984, the U.S. Department of Agriculture initiated a peer-reviewed program of training grants to university departments to support 302 predoctoral students. Approximately 35 percent of the $5 million in training grants were in biotechnology. The same students, who had been guaranteed 3 years of support, received an additional $5 million in 1985, but no new grants could be awarded as no additional funds were available. In 1986, funds were cut to $3 million, thus reducing support for each student. A 1987 appropriation provided $2.8 million dollars, which will be used to fund a new crop of students for the full 3 years, thus substantially reducing the number of awards that can be made (55).

The Agricultural Research Service initiated a competitive postdoctoral program in 1984 that supported 21 people for 1 to 2 years to work on specific projects at ARS laboratories, Award recipients increased to 50 in 1985 and 100 in 1986. The programs' 1986 appropriation was $4 million; about half of the fellowships involved biotechnology (55).

Agency for International Development

Training is an integral part of the AID research programs. Practically every AID-supported research project includes training and networking among the scientists of underdeveloped countries and scientists in the developed world. Training programs range from short workshops to longer, 6-month programs. Graduate training and postdoctoral training is included in many research activities. About one-fifth of all AID research funding is for training and networking, with the exception of the International Agricultural Research Centers, where support for training scientists from lesser-developed countries approximates 7 percent.

Other Federal Agencies

Other agencies provide some training support through various funding mechanisms. The National Oceanic and Atmospheric Administration supports approximately 50 students on 56 projects broadly related to biotechnology. The National Aeronautics and Space Administration supports 50 to 55 graduate and postdoctoral students via grants awarded to universities but has no dedicated money for training, The Food and Drug Administration, Environmental Protection Agency, Veterans Administration, and Department of Energy have no specific programs to support training.

State Funding

States provided about 45 percent of the funds for new initiatives in biotechnology training identified by OTA. Of those States responding to a separate OTA survey (see ch. 4), 17 reported that they directly fund training programs in biotechnology at their State universities and colleges. Not all were able to provide exact dollar figures, In many cases, the State department of higher education provides funds for research and training, under which biotechnology may fall. Because these funds are dispersed to many institutions and many departments within those institutions, accounting for spending specifically on biotechnology training is complex.

Some States, however, were able to report on expenditures for biotechnology training programs. The nature of the programs and the degrees offered were not specified. Of those reporting, expenditures in fiscal year 1987 ranged from $40,000 in Pennsylvania to $1.3 million in Georgia. Others included $250,000 in Connecticut, $500,000 in Iowa, $300,000 in Maryland, $450,000 in Connecticut, $63,000 in New York, and $50)000 in North Dakota. In Massachusetts, funding for biotechnology training must go through the Bay State Skills Corporation, with a requirement for an industry match. The State provided $165)000 in fiscal year 1986 and $75)000 in fiscal year 1987.

Industrial Funding

Industry funding accounted for just under IO percent of the funds of biotechnology training programs surveyed by OTA. In a 1984 survey, 32 percent of 106 biotechnology firms responding indicated that they provided grants and fellowships to schools and individual trainees (12). Based on that survey, it was estimated that biotechnology companies provided between $8 and $24 million for training grants and scholarships in 1984 (11). In addition to grants and scholarships, approximately 12 percent of trainees at research-intensive universities receive industrial support for their research, and 10 percent receive some industrial contribution to their salary. All together, about 19 percent of trainees receive some direct financial assistance from industry in the form of training grants, scholarships, research support, or salary (31).

Private Philanthropy

The Howard Hughes Medical Institute has recently become a principal sponsor of biological education. In 1988, Hughes will announce grants totaling $30 million to bolster undergraduate sciences at liberal arts and historically black institutions. The awards are part of a new 10-year program that will provide $500 million for education in medical and biological sciences. The institute is also funding education projects at several laboratories and gave the National Research Council almost $600,000 to study high school biology education.

The Institute also plans to award 3-year graduate fellowships (renewable for 2 additional years) to 60 students each year. This year's fellows will receive stipends of $12)300, plus $10,700 for tuition and fees.

SUMMARY AND CONCLUSIONS

For the most part, the supply of specialists in biotechnology seems adequate to meet demand at the present time, though shortages in particular areas are evident. Shortages in cutting-edge areas, such as protein engineering, have occurred, but are largely unavoidable. Anticipated shortages of bioprocess engineers have not yet occurred, but may yet occur as more biotechnology products reach the later stages of commercialization. Demand for expertise in plant and animal tissue culture and protein chemistry is high and may be outstripping supply. A shortage of microbial ecologists has been brought about by the need to assess the risks of releasing engineered microorganisms into the environment. A large pool of postdoctoral fellows and trainees in molecular biology who could shift into new areas has prevented the serious shortages of plant molecular biologists predicted several years ago. Many of these scientists were originally trained in bacterial systems.

Growth in employment in biotechnology has been rapid and will continue, although biotechnology is not expected to generate a substantial number of jobs compared with traditional industrial sectors. The need for specialized biotechnology workers, coupled with time required to train personnel, demands planning for future personnel needs. Current employment trends include greater opportunities for technicians and an increase in demand for bioprocess engineers.

University programs in biotechnology have proliferated in recent years, addressing a variety of educational levels. State sources have provided a large percentage of funds for these programs, and Federal funds have provided a much smaller percentage. Consultation with industry is the rule rather than the exception in the development of biotechnology programs. It is too early to assess the effectiveness of most of these programs or industry's satisfaction with the training students in these new programs have received. Nonetheless, the nation's campuses have clearly moved quickly to establish new initiatives in biotechnology research and training.

Biotechnology programs usually emphasize recombinant DNA techniques. Other aspects of biotechnology, such as plant and animal tissue culture, are common though less frequently found in biotechnology curricula. Bioprocess engineering is less evident in the programs identified by OTA, but is gaining in importance. Bioprocess engineering will often be taught as part of a chemical engineering department, and may be less readily identifiable as biotechnology. Only a few programs explicitly cover bioprocess engineering in depth. Many of the best researchers in the field are scattered at various universities, so few programs are focal points of research and training. While the supply of bioprocess and biochemical engineers has not become a bottleneck for the industry, this area remains a major training need.

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