Chapter 3

Federal Funding of Biotechnology Research and Development

"The Administration's R&D budget, like all budgets, must not be viewed in isolation. Budgets are 'carved out' in an environment that is influenced by external pressures and impacts, as well as internal constraints."

Don Fuqua
President, Aerospace Industries Association
Apr. 10, 1987

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INTRODUCTION

Historically, the United States, both in absolute dollar amounts and as a percentage of its research budget, has had the largest commitment to basic research in biological sciences worldwide. The vast majority of Federal research support in the biological sciences goes to university scientists conducting basic research, whereas applied research and development (R&D) has always been considered the responsibility of industry. In 1984, OTA suggested that this division of responsibility has contributed to a widening scientific gap between purely basic research funded by the Federal Government and relatively short-term, product-specific applied research funded by private industry. Lack of research dollars for applied fields, such as bioprocess engineering and applied microbiology (generic applied research), was predicted to create a bottleneck in this country's efforts to commercialize biotechnology (6).

There is no hard evidence that this has occurred. Anecdotal evidence, however, suggests that some critical areas of generic applied research in biotechnology remain underfunded because Federal research agencies consider them too applied and industry considers them too basic. As the technologies are integrated into the innovative processes of various industrial sectors, research needs will differ depending on the sector and its state of advancement. There appears to be broad consensus that Federal funding of both basic and applied research has been and will continue to be critical to the U.S. competitive position in biotechnology.

This chapter catalogues the extent to which Federal agencies are funding research in biotechnology-related areas.[1] It does not, however, attempt to evaluate the effect of Federal funding patterns on the U.S. competitive position in biotechnology. In a previous report, OTA described the difficulties of measuring returns from investment in research (9). The data presented in this report provide a foundation from which a careful analysis of existing strengths and weaknesses in the U.S. biotechnology research infrastructure can be derived—the first step in assessing the U.S. competitive position in biotechnology.

Twelve Federal agencies and one cross-agency program (the Small Business Innovation Research Program) have expended substantial funds for biotechnology R&D in recent years. Basic research is the primary mission of several of these agencies, such as the National Institutes of Health (NIH) and the National Science Foundation (NSF). The National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the National Oceanic and Atmospheric Administration (NOAA) have large technological development programs but are also substantial supporters of basic research, including biotechnology. Other agencies with diverse missions, such as the Department of Defense (DoD) and the U.S. Department of Agriculture (USDA), fund large numbers of R&D projects related to biotechnology. In addition, agencies with substantial regulatory functions, such as the Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (EPA), fund research relevant to their regulatory and scientific missions. Finally, agencies traditionally viewed as service oriented, such as the Veterans' Administration (VA), the National Bureau of Standards (NBS), and the Agency for International Development (AID), fund biotechnology research relevant to their service roles.

[1] The biotechnology funding data presented in this chapter covers fiscal years 1985, 1986, and 1987. All of the data available from the agencies by March, 1988 is included here, Fiscal year 1988 appropriations to the funding agencies, although available, were not included in this report because it was not known how they would be distributed to biotechnology research projects. In certain instances, fiscal year 1988 appropriations to certain agencies are mentioned if biotechnology R&D funded by a particular agency appeared to be affected substantial}.

In September 1986, OTA held a workshop on "Public Funding of Biotechnology Research and Training" (8). Representatives from Federal agencies funding biotechnology research and training were invited to present an overview of their agencies' activities. Participants were encouraged to discuss the substance of the research and to be clear about the definition of biotechnology being used to determine spending levels. Chapter 8 addresses the Federal role in supporting training of biotechnology personnel.

Discussions during the 1986 workshop revealed the following points:

- The diversity of work underway using these technologies is remarkable, ranging from the most basic to the most applied. The tools developed through biotechnology have been fully integrated into both basic and applied work, making fiscal isolation of "biotechnology-related" work an arduous task. Because biotechnology draws from established fields such as biology and engineering, it is usually not separately identified in an agency's budget.
- Agencies define biotechnology differently. How an agency defines biotechnology greatly affects the estimate of its investment in the technology. This precludes any direct comparison of spending across agencies and makes summing up a questionable task. For example, EPA's definition of biotechnology is rather narrow compared to the definition used by NIH. Some agencies were able to provide spending figures under two definitions of biotechnology-one narrow and one broad.

This chapter presents an agency-by-agency overview of Federal investment in biotechnology R&D. The definition used by each agency for accounting purposes is presented for clarification. Most agencies provided actual spending figures for fiscal years 1985, 1986, and 1987, although some were unable to account for biotechnology spending, particularly in fiscal year 1985 (see table 3-l).

Table 3-1 .—Federal Support for Biotechnology Research, 1985-87 (current dollars in thousands)

Agency	FY 1985	FY 1986	FY 1987
National Institutes of Health:			
Basic	1,208,229	1,202,094	1,388,337
Applied	638,916	678,003	887,614
Total	1,847,145	1,880,097	2,275,951
Department of Defense:			
Basic	44,100	51,600	60,800
Applied	48,500	49,000	58,000
Total	92,600	100,600	118,800
National Science Foundation	81,570	84,072	93,800
Department of Energy:			
Basic	45,500	45,000	50,100
Applied	9,600	10,900	11,300
Total	55,100	55,900	61,400
USDA Cooperative State Research Service	48,000	46,000	49,000
USDA Agricultural Research Service	24,500	27,000	35,000
Agency for International Development:			
Broad definition	NA*	46,854	43,756
Narrow definition	NA	14,332	6,082
National Aeronautics and Space Administration	NA	6,400	7,200
Veterans Administration	5,400	6,365	9,400
Environmental Protection Agency	3,000	3,400	5,666
National Bureau of Standards	850	3,300	3,300
Food and Drug Administration	3,000	4,700	5,800
National Oceanic and Atmospheric Administration	2,144	2,215	2,680
Small Business Innovation Research* ●	12,033	12,000	NA

● NA: Not available.

" ● SBIR dollars are a part of the total spending reported by the above agencies. They should not be added on to total spending.

SOURCE: Office of Technology Assessment, 1988.

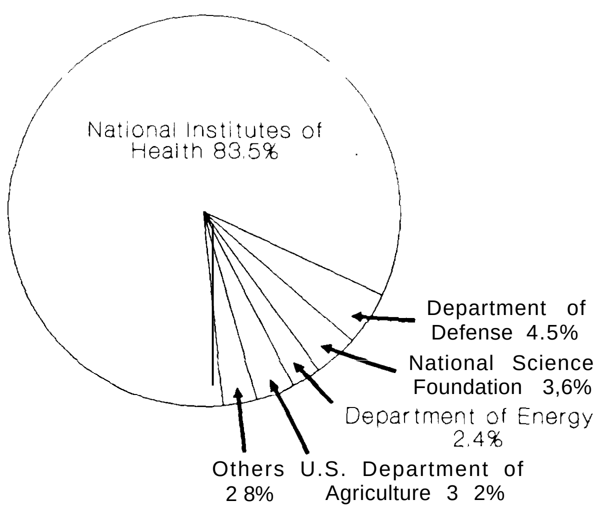
In some cases, estimates were provided for 1988. **In current dollars, the total Federal spending for biotechnology R&D was in the range of $2.16 billion in fiscal year 1985,$2.28 billion in fiscal year 1986, and approximately $2.72 billion in fiscal year 1987.**

NATIONAL INSTITUTES OF HEALTH

Biotechnology is the application of biological systems and organisms to technical and industrial processes. The technologies employed in this area include: classical genetic selection and / or breeding for purposes such as developing baker's yeast, conventional fermentation, and vaccine development; the direct in vitro modification of genetic material, e.g., recombinant DNA, or gene splicing, and other novel techniques for modifying genetic material of living organisms, e.g., cell fusion and hybridoma technology,

The bulk of support for basic biomedical research and training crucial to the development of biotechnology has come from NIH, the government largest nonmilitary research agency (see figure 3-1). NIH promotes research in two categories crucial to the development of biotechnology: basic research directly related to or using the new techniques that comprise biotechnology, and a larger science base of free-ranging research underlying biotechnology. NIH reported that $2.27 billion (38 percent of the total agency R&D budget) was spent in these two areas in fiscal year 1987. Every institute and research division maintains activities in these areas although there are no designated biotechnology programs. The proportion of funds spent in the two categories varies across institutes, with the most concerted efforts in biotechnology being expended by the National Cancer Institute and the National Institute of General Medical Sciences (see table 3-2 for total expenditures in biotechnology by each Institute, 1983-87).

Figure 3-1.-Federal Support **for**
Biotechnology R&D



SOURCE: Office of Technology Assessment, 1988

Basic research *directly* related to or using the new biotechnology includes manipulating genomes, cloning DNA, using special techniques to isolate, detect and characterize DNA, creating hybridomas and producing monoclinal antibodies, and using computer methods to analyze DNA and protein sequences and to design new biopolymers. In fiscal year 1987, NIH support for research and training in this category totaled $888 million, up $210 million over 1986 (see ch. 8 for further discussion of NIH support for training).

Basic research *underlying* the new biotechnology includes undifferentiated free-ranging investigations in genetics, molecular biology (investigations of the genetics of organisms, studies at the molecular level of gene replication and regulation), cell biology (examination at the cellular and organ level of development, growth, and senescence), and immunology (analysis of the structure and function of the immune system). Support for research and training in these areas was estimated at $1.39 billion in fiscal year 1987, $0.19 billion over 1986.

Data pertaining to biotechnology research funding are cataloged by NIH on the basis of grant applications or progress reports and indexed by key words. Budget figures provided are the total costs associated with the awards, including direct and indirect costs, and are not re-

Table 3-2.–Funding of Biotechnology by Each Institute of the National Institutes of Health: 1983-87

	Year (dollars in thousands)				
Institute*	1983 actual	1984 actual	1985 actual	1986 actual	1967 actual
NCI	335,661	379,737	561,325	559,281	645,588
NHLBI	128,098	154,783	145,215	150,226	169,980
NIDR	13,743	14,170	20,802	21,579	22,003
NIDDK	198,863	224,237	161,354	163,300	246,660
NINCDS	105,212	123,652	142,413	149,758	158,989
NIAID	206,465	221,204	224,828	229,300	297,003
NIGMS	246,421	280,311	282,169	308,775	356,100
NICHE	95,928	108,065	123,673	122,837	161,215
NET	22,080	28,792	35,225	33,780	37,695
NIEHS	10,941	10,918	13,438	13,714	14,556
NIA	6,222	9,134	13,912	14,775	20,328
NIAMS	—	—	40,757	29,700	48,903
DRR	66,738	87,222	82,034	82,972	96,181
NLM	—	—	—	100	750
Total	1,436,372	1,642,225	1,847,145	1,880,097	2,275,951

“Institute abbreviations refer, in order, to the following: National Cancer institute; National Heart, Lung, and Blood Institute; National Institute of Dental Research; National institute of Diabetes and Digestive and Kidney Disease; National institute of Neurological and Communicative Disorders and Stroke; National Institute of Allergy and Infectious Diseases; National institute of General Medical Sciences; National Institute of Child Health and Human Development; National Eye Institute; National Institute of Environmental Health Sciences; National Institute on Aging; National institute of Arthritis, Musculoskeletal and Skin Diseases; Division of Research Resources; National Library of Medicine.

SOURCE: National institutes of Health, 1988.

lated to the proportion of recombinant DNA research in the total research effort. Thus, some overestimation of the amount going directly to research probably occurs.

In recent years, there has been increasing pressure from the White House and others for NIH to expand its biotechnology support (1,11). NIH maintains that it best supports the scientific base necessary for biotechnology by approving the best basic research proposals submitted to the Institutes for funding. At a 1985 meeting of the NIH director’s advisory committee, representatives of some of the smaller biotechnology companies argued for funding by NIH of more generic applied research, those areas requiring intensive capital and posing high risk, such as bioprocessing technologies. They also suggested that NIH promote “intellectual support’’ for biotechnology companies, allowing NIH scientists to consult with industry, a policy already in the process of change at the time of the meeting.

In 1987, an NIH committee began drafting guidelines that will give companies unprecedented access to NIH resources. These guidelines are in response to the Technology Transfer Act of 1986 (Public Law 99-502), which requires Federal laboratories and their scientists to share their work with industry. Under the guidelines, companies will be guaranteed exclusive licensing rights to the fruits of any research undertaken with a government laboratory. In addition, NIH scientists will be encouraged to seek commercial applications for their work through a system of incentives that includes a share of the royalties gained from product development. The opening of NIH laboratory doors offers great promise to commercial biotechnology, which is so reliant on research funded by NIH and research conducted by NIH scientists (2).

Other important resources for biotechnology firms supported by NIH are the Human Mutant Cell Repository, a cell bank in Camden, NJ, and GenBank®, the nucleic acid sequence data bank, which is also supported by DOE. BIONET is a resource for providing analytical services regarding DNA and protein sequences.

NATIONAL SCIENCE FOUNDATION

Work categorized as research related to biotechnology includes activities in fundamental genetics, cell physiology, cell culture biology, basic biochemistry and enzymology, and bioprocessing engineering, which are generally regarded as being directly related to the further development of biotechnology.

The National Science Foundation has as its mission the support of basic research in colleges and universities in the United States. The NSF budget accounted for about 8 percent ($1.5 billion) of the fiscal year 1987 Federal nondefense budget for R&D. Approximately 94 percent of the NSF budget goes to basic research, with only 6 percent being awarded for applied research. In 1985, NSF made its first awards in its Engineering Research Centers program, established to facilitate technology transfer and multidisciplinary research. One of the first six centers is the Biotechnology Process Engineering Center at the Massachusetts Institute of Technology, which received start-up funds of $2 million from NSF and $150,000 from the National Institute of General Medical Sciences and the National Cancer Institute (both of NIH) in 1985 to investigate engineering technologies for bioprocessing (see box 3-A for further discussion).

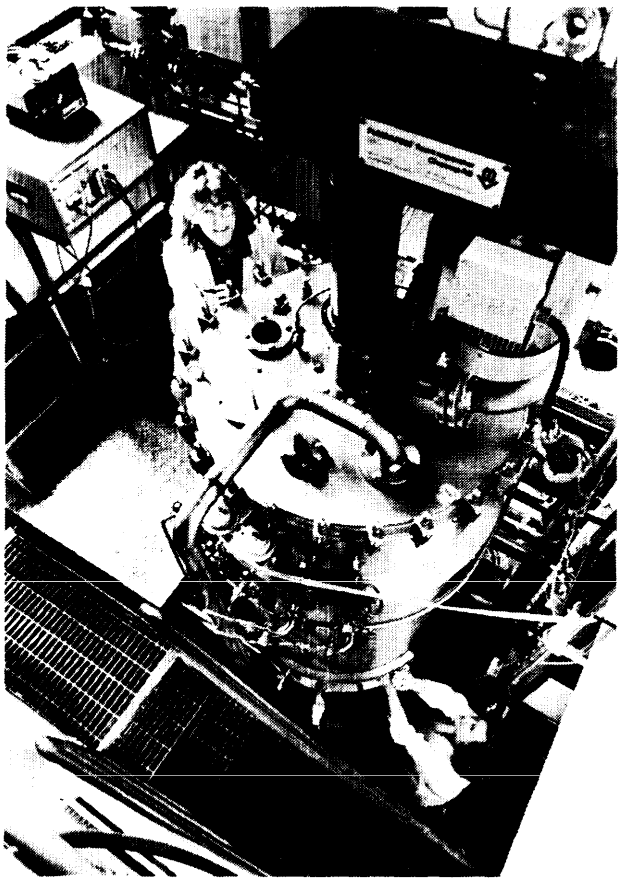


Photo credit: Marvin Lewiton

Undergraduate students working with a 1,500-liter fermenter in MIT's Bioseparations Research Laboratory, supported in part by the National Institutes of Health and the National Science Foundation.

NSF reports that it funded 1,712 biotechnology projects at $84 million in fiscal year 1986. Expenditures for biotechnology R&D in fiscal year 1987 stand at $93.8 million. NSF has requested $108.5 million for biotechnology research in its fiscal year 1988 budget.

NSF determines its biotechnology spending va a new data collection system implemented by an Office of Biotechnology Coordination at NSF. Program officers are required by NSF to judge all new awards for biotechnology relatedness on a subjective scale from none to all by one-third increments. NSF specifies a category of work as related to biotechnology if it includes research activities in fundamental genetics, cell physiology, cell culture biology, basic biochemistry and enzymology, and bioprocess engineering. The largest single area in which NSF identifies research related to biotechnology is genetics, both prokaryotic and eukaryotic. The second largest area is regulation of gene expression.

In addition to direct research support, the NSF instrumentation program provides a great deal of research support for instrumentation acquisition; microchemical instrumentation, most commonly used in biotechnology, is a part. Awards in the instrumentation program are not coded for biotechnology relatedness because use is difficult to predict and the awards are usually made to groups of individuals.

The NSF Engineering Directorate has initiated a program to support multidisciplinary groups in applied biotechnology. This program focuses on the application of engineering to the recent advances in molecular biology, genetics, microbiol-

Box 3-A.—The Biotechnology Process Engineering Center at the Massachusetts Institute of Technology

The Biotechnology Process Engineering Center (BPEC) at the Massachusetts Institute of Technology (MIT) was established in 1985. Funding is provided by the National Science Foundation, the National Institutes of Health, MIT, and industry. Contributions by NIH and NSF since 1985 are:

	NIH	NSF
Fiscal year 1985	$150,000	$2,000,000
Fiscal year 1986	$100,000	$3,000,000
Fiscal year 1987	$100,000	$3,295,000

NSF will provide support for the Center for the first 5 years, after which it must be self-sufficient. NIH funds are primarily intended for undergraduate and graduate training.

Scientists at the Center come from five different departments of two schools within MIT. The School of Engineering contributes faculty from the Departments of Chemical Engineering, Electrical Engineering, and Nuclear Engineering. The Departments of Applied Biological Sciences and Biology participate from the School of Science. The Director of the Center reports to the Dean of Engineering and works with university-comprised committees and an Industrial Advisory Board consisting of 11 biotechnology industrialists. An Operating Committee oversees the education and research of the Center as well as the activities of the Center's Industrial Consortium.

The Center provides educational opportunities for both undergraduates and graduates, and training programs for industrialists in courses such as fermentation technology, microbial principles of biotechnology, drug delivery, downstream processing, and modeling, simulation, and optimization. In addition, the Center houses visiting scientists from industry who spend extended periods of time working in the laboratories.

Foremost on the mind of those involved in the Center is the need to generate industrial sponsorship. By 1987, 15 companies had supported 16 projects totaling approximately $1.5 million. Companies can also donate equipment. In 1986, $770,000 worth of equipment was received. Industry donated $2,4 million for the construction of a fermentation and downstream pilot plant located on the MIT campus that became operational in 1986. The pilot plant, a small but impressive facility, will handle biotechnology processes from fermentation to product isolation.

The Center also hopes to attract a degree of financial independence through its industrial Consortium, which provides a more formal basis for interaction and collaboration between the Center and industry. Members of the consortium pay an annual subscription fee ranging from $2,000 to $20,000 to receive information and services relating to the activities of the Center. By 1987, 50 companies had signed up.

While still in its youth, the BPEC faces impending adulthood when the Federal purse closes in 1990. Critics of the mandated fund-raising strategy are concerned that superb scientists are spending their time on desperate attempts to raise money when they should be conducting research. Others are skeptical about the ability of the Center to raise sufficient funds from an industry that has no money to spare and plenty of other places to spend it. Proponents of the Center assert that it is encouraging university-industry collaboration in an area where critical applied research and development needs exist.

SOWICE: D.I. Wang, "Biotechnology process Engineering Center," *The Engineering Research Centers: Leaders in Change* (Washington, DC: National Academy Press, 1987). personal communication, Office of the Director, Biotechnology Process Engineering Center, August 1987.

ogy, cellular physiology, and biochemistry that have made it possible to use living systems to produce a wide range of economically important substances. Up to $500)000 per year will be provided, for up to 5 years, for research teams to advance capability in biotechnology engineering and to provide a training environment for the biotechnologies of the future.

NSF also funds environmental biology pertinent to biotechnology regulation ($3 million in fiscal year 1985 and $1.9 million in fiscal year 1986), and an area called "impact of biotechnology" ($255)500 in fiscal year 1985 and $241,400 in fiscal year 1986). Bioengineering and bioprocessing research funds increased dramatically from *$2,891,000* in fiscal year 1985 to $4,330,200 in fiscal year 1986, Cell culture and genetics also received more funds in 1986 than in 1985, but bioelectronics, bioenergetics, and cell fusion received significantly less support in 1986 (see table 3-3 for a breakdown by field of spending in fiscal years 1985 and 1986).

NSF officials had anticipated the emergence of a new class of awards in the near future that will include greater interaction with the States for supporting larger biotechnology centers, a small number of cooperative activities, and a small number of "mini- centers," which are at the university departmental level. Each of these centers would not necessarily be problem oriented, but would stimulate cross-disciplinary research within the biological sciences. As of early 1988, the funding status of these centers was uncertain because the fiscal year 1988 budget for NSF was not at the level that the agency expected.

Table 3-3.—NSF Support of Biotechnology-Related Research in Fiscal Years 1985 and 1986 (dollars in thousands)

Field	1985	1986
Antibodies/antigens	3,774.8	**3,631.9**
Bioconversion	1,801.8	**1,414.3**
Bioelectronics	1,640.2	**755.1**
Bioenergetics	5,514.4	**2,778.9**
Bioengineering/bioprocessing	2,891.9	**4,330.2**
Biomembranes	4,317.5	**4,754.5**
Cell regulators/cell modulators	9,423.7	**10,763.1**
Cell culture	2,598.7	**4,444.3**
Cell fusion	446.8	**222.2**
Chemistry	7,732.5	**6,552.2**
Environmental biology	3,010.2	**1,945.2**
Enzyme structure/function	7,099.1	**8,608.4**
Genetics	26,501.1	**30,699.0**
Impact of biotechnology	255.5	**241.4**
Reproduction	2,600.3	**2,384.4**
Special resources	1,961.7	**546.8**
Total	81,570.2	84,071.9

SOURCE: National Science Foundation, 1987.

DEPARTMENT OF DEFENSE

Biotechnology is defined as any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants, or to develop micro-organisms for specific uses. The technologies specifically included in this definition are recombinant DNA, novel bioprocessing techniques, cell fusion technology including hybridomas, and somatic cell genetics.

The Department of Defense supported 69 percent of total Federal R&Din fiscal year 1987, with an R&D budget of $40.8 billion. This is its highest share of Federal R&D since 1962.

In 1986, DoD established a steering committee under the Deputy Undersecretary of Defense for Research and Advanced Technology to examine biotechnology policy within the agency. The committee reports that the DoD effort in biotechnology is essentially divided between two branches of the armed forces; the Army, which supports mostly medical biotechnology; and the Navy, which supports mostly nonmedical biotechnology. The Defense Advanced Research Projects Agency (DARPA) and the Air Force also initiated a small investment in nonmedical biotechnology in fiscal year 1986. DoD intends to decrease funding levels in medical biotechnology and increase funds for nonmedical biotechnology over the next several years.

DoD runs a distant second to NIH in Federal funding of biotechnology research, having spent the equivalent of l/20th the NIH budget for biotechnology in fiscal year 1987. In fiscal year 1985, the DoD spent a total of $92.6 million on biotechnology research ($44.1 million in basic research and $48.5 million in applied research). In fiscal year 1986, $100.6 million was spent ($51.6 million in basic areas and $49 million in applied). In fiscal year 1987, biotechnology funding was $118.8 million ($60.8 million in basic research and $58 million in applied areas). Overall, DoD funding for biotechnology research is almost evenly divided between intramural and extramural programs–$27.5 million for intramural and $21 million for extramural programs in fiscal year 1986. Since fiscal year 1985, funding has shifted slightly toward more extramural research. Eighty-five percent of the extramural research is conducted in universities. Fiscal year 1987 funding include a $3 million one-time carry over of funds from the Defense University Research Initiative Program (DURIP). Proposed funding of biotechnology R&D for fiscal year 1988 shows only slight growth.

Medical biotechnology is primarily directed toward vaccine development and diagnostic methodology. Targeted vaccines are those against militarily relevant diseases, such as Rift Valley Fever and dengue, that are not of public health concern in the United States but occur primarily in third world countries. DoD and NIH cooperate in vaccine research for malaria. The diagnostics efforts focus on use of DNA probes and monoclonal antibodies, which have also been developed by DoD for its chemical-biological defense program to produce methods for pretreatment, antidotes, and enzymes for decontamination. In 1986, the Army Medical Research and Development Command was largely responsible for funding 57 biotechnology projects ($42 million) in the area of chemical-biological warfare (4). In fiscal year 1986, DoD allocated $32 million for basic research and $49 million for applied research in medical biotechnology-a slight increase over the fiscal year 1985 levels ($30.3 million and $48.5 million respectively).

The nonmedical biotechnology programs in DoD are diverse. One of the areas receiving the greatest funding is materials research: biopolymers, fiber, and adhesives and intermediate compounds for use in composites. Other areas are pollution control, biosensors, biocorrosion and biofouling control, compliant coatings, and bimolecular electronics. Research in these areas was supported at a level of $19 million in fiscal year 1986; essentially all of it being basic research. This figure was up from $13.8 million in fiscal year 1985, primarily due to the DURIP where four universities were funded to do interdisciplinary research in biotechnology as it applies to new materials and marine science. Each program receives approximately $2 million a year, with funds decreasing slightly in fiscal year 1988 after the initial equipment capitalization. In fiscal year 1987, DoD allocated an additional $1.5 million for more applied research in these areas.

Under special programs DURIP supports the purchase of some equipment for biotechnology programs. DoD estimates that about $2.1 million was awarded to universities in fiscal year 1985 for instrumentation directly related to biotechnology. About 15 percent of the funds are spent on industry research.

DEPARTMENT OF ENERGY

Biotechnology related research is defined as research information and methodologies that could be used by industrial scientists to develop the products and processes of biotechnology, and includes research needed as the scientific base to develop that information.

Total expenditures for biotechnology R&D in the Department of Energy were over $61 million in fiscal year 1987, or about 1 percent of its total R&D budget. DOE supports both basic and applied research relevant to biotechnology. Applied research is supported under the Assistant Secretary for Conservation and Renewable Energy and the Assistant Secretary for Fossil Energy. These programs serve DOE's mission of developing a variety of energy resources in an environmentally sound way. Historically, DOE has been involved in research on the medical effects of radiation because of its mandate to oversee atomic energy. Expertise in this area has expanded to other areas of human genetics, plant biology, and biomass resources.

Under the applied research programs of Conservation and Renewable Energy, renewable biomass resources, such as woody and herbaceous crops, are being developed. Projects include species screening, plant breeding, and tissue culture studies ($3.5 million in fiscal year 1987). Other studies include the conversion of biomass to fuel ethanol. Under a biocatalysis project, bioreactors are being studied as a way to produce specialty chemicals ($5.9 million in fiscal year 1987). Biotechnology research in fossil energy includes coal cleaning, liquefaction and gasification, fuel gas upgrading, and techniques to enhance oil recovery from wells. Funding in this area in fiscal year 1987 was an estimated $1.9 million, down from $2.8 million in fiscal year 1986. Thus, the total applied research budget in biotechnology-related areas in fiscal year 1987 is estimated at $11.3 million (see table 3-4).

Research that is basic and relevant to biotechnology is supported by the Office of Basic Energy Research (OBER) and the Office of Health and Environmental Research (OHER). Total support for basic research relevant to biotechnology totaled $50.1 million in fiscal year 1987. In OBER, studies are conducted in plant sciences, quite extensively in bioenergetics, photosynthesis, and control of plant growth and development. Microbial research is conducted dealing with mechanisms of lignocellulose degradation, fermentation, and microbe interactions. In fiscal year 1987, $16,5 million was spent on biotechnology-relevant research in that Office, up from $12 million in fiscal year 1986. Thirty-three percent of the research is conducted intramurally.

OHER has programs in molecular and cellular biology; molecular genetics, cytogenetics, and mouse genetics; structural and analytical studies of macromolecules; and physical ecology. Much of the biotechnology work in OHER is aimed at explaining the molecular basis of mutagenesis and gene expression and the structure of nucleic acids and proteins. The fiscal year 1987 budget for biotechnology in OHER was $33.6 million, modestly increased over fiscal year 1986. Eighty-five percent of the biotechnology-related research is conducted intramurally.

Table 3-4.-DOE Support of Biotechnology R&D, Fiscal Years 1985-87 (dollars in millions)

	1985	1986	1987
Basic research:			
Office of Health and Environmental Research	33.1	33.0	33.6
Office of Basic Energy Research	12.4	12.0	16.5
Subtotal	45.5	45.0	50.1
Applied research:			
Biomass Energy Technology Division	5.6	5.5	5.9
Energy Conservation and Utilization Technologies	2.0	2.6	3.5
Fossil Energy	2.0	2.8	1.9
Subtotal	9.6	10.9	11.3
Total	55.1	55.9	61.4

SOURCE: Department of Energy, 1987.

DOE labs have historically been interested in the human genome, primarily for the purpose of developing techniques that would allow measurements of mutation rates in human populations. In 1986, OHER held a conference, hosted by DOE's Los Alamos National Laboratory, to discuss the feasibility of undertaking sequencing of the human genome. Los Alamos, together with Lawrence Livermore National Laboratory has been involved in the National Laboratory Gene Library Project, an effort to construct a chromosome-specific gene library from isolated human chromosomes.

DOE has proposed mapping the entire complement of human chromosomes known as the human genome—a massive effort ultimately requiring the order of each nucleotide along the DNA in each chromosome to be determined. There has been considerable debate over the extent to which such an effort should be undertaken by the Federal Government and over which agency should coordinate the effort, A subcommittee of the Health and Environmental Advisory Committee (HERAC) of OHER strongly urged that DOE commit a large, multi-year, multidisciplinary undertaking to make a complete physical map of the human genome (10). In February 1988, a National Research Council report urged funding a project to map the entire human genome, but did not specify which agency should lead such an initiative (3). Funding for the DOE initiative in mapping the human genome began in fiscal year 1987, with $4.7 million going to 10 projects at 3 national laboratories and Harvard and Columbia Universities. These projects are aimed at improving existing methods for mapping and sequencing DNA, devising advanced computer analysis methods, and employing automation and robotics to generate new tools for molecular biologists. OTA has published an assessment of issues relating to a human genome mapping initiative (7).

Biotechnology research is also conducted at other DOE labs, such as the Ames Laboratory, Argonne National Laboratory, the Savannah River Laboratory, Brookhaven National Laboratory, Idaho National Engineering Laboratory, Oak Ridge National Laboratory, Pacific Northwest Laboratory, and Lawrence Berkeley Laboratory. These programs are funded primarily out of OEHR's intramural program.

U.S. DEPARTMENT OF AGRICULTURE

Because of the size and complexity of the USDA, programs in biotechnology research and training have been examined in the two major agencies responsible for R&D within the Department—the Cooperative State Research Service (CSRS) and the Agricultural Research Service (ARS). These two agencies differ greatly in both mission and budget. In addition, they define biotechnology differently. Combined, they report spending $73 million on biotechnology research and development in fiscal year 1986. The combined budget increased to $84 million in fiscal year 1987 but will fall to $82 million in fiscal year 1988. CSRS and ARS have been examined separately in this report. Chapter 10 presents a more thorough discussion of U.S. investment in plant agriculture as related to biotechnology.

Cooperative State Research Service

> Biotechnology refers to the improved or modified organism, microbe, plant, or animal, and 'new research techniques' or 'technology' refers to contemporary 'tools' available to scientists for the purpose of biotechnology development.

CSRS is the USDA's liaison to the State university system for the conduct of agricultural research. Of all Federal agencies, CSRS handles the most diverse types of research funding, including formula funds, such as the Hatch Act (1862 Universities), MacIntire-Stennis Cooperative Forestry funds, Evans-Allen funds (1890 Colleges and Tuskegee University), and the Animal Health and Disease Section 1433 funds. The States provide research funds on a matching basis, which now exceed the requirement by about three-fold. Of the total State Agricultural Experiment Station (SAES) research funding, Federal formula funds average 19 percent, State funds over 60 percent, and all other funds (private, Federal grants, etc.) about 20 percent. In addition, CSRS handles the Special Research Grant Program, Competitive Research Grants Program, and USDA Higher Education Fellowships. There are biotechnology programs in all of these funding categories. The diversity of funding mechanisms complicates efforts at developing a central data management system to track all research being done in biotechnology.

The biotechnology research funding from CSRS for fiscal year 1987 totaled $49 million and supported nearly 2,000 individual projects. This is up from $46 million in fiscal year 1986. Funding for biotechnology in 1985, however, was more than double that from the previous year. This was a result of a congressional appropriation of $20 million awarded to the Competitive Grants program for research targeted to agricultural biotechnology.

Research projects in biotechnology include areas using techniques such as tissue culture where specific selection and directed mutagenesis has been used, drug development through use of monoclonal antibodies, DNA probes, DNA sequencing, and protein sequencing. Six hundred projects are being supported in an area labeled "fringe biotechnology," which includes categories such as tissue culture for plant propagation purposes, isozyme isolation for speciation, classical serological work for relationships or for identification, and metabolic studies. Eleven projects being funded are examining the economic and social effects of biotechnology.

The $49 million within CSRS is divided as follows within each funding category: Hatch Act, $11.6 million; MacIntire-Stennis Cooperative Forestry, $231,000; 1890 Colleges and Tuskegee University, $210,000; Special Research Grants, $4 million; Competitive Research Grants, $28.6 million; and Animal Health and Disease, $514,000. The Forestry Competitive Research Grant Program administered by CSRS has $1.7 million for biotechnology and is included in the preceding total. The preceding totals do not include biotechnology research supported by State funding.

Agricultural Research Service

> Biotechnology includes projects that use techniques such as gene cloning in micro-organisms, nucleic acid hybridization, biological and biochemical synthesis of nucleic acids and proteins, use of monoclinal antibodies, affinity column separation of antigens, use of immobilized enzymes and cells, protoplasm fusion, regeneration of plants from tissue culture, transfer of embryos, gene mapping, and synthesis of peptide neurohormones.

As its name implies, ARS is the primary research agency within the USDA. It is the in-house agency of USDA on intramural research programs, although it does spend about $20 million a year on specific cooperative agreements. ARS conducts research for specific user groups within the USDA, such as the Animal and Plant Health Inspection Service, Food Safety Inspection Service, and Soil Conservation Service. ARS reports that it is applying the new technologies, particularly the advances in molecular biology, to study and understand fundamental biological processes and to modify and regulate these processes for the solution of agricultural problems. ARS does not consider biotechnology as a discipline or area of research. Thus, resources are allocated to specific high priority problems, and biotechnology techniques or methodologies are used in research projects throughout much of the total program.

In fiscal year 1986, ARS projects using biotechnology techniques totaled about $27 million. These projects involved about 200 scientists who use biotechnology techniques. By the end of 1987 these totals increased to about $35 million and about 350 scientists.

DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

Biotechnology is the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services.

For the past several years, the National Sea Grant College Program of NOAA has invested a small but significant share of its budget to research that will aid in the development of marine biotechnology. Research on marine natural products includes fundamental chemical and biological studies directed toward discovering novel biochemical whose properties make them of potential use in medicine, medical research, and agricultural and chemical studies directed toward the development of industrial chemicals and materials. In fiscal year 1985, 56 projects in the categories listed below were supported with $2,144,000 in Federal funds and $1,361,000 in matching funds. This accounted for roughly 5.5 percent of the Sea Grant Budget. In fiscal year 1986, total NOAA spending on biotechnology was $2,215,000 for 55 projects. This figure was matched by an additional $1,702,000. In fiscal year 1987, NOAA spending on biotechnology was at $2,680,000 for 66 projects, and matched by an additional $1,789)000.

There are four categories of research: biochemistry and pharmacology (up from $865,000 in fiscal year 1986 to $916,000 in fiscal year 1987); genetic engineering (up from $624,000 in fiscal year 1986 to $778,000 in fiscal year 1987); biochemical engineering (down from $581,000 in 1985 to $393,000 in 1987); and microbiology and botany (up from $342,000 in 1986 to $593,000 in fiscal year 1987) (see table 3-5). All Sea Grant research is conducted extramurally.

Research in biochemistry and pharmacology—the fields receiving the most funds—is directed toward isolation, identification, and biological evaluation of novel marine substances of potential use in medicine or industry. Two new anticancer compounds, for example, were isolated and are under further evaluation by the National Cancer Institute. Other research areas focus on manipulation of the genetic complement of animals or micro-organisms to produce useful diagnostic or quality control reagents, control diseases of marine organisms, process waste materials, and enhance the growth and competence of aquacultured species.

Projects categorized under “biochemical engineering” concern the production of materials and development of processes potentially useful in industry. For example, academic scientists interested in the nutritional role of vitamin B and its analogues--the cobalamins—in the biological processes of the ocean have isolated from marine animals novel proteins with an extraordinary affinity for vitamin B. Subsequent studies showed the proteins to be cheaper and more specific reagents for determining vitamin B than current reagents used in clinical chemistry. Their commercialization, which is in the early collaborative stages with

Table 3-5.–NOAA Funding for Sea Grant Projects in Biotechnology in Fiscal Years 1978 to 1987 (dollars in thousands)

Category	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Biochemistry and pharmacology	382	465	440	402	525	440	671	820	865	916
Genetic engineering	—	—	—	100[a]	266	419	487	537	624	778
Biochemical engineering and industrial chemicals	206	246	349	285	454	515	540	581	384	393
Microbiology and phycology	—	—	—	50[a]	100[a]	284	248	206	342	593
Totals	588	711	789	837	1,345	1,658	1,946	2,144	2,215	2,680

[a]Estimate

SOURCE: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1988.

industry, is expected to be successful and to increase the sophistication of studying diseases such as pernicious anemia and certain mental disorders.

National Bureau of Standards

Biotechnology is the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services.

The Senate Committee on Commerce, Science and Transportation in its report on the authorization of the National Bureau of Standards (NBS) for fiscal year 1985, directed NBS to prepare a plan on a national effort in measurements and standards for biotechnology. The plan recognized that commercialization of biotechnology will be measurement intensive with an estimated cost of up to 25 percent added to the products of biotechnology for measurement. Measurements are made at each stage in the development of biotechnology products, from the original design of production processes, through the acquisition of raw materials, to the ultimate consumption of products in the marketplace. These measurements are primarily chemical and physical in nature.

The Biotechnology Program at NBS is a new program, created to develop measurement methods and standards to advance the commercialization of biotechnology in the United States. The main focuses of the research are:

- development and standardization of techniques needed to achieve homogeneity in protein samples;
- assessment of purity of samples produced by biotechnological methods including primary protein structure determination; and
- aiding industry on standards problems related to the scale-up and automation necessary to get biotechnology from the laboratory to the commercial marketplace. This includes research in catalysis, analytical and process measurements, and separation technology.

In fiscal year 1985, NBS spent $850,000 to determine its capabilities in advance measurement in biotechnology, setting of standards, and developing reference data. In fiscal year 1986, $1.9 million was allocated from the NBS Director's competence fund and $1.4 million was allocated for the new biotechnology initiative by congressional appropriation; $411)600 of this was spent on equipment. Thus, a total of $3.3 million was allocated in fiscal year 1986 for biotechnology, approximately 2 percent of the total NBS budget. The fiscal year 1987 budget for biotechnology remained at $3.3 million.

Approximately 40 percent of the research is basic and 60 percent is generic applied. An example of generic applied research is two-dimensional electrophoresis, where research is needed to improve technique reproducibility. Another example is research on the dynamic properties of fluids, an area critical to bioengineering.

One of the most ambitious new biotechnology projects at NBS is a joint venture with the University of Maryland in Montgomery County, MD. This venture, called the Center for Advanced Research in Biotechnology (CARB), will combine interdisciplinary, biotechnology-related resources from academia, industry, and government in an organization that will serve as a national resource for biotechnology-related measurement research and services (see ch. 9). There are plans to involve more universities in this joint venture.

A committee within NBS has been established to define standards that will be needed in biotechnology. Examples are characterization and identification of biomolecules, bioengineering processing and controls, and improved x-ray and neutron data collection.

NBS anticipates a growing need for the development of clinical standards for testing new biotechnology products, such as standards that are used to calibrate scientific instruments and to validate and evaluate data. Work being done to provide data needed in bioengineering is mainly focused on fermenters, establishing equilibrium constants, diffusion coefficients, and mass transport coefficients needed to build from the laboratory to the industrial bioreactor. The Center for chemical Engineering at NBS is developing sensors that can be used in connection with bioreactors.

AGENCY FOR INTERNATIONAL DEVELOPMENT

Biotechnology, broadly defined, includes any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses.

AID, an agency of the State Department, is the foreign assistance arm of the U.S. Government and is not, per se, a research agency. The Agency's mandate is to work with developing countries in their efforts to meet basic human needs—to overcome the problems of hunger, illiteracy, disease, and early death. Technology development and transfer, including biotechnology, is one of the basic components in the Agency's strategy to achieve its goal. Given the nature of this goal, the research supported by AID is clearly directed to the development of specific products or systems that will be useful in improving human health conditions, agricultural production, and rural development in the developing world. AID supports projects in the United States and overseas. In general, AID finances research that is expected to produce usable results within 3 to 5 years.

The overall research portfolio is comprised of projects supported from several offices within AID, and reflect the Agency's organization. AID is divided into central and regional bureaus and independent offices. Regional bureaus focus on the needs of a specific geographic region and serve as the Washington coordinating arm of the field activities conducted by AID missions. Central bureaus address agency-wide questions, e.g., private enterprise. The central Bureau for Science and Technology provides technical assistance for the entire agency, and supports and initiates worldwide programs in science and technology. This bureau also coordinates AID's support of the 13 International Agricultural Research Centers. An additional locus of research activity was established in 1980, with the creation of the Office of the Science Advisor. The purpose of this office is specifically to encourage an innovative and collaborative approach to development research, technology transfer, and related capacity building.

AID tries to enter established research programs and applies its funds to direct some of the established work toward a particular problem that is currently underfunded. For example, a project to develop a vaccine to rinderpest—a serious prob-

Table 3-6.—AID Funds for Biotechnology in Fiscal Years 1986 and 1987

	(dollars in thousands)			
	Broad definition		Narrow definition	
Administrative unit	1986	1987	1986	1987
Regional Bureaus/Country Missions				
Thailand	4,400	2,000	1,100	
India:				
Agricultural	1,617	1,500	404	
Health	4,600	5,413	1,150	
Latin America/Caribbean	–	45	–	
Bureau for Science and Technology				
Agriculture:				
Plants	2,662	1,460	663	
Animals	1,135	714	898	
International Agriculture Research Centers	10,000	5,000	2,000	2,000
Health:				
Vaccines	9,000	9,400	3,000	
Diagnostics	800	2,400	400	
Therapeutics	–	4,300	–	—
Vectors	1,700	—	200	—
Population:				
Contraceptive immunology	918	1,000	918	250
Office of the Science Advisor:				
Health	2,996	3,099	1,032	1,215
Agriculture	7,026	7,425	2,567	2,617
Totals	46,854	43,756	14,332	6,082

SOURCE: US. Agency for International Development, 1987, lem in Africa—is being conducted by scientists at the University of California at Davis, where research was underway prior to AID involvement. AID has supplemented the effort through additional funds and is supporting postdoctoral training for two African scientists so that they can continue research in their native country. In another example, AID has piggybacked onto a Colorado State University (CSU) research project that is directed toward increasing the genetic diversity of rice, sorghum, millet, and other crops heavily used in underdeveloped countries. Researchers from developing countries are supported for a 6-month training program at CSU.

AID provided OTA with two sets of budgetary figures for biotechnology activities in fiscal years 1986 and 1987 (see table 3-6). One set adopts the broader OTA definition and arrives at a total figure of $46.8 million in 1986, and $43.7 million in 1987 (about 3 percent of the total AID budget); the second set narrows the definition to focus specifically on recombinant DNA, cell fusion, and novel bioprocessing techniques, arriving at a total figure of $14.3 million in 1986 and $6 million in 1987 (1 percent of the total AID budget).

U.S. ENVIRONMENTAL PROTECTION AGENCY

Biotechnology is defined generally as the use of living organisms to produce products beneficial to mankind. It is the application of biological organisms to technical and industrial processes. It involves the use of 'novel' microbes, which have been altered or manipulated by humans through techniques of genetic engineering.

The U.S. Environmental Protection Agency (EPA) is primarily a regulatory agency, although research programs providing a scientific basis for regulatory activities accounted for nearly 25 percent ($320 million) of the agency's total budget in fiscal year 1985. Roughly 1 percent of the R&D budget ($3 million) was devoted to biotechnology research and biotechnology risk assessment. The majority of those funds, approximately $2.5 million, was devoted to areas relevant to risk assessment; $500,000 was devoted to product development, most of which is relevant to risk management for deliberate release of genetically engineered organisms. Total spending on biotechnology in fiscal year 1987 increased to nearly $5.7 million from $3 million in 1985 and $3.4 million in 1986.

At EPA, biotechnology research is principally focused on the fate, public health, and environmental effects that might result from the accidental or purposeful release of genetically manipulated organisms into the environment. Officially initiated in 1985, the research program attempts to develop the capabilities for the regulatory programs within EPA to predict and thus avoid unreasonable adverse effects on the environment.

The techniques and knowledge gained through the biotechnology research program are used directly in the risk assessment process required to fulfill the EPA's legislative mandates. Most of the risk assessment work is done at the EPA Corvallis Laboratory in Oregon, which focuses on terrestrial activities, and the Gulf Breeze Laboratory in Florida, focusing primarily on aquatic research and product development. Eighty percent of the program is funded extramurally.

A major need, presently central to research program planning, is predictive risk assessment models for products of manipulated microbes. In conducting its research in this area, EPA actively coordinates and cooperates with industry, public interest groups, academia, and other Federal agencies.

The use of bioengineered organisms to degrade and otherwise mediate hazardous wastes promises great economic reward. EPA policy states that the development of these processes should be the prerogative of the private sector, To build a knowledge base by which to monitor these technologies, EPA is involved in limited studies of genetically engineered microbes for degradation of toxic wastes to better understand potential environmental and health effects as well as the needs for remedial action (see ch. 11). In fiscal year 1986, $589,000 was allocated for these studies; in fiscal year 1987, $531,000. The remainder was spent on research directly related to risk assessment.

VETERANS ADMINISTRATION

The Veterans Administration adopted the OTA definition of biotechnology for the purpose of accounting. Specifically, funding data were provided for projects involving cell fusion, gene splicing, monoclonal antibodies, and recombinant DNA.

During fiscal year 1985, the Veterans Administration (VA) Office of Research and Development tracked a total of 11,355 research projects conducted by 5,808 principal investigators in 143 hospitals. Most VA research concerns clinical medicine ($164 million of a total R&D budget of $184 million in fiscal year 1985). In 1985, of the 11,355 projects, the VA estimates that 100 projects were clearly directed toward the development of biotechnology products or produced information that may later be incorporated into the development of a biotechnology product. These 100 projects were funded at a level of $5.4 million (approximately 2.9 percent of the total R&D budget).

In 1986, the number of projects directly or indirectly related to biotechnology nearly doubled to 196, with support totaling $6.36 million, or approximately 3.5 percent of the total R&D budget for 1986. A total of 266 biotechnology projects were funded in fiscal year 1987, with support totaling $9.40 million, or approximately 4.2 percent of the total R&D budget.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Space biotechnology includes natural and manipulative processes involving biological materials, such as cells and proteins. The changes that occur in these processes in the reduced gravity environment are dependent on the relationship of the forces involved in the process and in the techniques used.

Biotechnology research at NASA is conducted principally through the Microgravity Science and Applications Program. The purposes of this program are:

- to use the microgravity environment to enhance certain separator processes for purification of biological materials for therapeutic and diagnostic application to diseases and to solve basic research problems;
- to use the microgravity environment to enhance crystallization of proteins and other macromolecular materials for detailed studies of molecular structure and to enhance production of biocompatible materials; and
- to obtain basic information on the effect of the microgravity environment on certain biological processes in cells, organs, and organisms such as cell secretion, cell-cell interaction, cell growth and differentiation, biorheology, and animal and plant cell manipulations.

Funded at a level of $7.2 million in fiscal year 1987, the program involves investigators from 11 universities, two NASA Centers, one research center, two industrial firms, and two Centers of Excellence. The Centers of Excellence are located at the University City Science Center in Philadelphia ($450,000) and the University of Arizona ($450,000). The Bioprocessing and Pharmaceutical Center in Philadelphia is a consortium of universities looking at separation processes, cell culturing, and cell harvesting. The Center for Separation Science in Arizona also investigates separation processes, primarily in the area of isoelectric focusing,

Of the $7.2 million, NASA spent $1.2 million on university research in separation techniques, cell productivity in reduced gravity, theoretical flow analysis, cell culture and product harvesting in low gravity, and biorheology; $1.9 million on university funding in protein crystal growth and macromolecular crystallography; and $3.1 million in-house at the Marshall Space Flight Center and the Johnson Space Flight Center on many of the preceding areas and flight hardware development.

FOOD AND DRUG ADMINISTRATION

Biotechnology is the application of biological systems and organisms to technical and industrial processes.

The purpose of FDA's research, including biotechnology-related research, is to generate and gather essential scientific information that the agency needs to make regulatory decisions. Under the Federal Food, Drug, and Cosmetics Act and related laws, the FDA is responsible for ensuring that the Nation's pharmaceutical, biological, medical devices, and radiological products are safe and effective and that the food supply is safe and nutritious. To accomplish these activities, FDA uses an institutional research capacity that can fulfill the needs that are unique to its regulatory mission.

Some research, for example, enables FDA to develop quick, accurate, sensitive, and reproducible methods that can be applied in response to public health emergencies (e.g., Tylenol tampering, *Listeria* contamination of cheese). Other FDA research findings are translated into the development and approval of products critical to public health (e.g., licensure of HIV antibody test kits) or are used to enable FDA to meet long-term regulatory responsibilities (e.g., risk assessment). While most of FDA's research is performed inhouse, a small portion is supported through extramural grants and contracts, such as the Orphan Product development program.

FDA research efforts, including those related to biotechnology, are targeted to these areas:

- product testing;
- scientific review of new product applications;
- identification of hazards;
- development of new or improved physical, biological, toxicological, or chemical tests;
- determination and establishment of standards, and determination of product compliance with those standards; and
- clarification of mechanisms underlying toxicologic and pharmacologic effects-.

FDA reported difficulty in assessing accurately the extent to which the agency's research fits the broad category of biotechnology. While many of FDA's research programs may use biotechnology methods, these methods serve as a means to an end—the technology itself is not an endpoint. The FDA spent approximately $3 million in fiscal year 1985 (3,7 percent of the total R&D budget) on research activities that can be considered biotechnology related. This figure rose to $4.7 million in 1986 and $5.8 million in 1987. Most of the funding increase has gone to research in the Center for Drugs and Biologics, involving recombinant DNA or monoclinal antibody methodologies. The research projects are categorized as involving specific pathogens, interferon research, research on antibodies and immunity, and related drug research.

SMALL BUSINESS INNOVATION RESEARCH PROGRAM

Biotechnology is a broad term that includes a number of techniques, such as genetic engineering, protein engineering, processes for making monoclinal antibodies, and other molecular biological techniques; the development of instruments to carry out such techniques is also included in the broad definition of biotechnology R&D.

Approximately $1.1 billion was awarded to small businesses by Small Business Innovation Research (SBIR) programs through fiscal year 1987 (5). The Small Business Development Act of 1982 (Public Law 97-219) established these programs to encourage innovation by requiring Federal agencies to set aside portions of their research funds to small businesses through special research programs. The Act requires Federal agencies that spend more than $100 million annually on extramural research to set aside 1.25 percent (when fully operational) of those funds for an SBIR program. Small businesses submit proposals in response to research topics contained in agencies' solicitation agreements, published at least annually by each participating agency.

Biotechnology companies have done well by the SBIR program. The National Institutes of Health, with the largest civilian research budget, contributes the largest dollar amount to SBIR. NIH awarded 98 of a total of 482 SBIR grants and contracts to 58 biotechnology companies in fiscal year 1986. The awards were worth approximately $5 million.

Biotechnology companies have received a smaller proportion of the total awards from the SBIR programs of the National Science Foundation, the USDA, and the Department of Energy. **In the years 1983-86, 10 percent of the total awards ($36,410,000) made by all SBIR programs have gone to biotechnology and microbiology research in entrepreneurial firms. Three-fourths of those funds came from NIH.** Agencies include SBIR funds in their biotechnology funding figures; thus, the SBIR contribution to biotechnology R&D is subsumed under total Federal spending on biotechnology. SBIR support for biotechnology research surpasses support for information processing, and medical instrumentation, the next runners up.

Recipients of SBIR funds praise the program, stating that it has given them the boost needed to seek commercialization of new products. Public Law 97-219 included a sunset provision and was scheduled to terminate October 1, 1987, but was reauthorized for 5 years—until 1993. SBIR funds are one of the few sources of direct Federal support for applied research and development conducted by small companies, and the SBIR program is widely supported by dedicated biotechnology companies in many business sectors.

SUMMARY AND CONCLUSIONS

Federal support of biotechnology research and development exceeded $2.72 billion in fiscal year 1987, and has not changed substantially in current dollars since 1985. NIH provides by far the most Federal funds for both basic and applied biotechnology research, supplying nearly 84 percent of the Federal Government's biotechnology research dollars. The Department of Defense biotechnology R&D effort consists of an additional 4.5 percent of total spending, and the National Science Foundation funds 3.6 percent. The fact that so many other agencies, including those with missions that are not primarily research, fund work in biotechnology attests to its wide-reaching applications.

Diverse biotechnology applications are supported by most of the Federal agencies. The DoD supports work in materials science and medicine, while NSF funds biotechnology research applications in genetics, bioelectronics, and environmental biology. Some redundancy, a necessary and healthy attribute of the U.S. research infrastructure, also exists across many agencies. In some cases, agencies have cooperated on projects of common interest. Examples in this category are GenBank®, and programs in plant biology and vaccine development.

From the funding data, it appears that Federal agencies are supporting more applied work in biotechnology than was reported to **OTA in 1984.** Increased attention to application has been most noticeable through the success of the SBIR program in assisting small biotechnology companies. The National Science Foundation hopes to eventually devote additional funds to Engineering Research Centers that focus on biotechnology. NIH, DOE, and DoD also report more funds being dedicated to applied research related to biotechnology. However, OTA did not request information to determine whether the apparent increase in applied research was due to decisions by the agencies to target this area for increased funds, or to their increased proficiency in accounting for applied work.

Some caution must be taken in interpreting the OTA totals for Federal funding of biotechnology R&D. The fact that different agencies define biotechnology differently makes it difficult to compare funding across agencies. The difference in definitions reflects the different scientific and political perspectives and varied missions of the agencies. Some agencies, such as NSF and DOE, define biotechnology broadly, in terms that include biotechnology applications typical of the years before the development of recombinant DNA technology. In contrast, agencies such as DoD, the Agricultural Research Service, and the Veterans Administration use definitions similar to the OTA definition of new biotechnology (6) that includes recombinant DNA, cell fusion, and novel bioprocessing techniques. Furthermore, agencies such as NIH and NSF have implemented more efficient mechanisms for cataloging and accounting for research and spending in certain areas, such as biotechnology.

The estimated $2.72 billion spent by Federal agencies in fiscal year 1987 could overshoot or undershoot the actual value, because it is not based on a single definition. These same problems affect biotechnology funding figures submitted by the individual States (ch. 4), or by different companies representing different industries (ch. 5). Nevertheless, totaling the dollars invested in biotechnology R&D by the Federal, State, and private sectors is the only way to compare their relative contributions.

Institutionalization of a government-wide definition of biotechnology could have limited value. Even if a uniform definition were adopted, agencies would still be likely to overcount or undercount, either because they do not have reliable systems for accounting for biotechnology research, or because it is in their institutional interest to do so. Systematic accounting mechanisms on the part of each of the agencies should be sufficient for budgetary purposes, and given the diversity of agency missions, a cross-agency comparison seems pointless.

The information contained in this chapter was collected to provide a foundation that future studies can use to address a number of important policy questions pertaining to Federal funding of biotechnology R&D, including:

- Are some categories of research overfunded or underfunded based on the perceived needs of the specific agencies, State and local needs, national needs, and the needs of other nations?
- Are expenditures sufficient to promote the growth of future biotechnology applications?
- Is the research base in biotechnology funded by the Federal Government adequate to maintain or enhance the U.S. competitive position internationally in the various industries affected by biotechnology R&D?
- Is the distribution of Federal funds among the various agencies and their respective missions (e.g., health, agriculture, and defense) appropriate?

Obtaining answers to these questions is beyond the scope of this report. However, the case studies on the U.S. investment in applications of biotechnology to human therapeutics, plant agriculture, and waste management (chs. 9, 10, and 11, respectively) offer a deeper analysis of many of the policy issues relevant to these business sectors, and demonstrate how the factors influencing investment in biotechnology R&D must be considered on an industry-by-industry basis.

CHAPTER 3 REFERENCES

1. Culliton, B.J., "NIH Role in Biotechnology Debated, " *Science* 229:147-8, July 12, 1985.
2. Gladwell, M., "NIH's Doors Opening to Private Companies: New Rules Will Let Researchers Share Knowledge," *Washington Post,* Sept. 14, 1987.
3. National Academy of Sciences, National Research Council, *Mapping and Sequencing the Human Genome* (Washington, DC: The National Academy Press, 1988).
4. Richards, B., and Barrington, T., "Military Science: Controversy Grows Over Pentagon's War on Biological Agents," *Wall Street Journal,* Sept. 17, 1986.
5. U.S. Congress, General Accounting Office, *Effectiveness of Small Business Innovation Research Program Procedures, GAO/RCED-87-63,* Washington, DC, 1987.
6. U.S. Congress, Office of Technology Assessment, *Commercial Biotechnology: An International Analysis,* OTA-BA-218 (Elmsford, NY: Pergamon Press, Inc., January 1984).
7. U.S. Congress, Office of Technology Assessment, *Mapping Our Genes, OTA-BA-373,* (Washington, DC: U.S. Government Printing Office, April 1988).
8. U.S. Congress, Office of Technology Assessment, *Public Funding of Biotechnology Research and Training,* transcript of workshop proceedings, Washington, DC, September 1986.
9. U.S. Congress, Office of Technology Assessment, *Research Funding as an Investment: Can We Measure the Returns? OTA-TM-SET-36* (Washington, DC: U.S. Government Printing Office, April 1986).
10. U.S. Department of Energy, Office of Health and Environmental Research, *Report on the Human Genome Initiative for the Office of Health and Environmental Research* (Washington, DC, April 1987).
11. U.S. Department of Health and Human Services, National Institutes of Health, *The NIH Role in Fostering Leadership in Biotechnology,* Proceedings of the 51st Meeting of the Advisory Committee to the Director, Bethesda, MD, June 24-25, 1985.