Biotechnology and the Creation of a New Economic Space

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The commercial potential of molecular biology and its kindred disciplines was first recognized in the mid-1970s. In the following years capitalist enterprises in the United States and abroad adopted the techniques of molecular biology, a scientific discipline. In the process, molecular biology has transformed an engineering discipline, bioprocess engineering, and spawned an industrial field, biotechnology. Biotechnology as a business arises out of an intersection of the scientific practices of molecular biology—formerly undertaken only in universities — and the engineering practices of biochemical engineering and other technologies necessary to produce biological commodities. In Joseph Schumpeter's terms, it was at this intersection that a "new space" for economic activity was created.'

The creation of a new economic space for biology is not unique in the history of capitalist development. There is a long history of the results of biological research being commercialized.' However, biotechnology presents unusual features. For the sake of brevity, this article begins with the 1970s, and I do not discuss the "mechanism" orientation of molecular biology, though some have argued the importance of this perspective to its development.' True, as George Basalla pointed out, any particular technology has evolved from previous developments.[4] The new biotechnology industry is built upon a base of knowledge in fermentation and biological materials processing developed in the pharmaceuticals and food processing industries.[5] Thus the commercialization phase has antecedents on several levels.

We should be extremely cautious when we term biotechnology "an industry." Only in the United States has biotechnology become an industry composed of freestanding enterprises; in other advanced industrial nations it has been subsumed under the traditional multinational pharmaceutical, chemical, and food firms and industries (hereafter, multinational companies or MNCs). For these established MNCs, biotechnology is what might be termed an "enabling" technology. Biotechnology will improve their ability to continue to operate in their current line of business as the techniques of molecular biology become central to their research and development efforts in biologically related fields. But outside the United States few new firms — and thus no new industry — have arisen. Nevertheless, for the sake of linguistic simplicity and because this article focuses on the United States, it treats biotechnology as an industry, even while recognizing the limitations of this characterization.

To operate a business in capitalism one needs a commodity that can be sold. The commodity is a crucial category, for it is what is traded in the marketplace. Not everything is a commodity, however, and things that were commodities can be removed from the realm of commodities and vice versa. For example, before the Civil War human beings of African descent were considered commodities (things) and traded!' Conversely, things that are not commodities can become commodities. The classic case of commodity creation is the declaration by Western colonialists that the new territories they had invaded and conquered constituted private property. The colonial authorities created a market in land, but they invariably had to use force to secure these commodity relations. Similarly, contrary to the ideology of contemporary economics, markets are not "natural"; rather, they are created by political action. These fundamental premises underlie my analysis of the creation of the biotechnology industry.

By definition, new economic spaces do not exist, but rather are created and ultimately populated by firms. To accomplish this, capital must be gathered, employees secured, legal norms and rules promulgated, and numerous other relations developed. For example, society must recognize the results of human activity in that particular area as commodities. If the results of a productive activity cannot be considered a commodity and sold in the market, private capital will not be invested. Thus industrial pioneers often must not only develop the product but create the social, legal, and economic institutions within which the product is embedded.'

Describing the establishment of a new economic space is difficult, because the various strands that create it are intertwined. Each strand has its own logic, which is not entirely derived from the other strands, and yet the strands also interact. For example, the development of the legal system relating to living organisms was synchronous and largely, but not entirely, related to the commercialization of biotechnology. In this sense, there is not one but rather a number of important previous strands. For this article, even though Genentech was not the first biotechnology company, since Cetus was established in 1971, Genentech's rapid success makes its establishment a convenient starting point.

This article is divided into four sections. The first examines the background in the 1970s from which the biotechnology industry would emerge. The second explores the establishment of the small start-up firms that pioneered the new biotechnology and the crucial role of venture capitalists in that process. The third section describes how burgeoning investment in biotechnology led to the creation of firms, industry associations, and trade newspapers that formed an infrastructure to support the biotechnology industry. The fourth section examines the MNC role in responses to and strategies for creating a new economic space in the form of a biotechnology industry. The conclusion reexamines the commercialization of university science from a Schumpeterian perspective. I argue that Schumpeter provides a unique perspective for examining the manner by which capitalist enterprises extend their sway into new areas of the natural world and in the process create new economic spaces.

The Background Environment

The contemporary biotechnology industry emerged from university-based research in the basic science of molecular biology. Laboratory success in the early 1970s at cloning transgenic bacteria initially sparked controversy over the safety of recombinant DNA.[8] By 1977 the safety issues had given way to arguments promising future agricultural and medical benefits of what had by then come to be called biotechnology.[9] The locus of public concern shifted to the impact that rapid commercialization of university knowledge and personnel had on the university as an institution.

Concern over the commercialization of university research has persisted because more than for any other commercialized technology, the techniques and even the target products of biotechnology were pioneered in university laboratories. Traditionally, information of interest to the pharmaceutical industries diffused from the university through the placement of students or professorial consultancies with firms. The pattern in biotechnology was quite different.

Whether living organisms and components of organisms could be patented was another important issue being settled as the biotechnology industry emerged. Whether patents were necessary for the industry's development is difficult to answer unequivocally, but the type and character of the evolving patent regime sparked great interest in its early days.[10] As Daniell Kevles points out in this volume, patents on biological materials are not without precedent. Still, the extension of intellectual property protection to living organisms was significant because developing and commercializing a pharmaceutical is extremely expensive. If the pharmaceutical is not patented, a rival can copy and produce an exact duplicate of the drug for far less investment than the initial inventor's. The patent allows the owner to attempt to recover costs through monopoly profits. Patents are especially important for start-up firms because knowledge and materials developed by research not only are capitalized in their stock value but often are the firm's only significant assets.

Besides deciding whether living organisms would be patentable, the federal government had to decide whether universities could patent professorial inventions. The invention that prompted the debate about the issue was Stanford University's petition to NIH in 1974 over the acceptability of its filing the basic genetic engineering patent, the Cohen-Boyer patent." The NIH decision to allow universities to patent and license in the field of genetic engineering simplified the privatization of university research by removing any claims on behalf of the public regarding ownership of government-funded research.

By the early 1980s, when it became clear how much money could be made, the ethos discouraging the patenting of biological materials changed significantly.' [2] Albert Halluin observes that "early discoveries [1972-77] on the construction of plasmids and vectors were published . . . but patents on such processes and compositions were not sought. [But] in recent years, patents have been sought and obtained on processes for obtaining vectors and plasmids." Halluin's conclusion can be illustrated by an example from the field of monoclonal antibody (MAb) techniques. In 1975 Cesar Milstein and Georges Kohler invented a process for creating MAbs for which they later won the Nobel Prize. They chose not to patent their invention, which became an important commercial technology. In the intervening five years the atmosphere changed drastically, and in 1980 Milstein filed for a patent on a particular MAb."

With increasing commercialization, the etiquette of exchanging biological materials changed significantly. About 1984 laboratories began requiring that researchers wishing to borrow biological materials complete forms prior to fulfillment of their requests. The Harvard University biological materials supply form resembles Genentech's except for a clause on publication. Genentech's permission says "I understand I may publish the results of my experiment using plasmid ______ but only with the consent of Genentech; such consent not to be untimely or unreasonably withheld." Harvard University requires only that the plasmids be used for research purposes and that the requesting party be "in periodic contact with [researcher] at Harvard . . . to report on [any] work which utilizes the plasmid." Cesar Milstein's laboratory at the Medical Research Council had a very different form requiring only that the cell lines be acknowledged, a preprint of the paper be sent to his laboratory, and any products not be made the subject of patent rights.' [4] This formalization of the conditions of exchange was a direct outcome of the privatization both of biological materials and tools and of the results of molecular biological research."

Resolution of health and safety issues, recognition that the university could legitimately patent and license biotechnology inventions, and increasing acceptance of the privatization of biological materials were crucial to the creation of a biotechnology industry. And yet the most important social development was society's acceptance that publicly funded research in tax-exempt universities was appropriate for privatization. This made it possible to have a market in biological materials and know-how.

Establishing an Industry

The most basic model of capitalism is one in which an entrepreneur invests in plant and equipment and hires labor. During most of the postwar period, however, the large pharmaceutical firms with research laboratories and extensive marketing networks drastically increased barriers to entry for interested entrepreneurs. Only in the United States did an unusual set of social circumstances combine with the technological discontinuity caused by the development of new biological techniques to allow creation of a biotechnology industry based on small firms.

The technical developments of recombinant DNA technology offered the hope that cells could be transformed into "factories" for valuable biological materials and thus open up business opportunities. Curiously, the debate and publicity about health and safety issues actually attracted the attention of venture capitalists, the potential financial backers; it may also have discouraged established pharmaceutical firms from capturing the technology.

The promise and perils of biotechnology generated the most intense attention and controversy in the San Francisco Bay area and around Boston. Both regions were also centers of innovation for the burgeoning microelectronics and computer industries. As with biotechnology, the electronics and computer industries required highly trained university graduates as employees, and some firms depended directly upon university research. Thus Boston and the Bay Area became hosts to a number of extremely successful electronics start-ups that rapidly grew to be established firms and in the process created an entrepreneurial environment.[16] Most important, the economic success of both regions helped create a set of specialized financial intermediaries, the venture capitalists.

Venture capitalists are, in large measure, a set of financial intermediaries unique to the United States. Venture capitalism first arose immediately after World War II; it has since grown to become a financial sector with assets in excess of $15 billion. Organized in partnerships with ten-year limits, venture capitalists seek capital from institutions and wealthy individuals and invest it in high-risk, high-reward ventures. For the most part they have confined their lending to high-technology fields. The growth of this sector was fueled by the extraordinary high returns secured by the venture capitalists who made the initial investments in what are now Fortune 500 companies Apple Computers, Digital Equipment Corporation, Sun Microsystems, Lotus, and Intel.[17]

Venture capitalists became involved in biotechnology at an early stage because they were already familiar with unproven technologies and willing to invest in them. Their experience with the high-technology electronics and semiconductor industries and their financial success made them comfortable with funding technologically sophisticated projects. Moreover, because the electronics industry was located near universities, the venture capitalists were also located near the university laboratories of the molecular biologists. This confluence of variables meant that biotechnology had available one of the preconditions to starting a business: a mobilizable source of capital.

Venture capital investments are quite different from traditional bank loans or equity investments. Their objective is to increase the value of the fledgling company rapidly so that the investors may sell equity to the public or to a larger corporation. To accelerate a firm's growth, a venture capitalist will help secure professional legal and accounting assistance, hire key executives, contact potential business partners, find the right underwriters for a public offering, and provide both the capital and the contacts necessary for a firm to become self-sufficient. Put another way, venture capitalists can assist an investment in transforming itself from a firm in name only to an actual operating firm. Through these activities, the venture capitalist lowers the entry barriers for en trepren eurs.[18]

The most important route for privatizing the knowledge and skills contained in the university was through the new biotechnology firms funded by venture capitalists. Venture capital financing of biology professors was first used to create a commercial firm based on the research undertaken at the University of California, San Francisco (UCSF). The company, Genentech, was founded in January 1976 by a venture capitalist who had been affiliated with the venture capital partnership Kleiner Perkins, Robert Swanson. His scientist partner was Herbert Boyer, a professor at UCSF. The business offices of Genentech were initially in the offices of Kleiner Perkins, which also made the initial $100,000 investment in the new firm. For the next two years Genentech would use Boyer's university laboratory for its experiments in cloning first a human somatostatin gene and then a human insulin gene into bacteria.[19]

Genentech's first employees were some of the postdoctoral students in Boyer's laboratory who began to work exclusively on company projects.[20] Their success was marked by Genentech's announcement in 1978 that it had cloned a human insulin gene. Eli Lilly, the largest U.S. producer of insulin, then announced that it had licensed the cloned microorganism from Genentech." This transaction validated biotechnology as an endeavor that could produce a commercially interesting result. The saga of Genentech's birth was completed in 1980 when an initial public offering of its stock was made. The offering price was $35 per share, but the stock was so oversubscribed that the price per share soared to more than $80 on the day of offer, after which it fell to approximately the offering prices. This successful offering demonstrated that biotechnology companies could be successfully sold to the public even while they had negative cash flow and no products on the market. That success triggered what Nicholas Wade, writing in *Science,* called a "gold rush" of entrants."

These new companies spawned rapidly, as escalating numbers of those founded reflect. From 1971 through 1978 only 19 firms were launched; 9 were established in 1979, 18 in 1980, and 33 in 1981.[23] The number of startups decreased to 11 in 1982 and 4 in 1983. Of the numerous possible explanations for this decrease, the most powerful has less to do with biotechnology than with the weakness of the market for initial public stock offerings. That is, the 1982-83 recession limited the ability of venture capitalists to sell their stock in newly established firms, forcing them to maintain their original investments in already-established biotechnology firms, which continued to lose money. The market for initial public offerings of small firms improved again in the late 1980s, and formation of new firms once again accelerated. According to a recent estimate there are now nearly 700 biotechnology firms in the United States.24

In the early phase of the industry there was no pool of expertise in industrial biotechnology per se. Both the managers and the technical employees to staff the start-up companies had to be drawn from other sectors of the economy. The obvious source for technical staff was the university, where a large pool of postdoctoral students could be recruited. More difficult was persuading university scientists to leave tenured, well-paying positions for the private sector; persuading the top scientists was often impossible. To circumvent this problem, the start-ups developed a unique structural feature, the scientific advisory board, touted as a "scientific board of directors" and usually consisting of prominent scientists from major universities. The company literature described their role as advisers, recruiters of trained personnel, and information sources on current developments in academic science.[2'] In return for participating in the scientific advisory board, these scientists received significant sums of stock. Later, several became multimillionaires when the company went public.

The new firms also needed managers familiar with the pharmaceutical industry; they secured them through such normal channels as advertising and executive search. The start-ups had little difficulty securing these trained personnel because they could offer stock options and rapid promotion. Thus the start-ups were able to create both managerial and scientific teams quite rapidly and begin operations. By the 1980s it was even possible to secure personnel with experience in the biotechnology industry by raiding other companies and increasing numbers of graduates sought employment in the now established industry. The new economic space had developed its own labor market, distinct from the university or the pharmaceutical industry.

Creating an Infrastructure

A new technology or industry does not and cannot exist in a vacuum. Clearly, a scientific enterprise also purchases inputs such as laboratory ware, scientific equipment, and other consumables. The creation of NBFs and the acceleration of spending in corporate research budgets fueled the development of an infrastructure of biotechnology input firms. In other words, backward linkages were rapidly built. Thus, for example, companies such as Applied Biosystems were established to produce machinery, reagents, and other inputs to the biotechnology industry. The new infrastructure then reinforced the capabilities of the biotechnology firms and speeded procedures such as sequencing and cloning genes.

Another indicator of the growth of the biotechnology industry was the rise of trade journals that knit the industry together and provided it with a voice. Before biotechnology was commercialized, peer-reviewed scholarly journals such as *Science* and *Nature* constituted the communication medium for molecular biologists. As biotechnology grew in the late 1970s, demand for business information increased, and a number of newsletters appeared. In 1981 the first self-conscious "industry" trade newspaper, *Genetic Engineering News (GEN)*, was published. *GEN* has a subscription fee but is largely supported by advertising revenue from biotechnology input suppliers. Biotechnology's growth as an industry can be traced in *GEN's* publication schedule: In 1981 it was bimonthly, by 1987 it was monthly, and in 1992 it became biweekly. Changes in its subtitle reflect the growing complexity of the industry. In 1981 it was "The Information Source of the Biotechnology Industry"; in 1987 it had changed to "The Source of Bioprocess/Biotechnology News"; and in 1992 it changed yet again to "Biotechnology, Bioregulation, Bioprocess, and Bioresearch." *GEN was* followed in 1984 by the British journal *Bio/Technology* and a French journal, *Biofutur.* The latter two journals depended more on subscriptions, but also had a significant number of advertisements by input manufacturers. Significantly, scientific labor continued to be recruited through the classified advertisements in *Science.* In effect, *GEN was* supported by the biotechnology input industry and became a voice for commercial biotechnology.

The growth of an industry can also be traced through the development of its industry associations. During the earliest days the Pharmaceutical Manufacturers Association was the de facto voice of the industry. In 1981 seven new firms combined to charter the Industrial Biotechnology Association (IBA), and membership quickly grew to eleven firms.[26] In 1984 Mary Ann Liebert, Inc., the publisher of *GEN,* and eleven other companies joined to form the Association of Biotechnology Companies (ABC), with the express purpose of representing the smaller biotechnology firms, some of which did not believe the IBA was articulating their needs.[27] In 1993 these two organizations, the IBA with 150 members and the ABC with 340 members, merged to form the Biotechnology Industry Organization. The new organization would represent firms with $5.9 billion in sales and the majority of the estimated 79,000 jobs in the biotechnology industry.28

The MNCs and the New Biotechnology

The established chemical and pharmaceutical MNCs constitute the other set of firms participating in the privatization of molecular biology. These firms have multibillion dollar revenues and are members of an established global industry. In the early 1970s, as the recombinant DNA controversy was under way, the Pharmaceutical Manufacturers Association was the most significant industrial lobbying group. At the time, however, its constituent pharmaceutical firms did not have significant internal expertise in molecular biology and especially in recombinant DNA. The MNCs initially thought of these techniques as research tools and not as potential generators of products. In general these companies were not able to integrate biotechnology quickly into their research programs. Thus a technological discontinuity emerged that, at least momentarily, lowered the entry barriers into the pharmaceutical industry.

Genentech's success at cloning a human insulin gene and Lilly's 1978 purchase of the rights to the microorganism created the possibility that the new biotechnology could outflank existing products and possibly lead to lucrative new products. The MNCs responded by following three strategies. First, they established their own internal biotechnology research programs in molecular biology. Second, they established their own linkages to university laboratories. Third, they developed strategic partnerships with the small start-up firms. Each of these strategies had advantages.

The MNCs' internal research programs had a number of significant early problems. Most important was difficulty in recruiting the best scientists. The reasons for this varied, but the one most mentioned is that the companies were not undertaking cutting-edge research. Moreover, these companies did not have the networks necessary to recruit the top molecular biology graduates, nor were their laboratories located near the top universities, as the start-up firms were, allowing easy recruitment. Even today the MNCs are still not considered to have the topnotch biotechnology researchers in their laboratories.

In the early 1980s the MNCs funded a number of long-term agreements with universities aimed at gaining access and intellectual property from academic laboratories. Perhaps the most publicized was the agreement made between the German chemical-pharmaceutical giant Hoechst and the Massachusetts General Hospital. By giving the hospital roughly $70 million, Hoechst was able to purchase access to the intellectual property of a newly constituted department. In the late 1980s these large, long-term arrangements tapered off, though occasional examples still occur, such as the agreement signed between the Hitachi Chemical Corporation and the University of California at Irvine in 1990. Undoubtedly, smaller arrangements continue to be signed between MNCs and university laboratories, but the trend appears downward. University patenting and licensing of the inventions of professors, on the other hand, continues to increase.

The dominant trend is for the small biotechnology firms to conclude cooperative agreements with the MNCs, because the skills and resources it takes to develop a new drug or diagnostic are quite different from those necessary to take a drug through clinical trials and FDA approval and to market it to doctors. The smaller start-ups can develop the new product, but the costs and personnel needed to secure FDA approval are often beyond their resources. The U.S. biotechnology industry consisting of small firms, thus depends for funding and certain types of skills on the MNCs. The difficulties of becoming a truly independent freestanding pharmaceutical firm are plain. Genentech, for example, one of the two most successful start-ups, sold 60 percent of its stock to Hoffmann-La Roche. Hybritech, one of the more successful MAb companies, was sold to Eli Lilly in 1985. There are very few start-ups that do not have at least one contract with an MNC.

The MNCs have successfully used their financial resources, skills in dealing with the regulatory process, and superior marketing expertise to secure access to developments in the new biotechnology. However, the MNCs have not been able to internalize the knowledge necessary to dispense with either university research or, especially, the start-ups. The MNCs therefore continue to contract with the start-ups for novel products or processes, and this keeps the new economic space separate from the pharmaceutical industry.

Conclusion

The context of biological research has changed markedly in the last two decades. In the late 1970s and early 1980s the commercialization of biological knowledge centered on the technologies of recombinant DNA and monoclonal antibodies. By 1993 firms had been formed to exploit liposomes, antisense molecules, peptides, carbohydrates, stem cells, synthetic small molecules, and many other biological materials. The new economic space opened by the small firms in the early and mid-1970s became an important field for profit making and continues to grow. The persistent predictions of a shakeout and reconsolidation into the pharmaceutical industry are based on the assumption that the new economic space will collapse. Yet some of the established biotechnology firms continue to survive and to progress toward commercializable products. Moreover, there continues to be a constant (though cyclical) flow of NBFs. Even as some firms are absorbed, new ones are formed.

Clearly, the biological sciences have undergone privatization in the last twenty years. But what is striking is that the public science continues to flourish and generate new possibilities for private appropriation. In this sense, the economic space continues to expand. Conversely, the partial reassertion of the MNCs indicates that though a new economic space has been created, it has not become entirely independent. Perhaps this can be understood by returning to our earlier bracketing of the debate as to whether biotechnology is an industry or an enabling technology. If biotechnology is an industry, then it should have developed a discrete economic space. If it is merely an enabling technology, then it should not be able to build space.

An organized venture capital community was crucial in opening this new economic space. In Europe and Japan, which did not have a venture capital community, biotechnology was reduced to practice in the large established chemical and pharmaceutical firms.[29] The institutional context had an important influence on the characteristics of the newly created economic space. Analysis of the socioeconomic institutions in which molecular biology and later biotechnology were and are embedded provides an important case study of how scientific developments in the public domain can be translated into private sector commodities.

There can be little doubt that biotechnology is now, in some measure, a private science. This constrained the free flow in biological materials and information not only among private sector entities, but also in the public sector. The "public goods" context upon which free flow was predicated, which existed prior to the commercialization, has changed fundamentally: what was formerly science is now technology. Similarly, the motives and conditions of all of the social actors in the field of biotechnology have changed to adjust to this privatization.

Notes

1. Joseph Schumpeter, *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process,* abridged by R. Fels (New York: McGraw-Hill, 1939).

2. See, e.g., Jack Kloppenburg, *First the Seed: The Political Economy of Plant Biotechnology* (New York: Cambridge University Press, 1987); Bruno Latour, *The Pasteurization of France* (Cambridge, Mass.: Harvard University Press, 1988); and the article by Angela Creager in this volume.

3. See Edward Yoxen, "Life as a Productive Force: Capitalizing the Science and Technology of Molecular Biology," in *Science, Technology and the Labour Process: Marxist Studies,* ed. Les Levidow and Bob Young (Atlantic Highlands, N.J.: Humanities Press, 1981), pp. 66-123; and Pnina Abir-Am, "The Discourse of Physical Power and Biological Knowledge in the 1930s: A Reappraisal of the Rockefeller Foundation's 'Policy' in Molecular Biology," *Social Studies of Science* 12 (1982), 341-82.

4. George Basalla, *The Evolution of Technology* (Cambridge: Cambridge University Press, 1989).

5. R. K. Finn, "Some Origins of Biotechnology," *Swiss Review for Biotechnology 7* (1989), 15-17. See also the article by Robert Bud in this volume.

6. The word *things* is used very broadly here. For the fundamental discussions of

what a commodity is, see Karl Marx, *Capital,* vol. 1. For further insightful theoretical discussions of the nature of commodities, see Kloppenburg, *First the Seed* (note 2).

7. Although I agree that the marketplace is clearly created, I do not take the radical subjectivist position that the commodities developed by biotechnology are the subjective creation of society, or that their efficacy is entirely an intersubjective creation. That position if reduced to the absurd would intimate that anything agreed upon socially would be "effective."

8. For a comprehensive discussion of the health and safety issues underlying the recombinant DNA controversy, see Sheldon Krimsky, *Genetic Alchemy: The Social History of the Recombinant DNA Controversy* (Cambridge, Mass: MIT Press, 1982). See also David Jackson and Stephen Stich, eds., *The Recombinant DNA Debate* (Englewood Cliffs, N.J.: Prentice-Hall, 1979). For a readable popular account see John Lear, *Recombinant DNA: The Untold Story* (New York: Crown Publishers, 1978). For further discussion see the article by Susan Wright in this volume.

9. Krimsky, *Genetic Alchemy* (note 8); and Martin Kenney, *Biotechnology: The University-Industrial Complex* (New Haven, Conn.: Yale University Press, 1986). See also the article by Susan Wright in this volume.

10. For a more general argument about the importance of patents see Eric Schiff, *Industrialization Without Patents* (Princeton, N.J.: Princeton University Press, 1971).

11. The Cohen-Boyer patent covers the insertion of foreign genes into a plasmid and then the transference of those genes to another microorganism.

12. Jorge Goldstein, "A Footnote on the Cohen-Boyer Patent and Other Musings," *Recombinant DNA Technical Bulletin* 5 (1982), 180-88, on p. 186.

13. Albert Halluin, "Patenting the Results of Genetic Engineering Research: An Overview," in *Patenting of Life Forms,* ed. David W. Plant, Niels J. Reimers and Norton D. Zinder, Banbury Report 10 (Cold Spring Harbor, N.Y.: Cold Spring Harbor Laboratory, 1982), pp. 67-126, on pp. 75, 79ff.

14. Compare Genentech, "Letter Agreement/Biological or Other Materials Supply" (ca. 1984); Harvard University, Committee on Patents and Copyrights, "Plasmid Supply Letter" (ca. 1984); and Cesar Milstein, "Cell Line Supply Form" (Cambridge, Mass.: MRC Laboratory of Molecular Biology, ca. 1984).

15. For a provocative analysis of the development of patenting in biological materials, see the article by Alberto Cambrosio and Peter Keating in this volume.

16. There are important differences as well as similarities between the biotechnology and electronics-based industries. Industry laboratories accomplished many of the central developments in computers and microelectronics, and professors were much less involved in establishing and managing electronics industry firms. Overdrawing the parallels can lead to misunderstanding the development of the two industries.

17. Richard L. Florida and Martin Kenney, *The Breakthrough Illusion: Corporate America's Failure to Move from Innovation to Mass Production* (New York: Basic Books, 1990). See also John Wilson, *The New Venturers: Inside the High Stakes World of Venture Capital* (Reading, Mass.: Addison-Wesley, 1985).

18. For further discussion see Florida and Kenney, *Breakthrough Illusion* (note 17).

19. See Lear, *Recombinant DNA* (note 8), pp. 232-34; and Laurel Glass, chairman-elect, Academic Senate, memorandum to Keith Yamamoto, University of California, San Francisco, 30 Aug. 1979. I thank Keith Yamamoto for providing a copy of this memorandum.

20. Kenney, *Biotechnology* (note 9).

21. Krimsky, *Genetic Alchemy* (note 8), p. 201.

22. Nicholas Wade, "Cloning Gold Rush Turns Basic Biology into Big Business," *Science* 208 (1980), 688-92.

23. Kenney, *Biotechnology* (note 9).

24. "Why Are We So Afraid of Growth?" *Business Week,* 16 May 1994, pp. 62-72.
25. Kenney, *Biotechnology* (note 9).
26. P. Germann, "IBA Gets Underway," *Genetic Engineering News,* Nov.-Dec. 1981, 13-6.
27. "Small Biotech Firms Form a Trade Group," *Chemical Week,* 25 Jan. 1984, pp. 13-14.
28. E. Christensen, "The Biotechnology Industry Organization: The Sum Is Greater than the Parts," *GeneticEngineering News,* 1 Apr. 1993, p. 17.
29. For discussion of Europe, and especially the United Kingdom, see the article by Herbert Gottweis in this volume. On Japan see Malcolm V. Brock, *Biotechnology in Japan* (London: Routledge, 1989).