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Biotechnology: The Next Industrial Frontier

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1. INTRODUCTION

Biotechnology, many observers now think, is a critical new industrial frontier. It belongs with supercomputers, superconductors, magnetic-levitation transportation systems, robotics, and space exploration. Together, these will constitute a pervasive set of new technologies with incalculable economic implications, equal at least to the previous generation of technologies -- consumer electronics, information technology, aerospace -- that triggered the long boom in the capitalist economy in the 1950s and 1960s (Hall and Markusen 1985, 16). If the historical analogy holds -- and there is increasing evidence, from research into long waves of capitalist development, that it does -- these implications will be felt with increasing force over the next 30 to 40 years (Mensch 1979; Freeman et al. 1982; Freeman 1984, 1985; Hall and Preston 1988).

Today, though, biotechnology barely constitutes an industry at all; in 1987, it is just emerging from the laboratory into the production stage. This is why it has potentially huge consequences for the future geography of urban and regional development -- consequences that are capable of being seized and guided by conscious policy. It is as if the date were December 1947, the transistor had just been invented at Bell Labs, and we had the opportunity to develop a strategy for the future growth of the information technology industries. That is the scale of the challenge -- but there is little evidence that policy makers are as yet conscious of it.

This paper is a beginning contribution to the discussion. In Section 2, we try to show what biotechnology is, and how it evolved between the mid-1950s and mid-1970s out of molecular biology; we then draw on existing studies to depict the development of the industry, and to discuss what may be its major directions in the immediate future. In Section 3, we turn to the implications for the new industry's geography, by analyzing an international data base on the location of biotechnology companies, and by then reviewing the factors that appear to be most important in the industry's location. Finally, in Section 4, we discuss some implications for regional and urban planning policy, both in the United States and in other advanced industrial countries. The knowledge-based industries, we argue, constitute one of the major new phenomena of the second half of the twentieth century; guiding their growth, in terms of their regional and urban distribution, is going to demand a new understanding of the relationship between science policy and traditional planning policies.

2. MOLECULAR BIOLOGY AND BIOTECHNOLOGY: FROM A NEW SCIENCE TO A NEW INDUSTRY

The experts do not agree on what constitutes the biotechnology set. For some, like the Office of Technology Assessment (1984), it embraces all industrial processes that involve the use of biological systems: a definition that could include such ancient processes as brewing and pickling. Here we adopt Kenney's stricter definition (1986), which includes only a particular subset of such techniques that have been developed in the 1970s and 1980s. These techniques are usefully listed by Daly (1985):

(1) Genetic Engineering: the use of "gene splicing" (Recombinant Deoxyribonucleic Acid, RDNA) to introduce particular genes and their harvesting to produce a desired product such as an enzyme, hormone, or other protein;

(2) Bioprocessing: the conversion of a raw material into a product using microbiological fermentation of enzymes, such as antibiotics, enzymes, amino acids, and other specialty chemicals;

(3) Monoclonal Antibodies (MABS): the production of specific antibodies from single clones of cells, to be used in <u>in vitro</u> diagnostic systems, <u>in vivo</u> diagnostic imaging, therapy (immunization, immunotoxins), tissue typing for surgery and blood typing, and purification and separation of biological molecules;

(4) Protein Engineering: the modification of protein structures to improve their function or to design new proteins;

(5) Bioinformatics: the convergence of biotechnology and information technology, including the uses of computers in protein engineering,

> the use of special software for the analysis of DNA sequences, and similar techniques. It has been suggested that this marriage could be the truly radical technology of the next economic long wave, with implications at least as great as those of information technology itself in the last wave (Masuda 1985).

A Science is Born: Molecular Biology, 1935-1975

The birth of biotech is less fantastic than it might seem, since -- by this narrower definition -- biotechnology itself is the industrial application of molecular biology, a relatively new science which has curious analogies with the development of another equally young subject, information technology. (And biotech itself contains elements that draw on the synthesis of biology and informatics.) Elkington (1985) quotes the 1982 report of Genex, an American biotechnology company, which refers to the reading, writing, and editing of DNA as the language in which all of nature's scientific information is written. Kenney (1986) describes the scientific revolution thus:

> If life can be characterized as a computer program, then understanding of the programming language made reprogramming a possibility. (Kenney 1986, 21)

Or, in the words of another commentator, the central concept was that of organisms as "self-assembling, self-maintaining, information-processing organisms":

> The metaphors are informational; the idioms, without which one can scarcely think or talk biology nowadays, are drawn from computing, cryptography and cybernetics; the hardware and software of information technology is projected on to the cell. (Yoxen 1983, 44-45)

It would not be true to say that molecular biology borrowed these metaphors and images from cybernetics and information technology, for it was born earlier than either; but the parallels in thinking are clear. And, eventually, molecular biology engendered the development of technologies that "make living cells into tiny factories for the production of items satisfying human needs" (Kenney 1986, 2).

The story of the birth of molecular biology is a curious one. In the 1930s, biochemistry was a scientific backwater, involved mainly in low-level research to meet well-defined medical needs, and with little fundamental research. Then Warren Weaver, who became director at this time of the Rockefeller Foundation's biological program, launched a major research effort to revolutionize the subject; he injected techniques from physics and chemistry, thus reducing "life" to an assemblage of molecules; and it was he who coined the term molecular biology. His big, interdisciplinary research effort was concentrated in a few elite universities of that time: Harvard, MIT, Stanford, and Caltech. As a result, by the early 1950s the new subject -- still highly theoretical, and a sideline to mainstream biology -- was found only in a very few centers of excellence in the United States and Europe: Cambridge, Massachusetts; Cold Spring Harbor, New York; Stanford and Pasadena, California; Cambridge, England, and (through the old-established Institut Pasteur) Paris, France (Yoxen 1983, 36-39; Kenney 1986, 10-12).

At this point, there occurred an unusual conjunction of scientific and administrative developments. In 1944, DNA was identified as a substance; this was followed by Crick and Watson's historic discovery of its structure, the famous double helix, in 1953. In the United States, the National Science Foundation was established in 1950 and began in

effect to develop a joint research program with the National Institutes of Health, NSF concentrating on more fundamental, nontargeted, work, NIH on applications. NIH, faced with the implacable opposition of the AMA to establishing a National Health Service on British lines, diverted growing Federal funds into extramural research, spending $16 billion by the mid-1960s (Yoxen 1983, 40-43; Kenney 1986, 14-15).

Without this enormous Federal intervention, it seems clear, biotechnology would certainly not have developed as rapidly as it did, and perhaps not at all (Kenney 1986, 241-2). And -- a critical point for the development of the future industry -- it was concentrated on a relatively few top universities. Though Federal funding always represented the major share of all basic research done in the post-World War Two period -- 56.9 per cent in 1953, 66.5 per cent in 1984 -- its destination shifted: only 25 per cent went to universities in 1953, over 48 per cent in 1984. NIH, which shifted in this period from primarily in-house to primarily out-house research, was a part of this process. And, of the NIH moneys disbursed from 1972 to 1981, the top 20 recipients together never received less than 51 per cent. Outstanding among them, an illustration of the inertia principle, were the major East and West Coast laboratories already established as a result of the Rockefeller initiative (Kenney 1986, 18, 35-36).

Breakthrough came in the early 1970s, with the controlled manipulation of pieces of genetic material. In 1973, Stanley Cohen of Stanford and Herbert Boyer of the University of California's San Francisco medical campus announced that they had used plasmids to transfer genes between organisms, thus achieving the production of RDNA. The immediate result was concern among the scientific fraternity as to the environmental

consequences, leading to a research moratorium from 1974 to 1976; once it was lifted, with the establishment of only a minimal Federal regulatory regime, a new era of genetic engineering began (Yoxen 1983, 45; Kenney 1986, 23, 242). Meanwhile, at Cambridge in England, Cesar Milstein and Georges Kohler had succeeded in producing monoclonal antibodies -- a development for which they later won a Nobel Prize (Yoxen 1983, 130).

An Infant Industry: Biotechnology, 1975-87

From this point, effectively, the biotechnology industry was born. One result of this industrialization of research was a push to patent scientific discoveries: Stanford and the University of California succeeded in patenting the original Boyer-Cohen work in 1980, and -- after a struggle -- received a second patent in 1984. Critical here was a U.S. Supreme Court decision of 1980, which ruled that a man-made organism could be patent-protected (Elkington 1985a, 32, 34, 36). The other result was an escalating number of new biotechnology startup firms, NBFs for short. Cetus, a Californian company started in 1971, is generally regarded as the first such startup. Thence the number of NBFs hovered between one and three until 1977, when it took off: six in 1978, nine in 1979, 18 in 1980, and no less than 33 in 1981, when a major dip occurred (Kenney 1986, 140).

The distinguishing feature of these firms, observers agree, is that they were virtually all direct spinoffs from university research:

> The pervasive role of professors in managing and directing the startups is unique in business history ... Biotechnology, a science

> that is capable of being commercialized, has been totally dependent on university research. In no other fledgling industry have university scientists played such an all-encompassing role. (Kenney 1986, 4)

Though science played a major -- and indeed increasing -- role in earlier innovative industries such as chemicals, electrical engineering, and computing, none was developed entirely in academia. In electronics, key individuals had either left the university after graduation to found their firms, or had even dropped out. But in biotechnology, they had stayed in their university posts and entered into commercial ventures (Kenney 1986, 5, 90, 135-6). The typical method, pioneered by Herbert Boyer and the venture capitalist Robert Swanson when they founded Genentech in 1976, was for an active university researcher to team up with an outside supplier of capital (ibid., 94-5). One study, based on only a 20 per cent sample of public companies in 1984, found 345 academic scientists represented; of the MIT biology faculty, no less than 15 were associated with six different companies (ibid., 4, 116). The NBFs themselves were organized on university lines, with a campus atmosphere and a tradition of publishing scientific results subject only to commercial protection (Daly 1985, 55, 129-30; Kenney 1986, 179-81).

By the mid-1980s, there were more than 100 NBFs in the United States alone, the great majority founded by academics and funded through venture capital; public stock offerings, like those of Genentech in 1980, were less common, as were limited R&D partnerships with existing chemical and pharmaceutical firms (Daly 1985, 16-18, 22-25). The startup companies had shown a very rapid evolution from research organizations that "resemble a university biotechnology department onto which a couple of staffless vice-presidents for production and marketing are grafted" into production firms with fully-fledged marketing and sales systems; the critical year

for this transition seems to have been 1983 (Kenney 1986, 167). But only four -- Cetus (the oldest), Genentech, Biogen, and Genex -- had achieved any size; most were still in the stage of R&D rather than production (Daley 1985, 16-17; Yoxen 1983, 111).

In the fledgling industry's earliest years, prior to 1980, the NBFs had the field almost to themselves: established pharmaceutical firms, though aware of developments, were slow to enter, and chemical firms were much less aware. But by 1983 all the major pharmaceutical companies, and some chemical companies, had made major investments in biotechnology. These investments took five main forms, with most companies pursuing more than one: in-house research laboratories; contracts with universities; licencing and marketing agreements with NBFs; limited R&D partnerships with NBFs; and purchase of equity in NBFs. The most common tactic was for the large corporation to buy equity in the startup while simultaneously financing contract research (Daly 1985, 25-26; Kenney 1986, 197-99, 211).

One element in this pattern is that the established companies had a clear interest in establishing links with second-rank universities which were eager to compete with the established centers. This interest was warmly reciprocated, as in Monsanto's links with Washington University in St Louis, or the agreements that Corning, Eastman Kodak, and Union Carbide made with Cornell. However, other companies negotiated with major established centers, such as DuPont with Harvard Medical School, Exxon with Cold Spring Harbor and W.R. Grace with MIT. The characteristic arrangement, in either case, was a large, one-term contract between a single company and a single university (Daly 1985, 27; Kenney 1986, 55).

By the mid-1980s, the future pattern of ownership and control of the new industry was still in balance. One conclusion was that:

> The MNCs may ultimately become the dominant actors in biotechnology -- most probably absorbing the small venture capital-financed startups. That is not to say that some startups -- such as Cetus, Genentech, and Biogen -- may not become independent, viable companies. Nevertheless, the vast resources of Monsanto, Lilly, or Du Pont will probably prove fatal to the undercapitalized startups. (Kenney 1986, 216)

That, however, would depend on whether the startups could capitalize on the loyalty of their workers and could successfully market the products they develop; the outcome of the battle was not yet decided (ibid., 240-41).

At this time, the biotechnology industry was still embryonic:

> The genetics industry at the end of 1984 was still largely confined to the sale of research inputs, some monoclonal diagnostics, an animal vaccine, and human insulin. (Kenney 1986, 168)

In 1983, the top 50 American biotechnology companies employed only 6000 people (Hacking 1986, 253). Yet there were obvious industrial applications: in pharmaceuticals, including possible treatments for cancer, inflammatory diseases, viral infections, neural and mental disorders, and parasitic infections, coupled with new diagnostic techniques; in specialty chemicals including enzymes, amino acids, and microbial polysaccarides; in food production; and in agriculture, including animal health and reproduction, and plant production and protection (Daly 1985).

These applications were however slow to achieve realization, partly (or even mainly) because of the long delay in gaining approval from the federal Food and Drug Administration (FDA). But in March 1987, despite bitter protests from environmentalists, Advanced Genetic Sciences won approval to spray fruit with a frost-resistant bacterium, engineered for the purpose by removal of one of its genes. In November 1987, Genentech

finally secured approval for its anti-blood clotting agent, tissue plasminogen activator (TPA), which will almost certainly prove one of the most important totally new biotechnology products; the same month, another group, from the NIH and Integrated Genetics, announced that they had succeeded in secreting TPA in mammals' milk, thus demonstrating the possibility of a new generation of anti-clotting dairy products. The strong likelihood, therefore, is that the biotechnology industry is just now being born.

3. THE LOCATIONAL PATTERN OF THE BIOTECHNOLOGY INDUSTRY

Biotechnology's location, we might surmise, would reflect the unique circumstances of its birth. There was the early concentration of basic research in a few prestigious universities, and the parallel concentration of venture capital in Boston and San Francisco, itself stemming from an earlier concentration of information technology innovation in the same group of universities; these contributed to a concentration of new biotech firms in a few locations. And there was a restricted pool of uniquely-qualified scientific labor, which reinforced this concentration process, and -- following the model earlier set by Silicon Valley -- aided the swarming of new firms (Daly 1985, 129; Kenney 1986, 134). All this suggests that the New Biotechnology Firms (NBFs) should be found to cluster around a few major research universities on the east and west coasts.

The older chemical and pharmaceutical companies, on the other hand, have from the start been concentrated in more traditional locations: in the United States, especially on the east coast between New York and Philadelphia, and in the industrial Mid-West; in Germany, on the upper Rhine; in Britain, at a few coastal locations. Insofar as they have recently sought to extend into biotechnology through establishing in-house laboratories, that pattern could be reinforced. Thus both Monsanto and Pfizer established their laboratories in Missouri, Du Pont in Delaware, Lilly in Indiana (Kenney 1986, 201). But to the extent that these firms had to reach out to universities, the pattern could be modified.

To understand how these structural features affect the location of the infant industry, we are able to draw on a unique data base on the biotechnology firms of the world. BioScan, produced by the Cetus Corporation, is updated five times each year; our analysis was based on the mid-1987 version in the library of the University of California, San Francisco. Care has to be used in analyzing this data base. It contains at least two major subsets: the first consisting of more or less "pure" biotechnology firms, new and relatively small; the other consisting of older pharmaceutical and chemical companies that have recently diversified into biotechnology. The latter present particular difficulties for analysis, because they are large and multi-locational, and because the data base shows them by the location not of their production units but of their headquarters. It proved very difficult, despite our efforts, to segment these two groups cleanly and accurately by means of the descriptions in the BioScan base. One way of approximating the distinction is in terms of dates of firm foundations. Cetus, often regarded as the first "true" biotech company, was founded in 1971. So, despite its obvious deficiencies, the method used here is to distinguish between the new biotech and the older companies, using a cutoff of post-1970 firm foundation date.

Within the United States, the BioScan base shows that biotechnology plants are heavily concentrated in relatively few states and urban areas. The state-level coefficient of localization, which measures the degree of such concentration, is 0.30 for all biotech plants and 0.39 for post-1970 plants; the theoretical maximum concentration is somewhere short of 1.00. No less than 24 per cent of all biotech plants, and 27 per cent of post-1970 foundations, are in California; 10 and 9 per cent respectively are in New Jersey, 8 and 11 per cent in Massachusetts (Table 1). Of

Table 1
U.S.A.: BIOTECH PLANTS BY STATE, 1987

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
U.S.A.	358061	100.0	512	100.0	265	100.0	17	100.0	1.0	1.0	1.0
California	47625	13.3	125	24.4	72	27.2	5	29.4	1.8	2.0	2.2
Connecticut	6693	1.9	15	2.9	9	3.4	1	5.9	1.6	1.8	3.1
Illinois	18618	5.2	23	4.5	5	1.9		0.0	0.9	0.4	0.0
Maryland	3883	1.1	24	4.7	17	6.4	1	5.9	4.3	5.9	5.4
Massachusetts	11017	3.1	41	8.0	28	10.6	1	5.9	2.6	3.4	1.9
New Jersey	15126	4.2	54	10.5	24	9.1	2	11.8	2.5	2.1	2.8
New York	32651	9.1	44	8.6	18	6.8	2	11.8	0.9	0.7	1.3
Pennsylvania	17669	4.9	21	4.1	10	3.8		0.0	0.8	0.8	0.0
Texas	20288	5.7	14	2.7	4	1.5	1	5.9	0.5	0.3	1.0
Washington	6791	1.9	16	3.1	12	4.5	0	0.0	1.6	2.4	0.0

course, these high proportions reflect the fact that these are among the nation's major industrial states: high proportions of all manufacturing plants are found there. A more useful measure is the Location Quotient, which measures the relative concentration of an industry in a place compared with the concentration of all industry there. California, Massachusetts and New Jersey all have Location Quotients of well above unity, both for all biotech plants and for the post-1970 new firm subset.

This pattern of concentration is replicated at the scale of the Metropolitan Statistical Area. Table 2 shows that the greatest single concentration of biotech plants is in the New York- Northern New Jersey-Long Island Consolidated Metropolitan Area, which contains over 14 per cent of the national total but a lower proportion, 11 per cent, of the post-1970 startups. But the Location Quotients are barely above unity, indicating that there is no special concentration of biotechnology in this area. In contrast the next biggest concentration, the San Francisco Bay Area, has L.Qs. of over 4 and 5, respectively. Further, this area has a far higher proportion than New York of the newer plants: nearly 16 per cent of the national total. It is fair to conclude, therefore, that this is by far the most important concentration of newer, innovative biotechnology firms in the United States.

The following five areas -- Greater Boston, Greater Philadelphia, Washington DC, San Diego and Seattle-Tacoma - all display a similar pattern: their shares of the newer biotech firms are significantly higher than their shares of all such firms. Together, these seven metropolitan concentrations account for over 44 per cent of all biotech operations and for nearly 60 per cent of the post-1970 foundations.

Table 2
U.S.A.: BIOTECH PLANTS, LEADING METROPOLITAN AREAS, 1987

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
U.S.A.	358061	100.0	512	100.0	265	100.0	17	100.0	1.0	1.0	1.0
New York CMSA	39100	10.9	74	14.5	29	10.9	5	29.4	1.3	1.0	2.7
New York PMSA	19534	5.5	22	4.3	7	2.6	2	11.8	0.8	0.5	2.2
Newark PMSA	4175	1.2	17	3.3	8	3.0	1	5.9	2.8	2.6	5.0
San Francisco CMSA	10526	2.9	65	12.7	42	15.8	2	11.8	4.3	5.4	4.0
Oakland PMSA	2883	0.8	21	4.1	13	4.9	1	5.9	5.1	6.1	7.3
San Francisco PMSA	3095	0.9	25	4.9	17	6.4		0.0	5.6	7.4	0.0
San Jose PMSA	3326	0.9	16	3.1	11	4.2	1	5.9	3.4	4.5	6.3
Boston-Lawrence NECMA	6798	1.9	41	8.0	28	10.6	1	5.9	4.2	5.6	3.1
Philadelphia CMSA	8700	2.4	32	6.3	19	7.2	0	0.0	2.6	3.0	0.0
Philadelphia PMSA	7495	2.1	17	3.3	12	4.5		0.0	1.6	2.2	0.0
Trenton PMSA	454	0.1	11	2.1	6	2.3		0.0	16.9	17.9	0.0
Washington MSA	2388	0.7	24	4.7	17	6.4	2	11.8	7.0	9.6	17.6
San Diego MSA	2522	0.7	18	3.5	13	4.9		0.0	5.0	7.0	0.0
Seattle-Tacoma CMSA	3669	1.0	14	2.7	10	3.8		0.0	2.7	3.7	0.0
Seattle PMSA	3077	0.9	13	2.5	10	3.8		0.0	3.0	4.4	0.0

This pattern is interesting to compare with the one described by Markusen, Hall, and Glasmeier (1986) for all high-tech plants and employment. There also, three concentrations -- there described as Greater San Francisco Bay, Chesapeake to Hudson, and Old New England -- loomed large in the entire national picture, corresponding to our San Francisco, New York, Philadelphia, and Boston concentrations. But neither the Washington DC nor the Seattle area made significant appearances there, because they were less well represented in the information technologies which made up so large a part of the 100 high-tech industries analyzed in High Tech America.

Outside the United States, the biotech industry is equally concentrated. In the United Kingdom, six of the 28 locations are in London (though five of these are Central London headquarters of major corporations or foundations); six are in the adjacent counties of Berkshire and Buckinghamshire, identified by Hall, Breheny, McQuaid, and Hart (1987) as Britain's major high-tech "Western Crescent" around London; another three are elsewhere in South East England; no less than four are in the university city of Cambridge, where Crick and Watson identified the structure of DNA in 1953 and where a major Medical Research Council research facility is located. In France, eight of the 15 locations are in Paris -- most, again, headquarters offices -- and another five are in the outer parts of the Paris region, four in France's own "Western Crescent". The concentration in Japan is even more striking: 33 of the 55 locations are in Tokyo, another 16 in Osaka.

Explaining the Distributions: Toward a Theory of Biotechnology Location

High-Tech America made an attempt was made to develop a theory of location for high-tech industry. Some of the traditionally important factors of neoclassical location theory, it was argued, were not important: transportation costs for materials and product were insignificant, and labor availability was more important than labor cost for the high-level scientific and technological segment (though costs might be very significant for the other part of a highly bipolar labor force). The really significant factors, the authors concluded, "are the ones often surmised to be important for high tech industry: they fall under the three headings of amenities, access, agglomeration" (Markusen, Hall, and Glasmeier 1986, 174-5). Amenity variables, such as a good climate and a range of educational options, were particularly important in explaining the long-term location of these industries. Access to the interstate highway system, and to a major airport, were also significant. Agglomeration economies -- such as the presence of major headquarters offices and a wide range of business services -- were also found important (ibid., 175). In contrast, unionization, wage rates and -- most surprisingly -- a strong research presence did not show up as important factors in the statistical analysis (ibid.).

Our data base would not allow us to make a similar statistical analysis for biotechnology. But it does appear that some of the factors would emerge with different weight. In particular, it seems clear that -- as earlier suggested -- biotechnology startup firms have disproportionately clustered around the major university and research institute

laboratories from which they stemmed. The concentrations in the San Francisco area, in Greater Boston, and in the Washington DC area reflect basic research achievements at Berkeley-Stanford, Harvard-MIT, and the National Institutes of Health respectively. Similarly, the strong presence in the Trenton subdivision of the Philadelphia metropolitan agglomeration is virtually all concentrated in Princeton, reflecting the research activities at the university there.

All this suggests that the NBFs have clustered almost without exception around the universities from where their founders came -- a pattern different from that of any earlier technology. This confirms Kenney's distinction between biotech and other sciences:

> [While] other sciences -- organic chemistry, electrical engineering, computer science, and physics -- have undergone a transformation from a science to a technology, with some scientists leaving academe to start companies ... none of these earlier technologies was developed entirely in academia. (Kenney 1986, 4-5)

Kenney's own analysis of the location of NBFs shows 35 in California, 22 of them in the San Francisco Bay Area, 6 in the Los Angeles area, and 4 in the San Diego area; 13 in the New York City area, including 8 in New Jersey, plus 2 in Pennsylvania; 10 in Massachusetts, and 6 in Maryland (ibid., 134). Significantly, perhaps, MIT and Stanford -- the two universities that have engendered perhaps the greatest numbers of NBFs -- have been the two universities that have consistently tried to "lower the threshold" between their academics and industry, by encouraging new startup companies -- in which they are aided by the large pools of venture capital that are available in the Boston and San Francisco areas (Elkington 1985a, 48).

For the older-established firms, locational determinants are very different. Many of these firms remain where they were founded, sometimes

a century or more ago. They represent previous waves of technological innovation, especially the one at the end of the nineteenth century, which effectively created the modern chemical industries. Thus they tend to be located in the industrial heartland, above all in the New York-Philadelphia corridor which was the crucible of American industrial innovation in that era. They are now increasingly challenged in their traditional production areas, notably petrochemicals, because of petroleum price increases, market saturation, and public concern about pollution; consequently, they are concerned to get a share in biotechnology. All this suggests that there must be some symbiotic interrelationship between these older firms and the newer startups in such areas as northern New Jersey (around the Rutgers campus) and southern New Jersey (around Princeton); but these connections remain to be detailed through further research.

Another factor influencing the spatial structure of the older firms is the prevalence of the "multimillion dollar, multiyear contract between a single university and single company" (Kenney 1986, 4). These stem from the attempts of the existing, long-established firms to establish a relationship with university research, both in the leading centers from which the NBFs also come, and in aspiring centers that have not yet made the top rank. A great variety of such relationships exists, including industrial affiliates (MIT, Stanford School of Medicine), cooperative research (MIT's Polymer Processing Laboratory), privately funded university research centers (Cornell Biotechnology Institute), and long-term contracts (Monsanto-Harvard, Dupont and Harvard Medical School, Monsanto and Washington University, Exxon-MIT, and Hoechst-Massachusetts General Hospital) (ibid., 36).

A critical question for the future, therefore, is whether the NBFs or the established companies take the lead in developing the infant industry. In the United States this outcome is still open; in Europe, where NBFs are far fewer, it is almost certain that the power of the giant multinational corporations will prove decisive. The concluding section examines some of the implications of this competitive struggle for regional and urban policy.

4. SOME QUESTIONS FOR RESEARCH AND POLICY

What policy lessons can be drawn from the brief history of the biotechnology industry? Within the United States, the first critical question for location is the one posed at the end of Section 3: whether the NBFs or the older companies will dominate the battle to develop and market the new products. Even if it is the older firms, the second question is whether they might win only by taking over the NBFs and in effect retaining R&D, and perhaps production, in the NBFs' locations. There is however a reverse side to this issue: whether, as they grow and mature, the NBFs may not increasingly detach themselves from their university bases and spatially disperse, as has happened to some information technology firms. A contributory factor, here, could be the growing unease about the potential conflicts of interest that may arise when professors hold substantial interests in companies that are commercializing their research (Prentis 1984, 181, Kenney 1986, 113).

A third question is whether, in the long run, the location of the industry may be affected by different regulatory regimes. Within the United States, most of the key regulations that have already affected biotechnology research, and are likely to affect it in future, are made at federal level. They thus have effects that are -- for good or ill -- uniform within the United States. But local attitudes can also affect the industry's location; it is evident here that -- following on the City of Cambridge's opposition to research conducted at Harvard and MIT in the mid-1970s -- some established academic locales have proved exceptionally sensitive on the biotech issue, in part because they contain large

concentrations of politically active scientists and environmentalists. One effect has been to drive the industry to more politically hospitable local enclaves which have traditionally been sympathetic to industry or have relatively few residential voters; examples include Emeryville and South San Francisco in the San Francisco Bay Area, which have increasingly hosted companies originally based in Berkeley. And, if environmental opposition continues or even intensifies in certain university communities, this trend may become even more evident.

A final question is whether, whatever the outcome, biotechnology will prove a large generator of new jobs. Some observers think that, like most of the chemical industries, biotechnology will prove highly capital- rather than labor-intensive. If so, the jobs will be few, and will be most likely restricted to highly-trained technicians, scientists, and administrators. What may prove more significant in employment terms are the firms supplying biotechnology with materials and above all with hardware and software for complex technical operations (Kenney 1986, 135). Additionally, future applications of biotech processes to agriculture, food processing, and informatics may open up the possibility of new products, industries, and employment. It is however too early to predict the extent of such growth.

In the rest of the world, finally, the position is very different. In few other countries do startups, or venture capital, play a significant role. The United Kingdom comes closest to the American model: here are both old-established companies like ICI, Burroughs Wellcome, Glaxo, and Beecham, and also the greatest number of NBFs outside the United States, including two started by cooperation between government and the private sector, Celltech and Agricultural Genetics (Daly 1985, 29, 32; Elkington

1985a, 193; Hacking 1986, 254). Germany, in contrast, has virtually no venture capital, and relies on old-established firms like BASF, Bayer, and Hoechst; the story in Switzerland is similar. France has managed to develop companies from publicly-funded research, including Transgène (through the Institut Pasteur and the Universitè de Strasbourg), and the Groupement de Génie Génétique (a subsidiary of several research institutes, including the Institut Pasteur) (Daly 1985, 32-34; Kenney 1986, 244). Perhaps predictably, the country that seems to present the greatest competitive threat to American supremacy is Japan; here, MITI has financed a $128 million, 10-year project in bioreactors, mass cell cultures, and Recombinant DNA, while some 150 companies are spending another $217 million a year, and significant breakthroughs have already occurred (Elkington 1985b; Hacking 1986, p. 254).

The contrasts among these major international competitors may be to some extent deceptive. All have provided major state funding for basic research, either in universities or in specialized institutes like France's Institut Pasteur or Germany's Max Planck Institut. All have their old-established companies dating from the great revolutions in chemistry in the last decades of the nineteenth century. But the United States is distinguished -- in biotech as in information technology -- by the exceptional vigor of its small startup firms, in which scientific research is allied with entrepreneurial skill. As the Congressional Office of Technology Assessment concluded in 1985, the United States had "the most effective and dynamic university-industry technical transfer process of the six countries" that it investigated (q. Elkington 1985a, 192). On the continued strength of that tradition may well depend its

supremacy in the next industrial transformation: the most fundamental question of all.

This outcome is intimately linked to the question of whether policy can consciously affect the location of an industry. We have very few examples of pure knowledge-based industries, and they are of fairly recent genesis; the information technologies, as suggested earlier, seem to represent the closest parallel. The question then can be put in retrospect: could the United States, immediately after the discovery of the transistor, have affected the location of the Information Technology industries? Could it have steered them towards the industrial heartland of the Mid-West, where they might have helped compensate for the decline of the older basic manufacturing industries that occurred after 1975? The answer is probably that it would have been not impossible, but difficult: the basic research was being done in a few universities like MIT and Stanford, not on Mid-Western campuses, a product of previous federal and university funding choices.

The same appears to be the case for the biotechnology industry in the mid-1980s. Only a massive diversion of federal funds, away from top-rank institutions like MIT and the University of California, and towards places now not so highly placed, would suffice. It could of course be done. But it would naturally conflict with the national interest of getting the best work done within the United States, and it would be likely to incur the opposition of the scientific community, intent on preserving the autonomy of their peer review process.

Very much the same argument applies to other countries, including those that -- at least in the recent past -- have pursued stronger regional policies. In the United Kingdom, major awards for biotechnology

research were announced at the end of October 1987: University College, London, was to receive £1.9 million, the University of Birmingham £1.6 million over four years; the funds are to establish two biochemical engineering complexes, which will study the problems of scaling up and controlling biological processes on an industrial scale -- a field in which the UK was in the forefront. No center was announced in the north of England or in central Scotland, the areas worst afflicted by the decline of basic industries and by resultant high unemployment; clearly, regional considerations had played no part in the decision. That neatly illustrates the dilemma: left to themselves, the knowledge industries are likely to multiply in just the locations where they are most strongly entrenched already.

Thus the questions for policy are four in number. Can a conscious governmental policy, by locating basic research work on biotechnology, affect industrial spinoff and thus the location of the industry? At what stage would such a policy prove effective? How many jobs would thus be generated, directly and indirectly? How many would be in biotechnology manufacturing, and how many in subsidiary industries such as the manufacture of hardware and software, and in service industries utilizing the new products?

Many of these answers must be speculative and judgmental, and so not appropriate for empirical research. But such research could throw some light on the issues. One critical research question concerns the trajectory of growth of the NBFs. At what point do they enter into manufacture? How far does the R&D function remain tied, whether by common personalities or shared knowledge and facilities, to the university base? How far can the two functions be geographically divorced, as seems to have

happened in some information technology firms? How sensitive are they, and at what stages of growth, to different regulatory regimes?

Another group of questions concerns science policy -- hitherto an under-researched area in urban and regional studies. How far is it possible to build up new, strong research centers away from existing top-class universities? Does World War Two provide examples? Are there examples of infant sciences developed outside top-grade campuses, due to the insight and energy of individuals, which then have a catalytic effect on these institutions? At what stage in the development of a new scientific discipline is it useful to intervene?

Such a research program might profitably go outside the narrow horizons of biotechnology, to look also at developments in information technology and other major developments of the last half century. It might also range internationally, to include not merely the United States but also other advanced industrial countries. The aim would be to trace subtle and complex links between national science policies and the geography of innovative industrial development. Though very partial approaches have been made to this question, the definitive work is still to be done.

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Appendix Table A

BIOTECH PLANTS BY STATE AND MSA, 1987

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
U.S.A.	358061	100.0	512	100.0	265	100.0	17	100.0	1.0	1.0	1.0
Alabama	5528	1.5	1	0.2	1	0.4		0.0	0.1	0.2	0.0
Birmingham	1089	0.3	1	0.2	1	0.4		0.0	0.6	1.2	0.0
Alaska	445	0.1		0.0		0.0		0.0	0.0	0.0	0.0
Arizona	3407	1.0	1	0.2	1	0.4		0.0	0.2	0.4	0.0
Tucson	534	0.1	1	0.2	1	0.4		0.0	1.3	2.5	0.0
Arkansas	3313	0.9	1	0.2	1	0.4		0.0	0.2	0.4	0.0
Non-Metro	2199	0.6	1	0.2	1	0.4		0.0	0.3	0.6	0.0
California	47625	13.3	125	24.4	72	27.2	5	29.4	1.8	2.0	2.2
Bakersfield	348	0.1	1	0.2		0.0		0.0	2.0	0.0	0.0
Los Angeles CMSA	28453	7.9	34	6.6	13	4.9	2	11.8	0.8	0.6	1.5
Anaheim PMSA	5433	1.5	14	2.7	4	1.5	2	11.8	1.8	1.0	7.8
Los Angeles PMSA	20474	5.7	17	3.3	7	2.6		0.0	0.6	0.5	0.0
Oxnard PMSA	631	0.2	2	0.4	2	0.8		0.0	2.2	4.3	0.0
Riverside PMSA	1915	0.5	1	0.2		0.0		0.0	0.4	0.0	0.0
Sacramento	1166	0.3	4	0.8	3	1.1	1	5.9	2.4	3.5	18.1
San Diego	2522	0.7	18	3.5	13	4.9		0.0	5.0	7.0	0.0
San Francisco CMSA	10526	2.9	65	12.7	42	15.8	2	11.8	4.3	5.4	4.0
Oakland PMSA	2883	0.8	21	4.1	13	4.9	1	5.9	5.1	6.1	7.3
San Francisco PMSA	3095	0.9	25	4.9	17	6.4		0.0	5.6	7.4	0.0
San Jose PMSA	3326	0.9	16	3.1	11	4.2	1	5.9	3.4	4.5	6.3
Santa Cruz PMSA	349	0.1	2	0.4	1	0.4		0.0	4.0	3.9	0.0
Santa Rosa PMSA	518	0.1	1	0.2		0.0		0.0	1.4	0.0	0.0
Santa Barbara	489	0.1	1	0.2	1	0.4		0.0	1.4	2.8	0.0
Stockton	465	0.1	1	0.2		0.0		0.0	1.5	0.0	0.0
Non-Metro	1601	0.4	1	0.2		0.0		0.0	0.4	0.0	0.0

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
Colorado	4406	1.2	11	2.1	6	2.3	1	5.9	1.7	1.8	4.8
Denver-Boulder CMSA	2838	0.8	8	1.6	5	1.9	1	5.9	2.0	2.4	7.4
Boulder PMSA	473	0.1	3	0.6	3	1.1		0.0	4.4	8.6	0.0
Denver PMSA	2365	0.7	5	1.0	2	0.8	1	5.9	1.5	1.1	8.9
Fort Collins	259	0.1	1	0.2		0.0		0.0	2.7	0.0	0.0
Greeley	132	0.0	1	0.2	1	0.4		0.0	5.3	10.2	0.0
Non-Metro	719	0.2	1	0.2		0.0		0.0	1.0	0.0	0.0
Connecticut	6693	1.9	15	2.9	9	3.4	1	5.9	1.6	1.8	3.1
Bridgeport PMSA	1892	0.5	9	1.8	4	1.5	1	5.9	3.3	2.9	11.1
Hartford	2212	0.6	2	0.4	2	0.8		0.0	0.6	1.2	0.0
New Haven	1732	0.5	4	0.8	3	1.1		0.0	1.6	2.3	0.0
Delaware	632	0.2	2	0.4		0.0		0.0	2.2	0.0	0.0
Wilmington PMSA	512	0.1	2	0.4		0.0		0.0	2.7	0.0	0.0
District of Columbia	514	0.1	1	0.2	1	0.4	2	11.8	1.4	2.6	82.0
Washington	2388	0.7	24	4.7	17	6.4	2	11.8	7.0	9.6	17.6
Florida	13723	3.8	11	2.1	5	1.9	2	11.8	0.6	0.5	3.1
Jacksonville	837	0.2	1	0.2		0.0		0.0	0.8	0.0	0.0
Melbourne	338	0.1	1	0.2	1	0.4		0.0	2.1	4.0	0.0
Miami CMSA	5023	1.4	3	0.6	2	0.8	0	0.0	0.4	0.5	0.0
Miami PMSA	3394	0.9	3	0.6	2	0.8		0.0	0.6	0.8	0.0
Sarasota	356	0.1	1	0.2		0.0	1	5.9	2.0	0.0	59.2
Tampa	2107	0.6	3	0.6	1	0.4	1	5.9	1.0	0.6	10.0
West Palm Beach	721	0.2	1	0.2	1	0.4		0.0	1.0	1.9	0.0
Non-Metro	1025	0.3	1	0.2		0.0		0.0	0.7	0.0	0.0
Georgia	8535	2.4	2	0.4	1	0.4		0.0	0.2	0.2	0.0
Atlanta	3232	0.9	1	0.2	1	0.4		0.0	0.2	0.4	0.0
Non-Metro	4013	1.1	1	0.2		0.0		0.0	0.2	0.0	0.0
Hawaii	967	0.3	1	0.2	1	0.4		0.0	0.7	1.4	0.0
Honolulu	780	0.2	1	0.2	1	0.4		0.0	0.9	1.7	0.0
Idaho	1405	0.4		0.0		0.0		0.0	0.0	0.0	0.0

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
Illinois	18618	5.2	23	4.5	5	1.9		0.0	0.9	0.4	0.0
Champaign	143	0.0	2	0.4	1	0.4		0.0	9.8	9.4	0.0
Decatur	140	0.0	2	0.4		0.0		0.0	10.0	0.0	0.0
Chicago-Gary CMSA	14591	4.1	15	2.9	4	1.5		0.0	0.7	0.4	0.0
Chicago PMSA	12281	3.4	10	2.0	2	0.8		0.0	0.6	0.2	0.0
Indiana	7960	2.2	7	1.4	4	1.5	0	0.0	0.6	0.7	0.0
Elkhart	727	0.2	2	0.4	1	0.4		0.0	1.9	1.9	0.0
Gary PMSA	458	0.1	5	1.0	2	0.8		0.0	7.6	5.9	0.0
Indianapolis	1663	0.5	1	0.2		0.0		0.0	0.4	0.0	0.0
Lafayette	97	0.0	2	0.4	1	0.4		0.0	14.4	13.9	0.0
South Bend	441	0.1	1	0.2	1	0.4		0.0	1.6	3.1	0.0
Non-Metro	2778	0.8	1	0.2		0.0		0.0	0.3	0.0	0.0
Iowa	3600	1.0	4	0.8	1	0.4		0.0	0.8	0.4	0.0
Des Moines	474	0.1	2	0.4		0.0		0.0	3.0	0.0	0.0
Non-Metro	2126	0.6	2	0.4	1	0.4		0.0	0.7	0.6	0.0
Kansas	3235	0.9	2	0.4	1	0.4		0.0	0.4	0.4	0.0
Non-Metro	1640	0.5	2	0.4	1	0.4		0.0	0.9	0.8	0.0
Kentucky	3502	1.0	1	0.2		0.0		0.0	0.2	0.0	0.0
Lexington	345	0.1	1	0.2		0.0		0.0	2.0	0.0	0.0
Louisiana	4107	1.1	1	0.2	1	0.4		0.0	0.2	0.3	0.0
New Orleans	1030	0.3	1	0.2	1	0.4		0.0	0.7	1.3	0.0
Maine	2009	0.6	4	0.8	4	1.5		0.0	1.4	2.7	0.0
Portland	340	0.1	4	0.8	4	1.5		0.0	8.2	15.9	0.0
Maryland	3883	1.1	24	4.7	17	6.4	1	5.9	4.3	5.9	5.4
Baltimore	2168	0.6	5	1.0	4	1.5		0.0	1.6	2.5	0.0
Massachusetts	11017	3.1	41	8.0	28	10.6	1	5.9	2.6	3.4	1.9
Boston	6798	1.9	41	8.0	28	10.6	1	5.9	4.2	5.6	3.1
New Bedford	1059	0.3	1	0.2		0.0		0.0	0.7	0.0	0.0
Michigan	15158	4.2	11	2.1	7	2.6		0.0	0.5	0.6	0.0
Battle Creek	193	0.1	1								
Detroit PMSA	7836	2.2	3	0.6	3	1.1		0.0	0.3	0.5	0.0

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
Kalamazoo	361	0.1	1	0.2		0.0		0.0	1.9	0.0	0.0
Lansing	356	0.1	2	0.4	2	0.8		0.0	3.9	7.6	0.0
Saginaw	399	0.1	1	0.2		0.0		0.0	1.8	0.0	0.0
Minnesota	6775	1.9	10	2.0	5	1.9	1	5.9	1.0	1.0	3.1
Minneapolis	4193	1.2	8	1.6	4	1.5	1	5.9	1.3	1.3	5.0
Rochester	74	0.0	1	0.2	1	0.4		0.0	9.5	18.3	0.0
Non-Metro	2101	0.6	1	0.2		0.0		0.0	0.3	0.0	0.0
Mississippi	3126	0.9		0.0		0.0		0.0	0.0	0.0	0.0
Missouri	7069	2.0	10	2.0	3	1.1		0.0	1.0	0.6	0.0
Kansas City	2137	0.6	4	0.8		0.0		0.0	1.3	0.0	0.0
St Joseph	110	0.0	1	0.2		0.0		0.0	6.4	0.0	0.0
St Louis	3274	0.9	5	1.0	3	1.1		0.0	1.1	1.2	0.0
Montana	1090	0.3	2	0.4	2	0.8		0.0	1.3	2.5	0.0
Non-Metro	883	0.2	2	0.4	2	0.8		0.0	1.6	3.1	0.0
Nebraska	1928	0.5		0.0		0.0		0.0	0.0	0.0	0.0
Nevada	853	0.2		0.0		0.0		0.0	0.0	0.0	0.0
New Hampshire	1981	0.6	2	0.4		0.0	1	5.9	0.7	0.0	10.6
Portsmouth	452	0.1	1	0.2		0.0		0.0	1.5	0.0	0.0
Non-Metro	912	0.3	1	0.2		0.0	1	5.9	0.8	0.0	23.1
New Jersey	15126	4.2	54	10.5	24	9.1	2	11.8	2.5	2.1	2.8
Bergen PMSA	3950	1.1	7	1.4	2	0.8		0.0	1.2	0.7	0.0
Middlesex PMSA	1718	0.5	10	2.0	2	0.8	1	5.9	4.1	1.6	12.3
Newark PMSA	4175	1.2	17	3.3	8	3.0	1	5.9	2.8	2.6	5.0
Trenton PMSA	454	0.1	11	2.1	6	2.3		0.0	16.9	17.9	0.0
Vineland PMSA	239	0.1	2	0.4	1	0.4		0.0	5.9	5.7	0.0
New Mexico	1223	0.3	1	0.2	1	0.4		0.0	0.6	1.1	0.0
Albuquerque	550	0.2	1	0.2	1	0.4		0.0	1.3	2.5	0.0
New York	32651	9.1	44	8.6	18	6.8	2	11.8	0.9	0.7	1.3
Albany	784	0.2	2	0.4	1	0.4		0.0	1.8	1.7	0.0
Buffalo	1604	0.4	2	0.4	1	0.4		0.0	0.9	0.8	0.0

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
New York CMSA	39100	10.9	74	14.5	29	10.9	5	29.4	1.3	1.0	2.7
Nassau PMSA	4879	1.4	8	1.6	5	1.9		0.0	1.1	1.4	0.0
New York PMSA	19534	5.5	22	4.3	7	2.6	2	11.8	0.8	0.5	2.2
Orange PMSA	350	0.1	2	0.4	1	0.4		0.0	4.0	3.9	0.0
Poughkeepsie	248	0.1	1	0.2		0.0		0.0	2.8	0.0	0.0
Rochester	1355	0.4	2	0.4	1	0.4		0.0	1.0	1.0	0.0
Non-Metro	2168	0.6	5	1.0	2	0.8		0.0	1.6	1.2	0.0
North Carolina	10134	2.8	5	1.0	3	1.1		0.0	0.3	0.4	0.0
Burlington	268	0.1	1	0.2	1	0.4		0.0	2.6	5.0	0.0
Charlotte	2038	0.6	1	0.2		0.0		0.0	0.3	0.0	0.0
Raleigh-Durham	655	0.2	3	0.6	2	0.8		0.0	3.2	4.1	0.0
North Dakota	587	0.2		0.0		0.0		0.0	0.0	0.0	0.0
Ohio	16966	4.7	12	2.3	3	1.1		0.0	0.5	0.2	0.0
Cincinnati CMSA	2329	0.7	3								
Cleveland PMSA	4299	1.2	5	1.0	1	0.4		0.0	0.8	0.3	0.0
Columbus	1484	0.4	3	0.6	2	0.8		0.0	1.4	1.8	0.0
Oklahoma	4169	1.2	5	1.0	1	0.4		0.0	0.8	0.3	0.0
Oklahoma	1159	0.3	3	0.6	1	0.4		0.0	1.8	1.2	0.0
Non-Metro	1413	0.4	2	0.4		0.0		0.0	1.0	0.0	0.0
Oregon	5659	1.6	2	0.4	2	0.8		0.0	0.2	0.5	0.0
Medford	261	0.1	1	0.2	1	0.4		0.0	2.7	5.2	0.0
Portland CMSA	2671	0.7	1	0.2	1	0.4		0.0	0.3	0.5	0.0
Portland PMSA	2401	0.7	1	0.2	1	0.4		0.0	0.3	0.6	0.0
Non-Metro	1941	0.5	1	0.2	1	0.4		0.0	0.4	0.7	0.0
Pennsylvania	17669	4.9	21	4.1	10	3.8		0.0	0.8	0.8	0.0
Allentown	1122	0.3	5	1.0	1	0.4		0.0	3.1	1.2	0.0
Philadelphia CMSA	8700	2.4	32	6.3	19	7.2	0	0.0	2.6	3.0	0.0
Philadelphia PMSA	7495	2.1	17	3.3	12	4.5		0.0	1.6	2.2	0.0
Pittsburgh CMSA	2664	0.7	5	1.0	1	0.4		0.0	1.3	0.5	0.0
Pittsburgh PMSA	2479	0.7	5	1.0	1	0.4		0.0	1.4	0.5	0.0

	Total Mfrg. Plants (1982)	% U.S. Total	Biotech Plants	% U.S. Total	Post-1971 Biotech Plants	% U.S. Total	Pre-1971 Biotech Plants	% U.S. Total	L.Q. All Biotech Plants	L.Q. Post-1971 Plants	L.Q. Pre-1971 Plants
Rhode Island	2856	0.8	2	0.4	1	0.4		0.0	0.5	0.5	0.0
Providence	2781	0.8	2	0.4	1	0.4		0.0	0.5	0.5	0.0
South Carolina	4205	1.2		0.0		0.0		0.0	0.0	0.0	0.0
South Dakota	748	0.2		0.0		0.0		0.0	0.0	0.0	0.0
Tennessee	6417	1.8	2	0.4	2	0.8		0.0	0.2	0.4	0.0
Knoxville	700	0.2	1	0.2	1	0.4		0.0	1.0	1.9	0.0
Nashville	1357	0.4	1	0.2	1	0.4		0.0	0.5	1.0	0.0
Texas	20288	5.7	14	2.7	4	1.5	1	5.9	0.5	0.3	1.0
Austin	680	0.2	1	0.2		0.0		0.0	1.0	0.0	0.0
Dallas CMSA	6070	1.7	4	0.8	1	0.4		0.0	0.5	0.2	0.0
Dallas PMSA	4033	1.1	3	0.6		0.0		0.0	0.5	0.0	0.0
Fort Worth PMSA	2037	0.6	1	0.2	1	0.4		0.0	0.3	0.7	0.0
Houston CMSA	5134	1.4	9	1.8	3	1.1		0.0	1.2	0.8	0.0
Houston PMSA	4813	1.3	9	1.8	3	1.1	1	5.9	1.3	0.8	4.4
Utah	1962	0.5	4	0.8	0	0.0	0	0.0	1.4	0.0	0.0
Provo	267	0.1	1	0.2		0.0		0.0	2.6	0.0	0.0
Salt Lake	1374	0.4	2	0.4		0.0		0.0	1.0	0.0	0.0
Non-Metro	321	0.1	1	0.2		0.0		0.0	2.2	0.0	0.0
Vermont	1104	0.3		0.0		0.0		0.0	0.0	0.0	0.0
Virginia	5568	1.6	7	1.4	4	1.5		0.0	0.9	1.0	0.0
Richmond	900	0.3	2	0.4		0.0		0.0	1.6	0.0	0.0
Washington	6791	1.9	16	3.1	12	4.5	0	0.0	1.6	2.4	0.0
Richland	103	0.0	2	0.4	2	0.8		0.0	13.6	26.2	0.0
Seattle-Tacoma CMSA	3669	1.0	14	2.7	10	3.8		0.0	2.7	3.7	0.0
Seattle PMSA	3077	0.9	13	2.5	10	3.8		0.0	3.0	4.4	0.0
Tacoma PMSA	592	0.2	1	0.2		0.0		0.0	1.2	0.0	0.0
West Virginia	1662	0.5		0.0		0.0		0.0	0.0	0.0	0.0
Wisconsin	8682	2.4	10	2.0	4	1.5	1	5.9	0.8	0.6	2.4
Madison	467	0.1	3								
Non-Metro	2941	0.8	1	0.2		0.0		0.0	0.2	0.0	0.0

Source: BioScan