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State economic development agencies are engaged in a variety of efforts to increase the capacity of the state to attract or create new biotechnology firms. Some states have established well-endowed organizations dedicated to promoting biotechnology, whereas others have adopted more modest programs or have incorporated biotechnology issues into other policy areas, such as education or agriculture. Despite the range of organizational forms and purposes, there is evidence of a common paradigm, "the incubator model," being used by state policymakers with respect to biotechnological economic development activity. The thrust of this strategy is to create a set of conditions that will nurture technological innovation and the formation of indigenous firms. The incubator model provides a coherent conceptual framework for policymakers to pursue a slate of recognizable programs. Changes in the structure of commercial biotechnology, particularly increasing fragmentation and externalization of productive relations, suggest that the local resources identified as the incubation base may provide regions with a competitive edge.

Over the past decade, regional economic development theorists and practitioners have spent considerable energy addressing the following propositions: (1) that a key element of economic competitiveness is technology-based development (the ability to produce qualitatively differentiated and functionally improved goods and services); (2) technology-based growth is spatially determined by the conditions in a particular location; (3) promoting the indigenous potential of regions to produce or to adapt innovations quickly is a desirable objective of economic development efforts; and (4) the public sector role as catalyst and/or facilitator can be influential in attracting technologically advanced firms, as well as creating or retaining such firms. These propositions have formed a basic paradigm for regional (state) economic development practice.

In their attempts to formulate new roles and missions, state government leaders have evoked attractive images and metaphors based on the experiences of Silicon Valley and Boston's Route 128. The language used in policy discourse often blurs the distinction between description and prescription. Policy concepts, embedded in high-technology success stories, are repeated and diffused through professional networks and the popular media.

In this article, we use the biotechnology industry as an illustration of how state officials design technology-oriented economic development policies. Lessons drawn from successful semiconductor and microelectronic production districts have changed the way policymakers look at

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economic development options in fast-changing technological fields. These regions are characterized by networked relationships among producers, suppliers, and customers in which collaboration and competition spur higher levels of innovation and specialized expertise.[1] With the Silicon Valley experience as an exemplar, many states have used the "incubator" metaphor both to evaluate the capacity of their economic base and to lay down a grow-your-own strategy as a cornerstone of the economic development policies.[2] Although some states have targeted specific industries, the policy concerns are usually more generic and process oriented, such as how to strengthen organized research, develop scientific talent, translate research breakthroughs into marketable products and processes, and link potential financial or scientific partners. The stress is on creating an atmosphere that *induces* high technology, rather than fashioning giveaways designed to attract firms from elsewhere.

For policymakers the incubator model provides a way of articulating the operational approach used to position themselves in various high-technology fields. The incubator notion, based on a grow-your-own strategy, provides a coherent conceptual framework that can accommodate a variety of policy tools. Although the incubating idea is frequently and casually mentioned in discussions of economic development specialists and local policymakers, there is a taken-for-granted quality about this metaphor. We are using a more careful explication of the incubator model to understand varying levels of government support for commercial biotechnology. Of course, designing long-term policy is complicated by the evolving structure of commercial biotechnology, for example, increasing levels of fragmentation and new patterns of strategic alliances among firms. The incubator approach provides an intellectual shorthand that suggests ways of addressing these transformations.

RETHINKING THE INCUBATOR METAPHOR FOR POLICY ANALYSIS

In a 1987 article, Allen Scott and Michael Storper critiqued the incubator model as "reasonable enough" from a "purely descriptive" standpoint, but "analytically sterile, a symptom of which is its readiness to fall headlong into biologistic metaphor."[3] With few exceptions, little attention has been given to the incubator model per se. However, it may be premature to dismiss the analytical potential of the model on the basis of its failure to yield a rigorous set of predictive relationships.

We propose, instead, that the analytical strength of the incubator lies in the metaphor itself.[4] Metaphors provide a way for inquiry to proceed by apprehending new relations through familiar categories and by helping us to see a common underlying form in things that superficially appear to be quite different or that exist in different contexts. They can reveal new attributes or cast old ones in a new light. With the incubator metaphor, however, there has been a tendency to use it without clarifying the analogies that are being drawn and how it is used for policy design.

The original incubator metaphor is attributed to the authors of the New York Regional Plan who referred to the dense concentration of people, ideas, and commercial linkages to be found in major urban areas that would stimulate new business formation.[5] "Incubation," in this context is a by-product of urbanness. In contrast, when the incubator concept is used in a policy context, it refers to efforts aimed at distilling the essential elements necessary to promote entrepreneurship and simulating the fertile ground of the urban environment—all within a more limited arena. Public authority is exercised to artificially re-create or alter the existing economic environment.

A look at everyday examples of incubators will help to illustrate the pertinent features of an incubating environment. Common settings for incubators are the hothouse, the laboratory oven for cultures of microorganisms, the specially designed crib for infants at risk, and the poultry hatchery. In each of these cases, there is a protected, controlled environment to maintain optimal conditions. Besides regular monitoring, experts are on hand to intervene if any problem arises. Incubators usually regulate ambient conditions, such as light, temperature, and humidity. But they also assemble the nutrients, treatments, and stimulation necessary to promote and sustain development. It is important to note that not all individuals need the care of an incubating environment. So too, selection is involved in determining which firms are vulnerable and would benefit from incubation. The incubator is usually limited to the fledgling stage; it is not intended as a long-term

habitat. However, the metaphor needs to be reconceptualized in the case of an industry that is innovation oriented, where some firms remain devoted to the early stages of product development. Thus even established biotechnology firms may find beneficial the incubating environment that spawned and nurtured their start-up. It is the nature of biotechnology, as production techniques and as an industrial form, that supports the use of the incubator metaphor as a working model for policy-making. And it is to commercial biotechnology that we now turn.

BIOTECHNOLOGY AS AN INDUSTRIAL FORM: FROM THE CRADLE

The Office of Technology Assessment (OTA) defines biotechnology as "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 use."[6] Techniques subsumed under the umbrella term "biotechnology" include recombinant DNA techniques, cell fusion, protein engineering, and novel bioprocessing techniques. They are used in several industrial sectors that are commonly categorized as human therapeutics, human diagnostics, plant and animal agriculture, supplies (reagents) and instrumentation, specialty chemicals, and hazardous-waste management.[7]

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Although biotechnology grew in the shadow of the computer and microelectronics industries, there are important differences between the two technical communities. Small computer firms are often started by engineers who previously worked for larger companies in closely related industries.[8] Second-generation biotechnology firms are beginning to emerge; however, most of the new enterprises are established by scientists associated with universities, often with little experience in production or in marketing products.[9] The nature of research and development (R&D) and the product life cycle also differ. The development phase of biotechnology products is relatively long. In particular, diagnostic and therapeutic products for humans and animals are subject to stringent regulatory procedures that have no parallel to the microelectronics market. The average time spent by companies getting their biotechnology products through clinical trials and regulatory review at the Food and Drug Administration is five years.[10] A "fast track" drug (such as AZT for AIDS treatment) can take half that amount of time. A very rough estimate of the cost to fund biotechnology products from early research to the market is $100 million, with at least two-thirds of that spent on human trials and market introduction.[11]

Some differences between biotechnology and microelectronics are beginning to erode. Not long ago, biotechnology products were sold primarily to end users or to professionals, unlike microelectronics products which are often sold as components of more complex systems. This difference is due to the many variations and incremental changes in style and performance that are possible in microelectronics compared to biotechnology, where every product starts from original scientific discovery, such as a new protein molecule. Recently, even biotechnology companies are incorporating the use of OEM (original equipment manufacture)—a concept borrowed from electronics. Suppliers that once furnished raw materials and basic reagents are finding increasing demand for "semi-finished" products and specialty biochemicals that are components of a drug or diagnostic kit.[12]

The changing nature of supply networks is indicative of biotechnology's evolving industrial form. But, then, it is well to remember that commercial biotechnology is only in its second decade. Biotechnology gained national attention in 1980 after Genentech became the first dedicated biotech firm to go public, receiving record-breaking valuations from Wall Street. In the same year, the U.S. Supreme Court validated patenting rights to genetically altered microorganisms. When analysts began looking at the industry, they were not surprised to find dynamic, state-of-the-art biotech companies in acknowledged high-technology hotbeds or incubators, such as the San Francisco Bay Area and Boston. Somewhat more surprising, however, were the other biotechnology companies found in many areas of the nation. As Walter Stohr suggested, it appeared that the geography of incubators was indeed adjustable at this time and with this industry.[13] In fact, the underlying potential to start biotechnology firms existed in almost all regions with universities engaged in high-quality microbiological research.

Through the early and mid 1980s, industry watchers and public officials alike expected the biotechnology start-ups to follow the trajectory of their counterparts in microelectronics. Small R&D companies would grow into fully integrated multinationals and, in the process, generate a lot of high-paying jobs, taxes, and other economic benefits. Meanwhile, there were also concerns that firms would move their lower-skill production jobs once biotechnology products reached the manufacturing stage. Two events in the latter half of the 1980s changed the outlook for biotechnology's future. The first event was the stock market crash of October 1987 that drastically reduced the ability of biotech firms to obtain middle- to later-stage public financing in order to continue expensive R&D programs and to pay for the clinical trials necessary to obtain drug approval. The second event was the acquisition by the Swiss multinational Hoffman-LaRoche of 60% of Genentech stock in April 1989 at a cost of $2.1 billion. Genentech is widely considered the premier biotech company and its decision to affiliate with a stronger financial power, rather than to remain independent, marked a watershed in the industry's development.

In the wake of the Genentech-LaRoche deal, the sentiment pervading biotechnology circles was that "If Genentech couldn't make it, who could?"[14] In actuality, this question probably overestimated the amount of independence even the largest dedicated biotech firms have been able to maintain. Though short of outright acquisition, strategic alliances have been a feature of biotechnology almost from the beginning and remain prevalent.[15] However, the objectives of strategic alliances have shifted over the years. In the early days, alliances were a means of technology transfer, allowing established corporations to learn about new technologies in an era when breakthroughs in traditional pharmaceuticals have become less common and many products are nearing the end of patent protection. Slow to start, large corporations now invest considerable sums on in-house R&D of biotechnology. Still, research by McKinsey & Co. and Harvard University have found that pharmaceutical research productivity (as measured by biotechnology patent applications per $10 million of R&D spending) is more than four times higher at small biotech firms than at industry leaders.[16] Given this relative efficiency, smaller companies with their freewheeling and innovative lab atmosphere can bring an important chip to the strategic alliance bargaining table.

For the dedicated biotech company, the primary motivation is straightforward: to generate income that will sustain further product development. With biotech products closer to market today, larger, more diversified corporations offer not only financing, but also expertise in downstream phases (such as clinical testing, production capability, and a ready-made distribution system). Strategic alliances reflect the values placed on different resources at different stages in the commercialization process. Barley and Freeman's research on strategic alliances finds a preponderance of agreements in phases beyond R&D, including manufacturing agreements, marketing agreements, and the broader category of licensing agreements (any combination of the previous two).[17] See Table 1.

As economic developers, we are interested in the spatial implications of these interfirm alliances. Is proximity as significant a concern for alliance building in biotechnology as it is in microelectronics? Will dedicated biotechnology firms increasingly detach themselves from their university bases and relocate closer to their corporate sponsors? Table 2 shows a sample of strategic alliances that were formed between large and small firms in 1989. Because it is based on public information, there may be a bias against linkages between biotech firms and regional (rather than multinational) corporations. However, the effect of any bias is expected to be small because of the oligopolistic nature of the industries involved, and regional corporations are not likely to have the financial and market powers sought by small biotech firms. In any case, the clear absence of any discernible geographic pattern is striking.

It is not unusual for biotech firms to enter into alliances with different partners for different product lines. Because these networks can be quite dispersed geographically and will change over time, there is no incentive for the biotech firm to move closer to one partner or another. Moreover, it is the scientist—not the science—on which alliances are built. Some of these scientists may be jointly affiliated with other institutions and unable to move, and all parties will be reluctant to disrupt the accustomed practices of a functioning lab. Thus, to the degree that biotech firms are

TABLE 1
Types of Strategic Alliances

Type of Relationship	All Firms		Dedicated Biotech Firms (U.S.)	
	Number	*Percentage*	*Number*	*Percentage*
Grant	83	3	67	4
Joint venture	201	8	97	6
R&D agreement	200	8	143	8
Development agreement	463	17	303	18
Research agreement	266	10	157	9
Supply agreement	75	3	54	3
Manufacturing agreement	140	5	103	6
Marketing agreement	551	21	379	22
Licensing agreement	478	18	315	18
Unspecified agreement	192	7	103	6
Total	2,649	100	1,721	100

SOURCE: Stephen Barley and John Freeman, "Technical Report: A Preliminary Analysis of Strategic Alliances in Commercial Biotechnology" (Cornell University, Ithaca, NY, 1990).

linked to a matrix of regional resources (universities, research institutes, clinical medical programs), they, in turn, become part of the technological base of the region.

Strategic alliances simultaneously bifurcate and bridge the production system from R&D to manufacturing to distribution. What is indeterminate is the allocation of functional responsibilities between the biotech firm and its corporate partner. This is where a set of incubator policy tools could be productively used. In the sections below, we argue that, for many regions the most likely sphere of public-sector economic development influence lies in the early stages of the product life-cycle.

THE INCUBATOR AS A WORKING MODEL FOR STATE POLICYMAKERS

State investment in biotechnology is actually quite small compared to the expenditures of the federal government and industry. For fiscal year 1987, state allocations specifically designated for biotechnology—excluding general university support—were estimated at $147 million. In comparison, 12 federal agencies spent roughly $2.7 billion and the private sector invested another $1.5 to $2.0 billion.[18] Given the relatively low funding levels, states necessarily have had to leverage their funds for maximum effect. Yet within these financial constraints, states have displayed considerable energy, even a sense of urgency as if some hypothetical window of opportunity might close at any time. The North Carolina Biotechnology Center, established in 1981, was the first major commitment of state resources to promote and propagate biotechnology as a source of indigenous industrial development. Just five years later, 33 states had economic development programs with some kind of explicit biotechnology element.[19] Part of the broad interest in biotechnology can be explained by the realization that competence in biotechnology goes beyond immediate job creation. Officials have alluded to the long-term and cumulative consequences of this new technological form. James Kenworthy, a program manager with the Michigan Strategic Fund, placed the issue in context:

> The computer industry is concentrated on the coasts but no region of the country can afford to be behind in applying the capability of computing to its existing business. . . . [Similarly] only a few areas of the country can expect to have the infrastructure necessary for being centers of the cutting edge science, but other areas will have to become expert at applying that science to their existing industries or risk migration of R&D and later new product production to these centers. State-funded economic development strategies need to crystal-

TABLE 2
Selected Biotechnology Collaborations, 1988-89

Smaller Company	*City*	*State or Country*	*State or Country*	*City*	*Larger Company*
Agouron Pharm.	La Jolla	CA	IN	Indianapolis	Eli Lilly
Applied bioTech	Cambridge	MA	DE	Wilmington	DuPont
Athena Neurosci.	San Carlos	CA	IN	Indianapolis	Eli Lilly
Biotech Res. Labs	Rockville	MD	Japan	Tokyo	Ajinomoto
British Bio-tech	Oxford	U.K.	NY	New York	Pfizer
British Bio-tech	Oxford	U.K.	IL	Abbott Park	Abbott Labs
Cal. Biotech	Mountain View	CA	Japan	Tokyo	Daiichi Seiyaku
Cal. Biotech	Mountain View	CA	NY	New York	Pfizer
Celltech	Slough	U.K.	NJ	Rahway	Merck
Cetus	Emeryville	CA	NJ	Nutley	Hoffman-LaRoche
Chiron	Emeryville	CA	NJ	Morris Plains	Warner-Lambert
Collegen	Palo Alto	CA	NY	New York	Bristol-Myers
Creative Biomol.	Hopkinton	MA	MO	Kansas City	Marion Labs
Genentech	So. S.F.	CA	Japan	Tokyo	Mitsubishi Kasei
Genetics Inst.	Cambridge	MA	CA	Palo Alto	Syntex
ImClone Systems	New York	NY	NY	Pearl River	Lederle Labs
Immune Response	San Diego	CA	PA	Ft. Washington	Rorer Group
Immunex	Seattle	WA	NY	Rochester	Eastman Kodak
InGene	Santa Monica	CA	PA	Great Valley	Eastman Pharm.
InGene	Santa Monica	CA	Japan	Osaka	Green Cross
Marrow-Tech	Albany	NY	NY	New York	Colgate-Palmolive
Nova Pharm.	Baltimore	MD	DE	Wilmington	DuPont
Nova Pharm.	Baltimore	MD	PA	Philadelphia	SmithKline Beckman
Procept	Cambridge	MA	MI	Kalamazoo	Upjohn
Synergen	Boulder	CO	NJ	Nutley	Hoffman-LaRoche
T Cell Sci.	Cambridge	MA	U.K.	London	Beecham
Xenova	Slough	U.K.	NJ	Nutley	Hoffman-La-Roche

SOURCE: Mark Ratner, "Dealing with Large Companies," *Bio/Technology* 7 (1989): 1013-1019.

lize this process of the intelligent decentralization of biotechnology capacities to the innovation needs of the basic medical and agricultural products of each region.[20]

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In 1988-89, the authors conducted a survey through the Biotechnology Industry Research Group (BIRG) to determine how states intervened in this complex industrial environment to promote their economic development interests.[21] Interestingly, states have underwritten "experiments" of considerable diversity in state-level biotechnology initiatives. In some cases, the lead has come from the Governor's Office, in other cases, the State Legislature or a multidisciplinary task force. Universities are also central actors in biotechnology promotion, given the importance of research and training resources. Yet despite differences in organizational structure, legal authority, and financing capability, the incubating idea cuts across many of the states' efforts. There is widespread feeling that encouraging home-grown development is a key policy approach. Seventy-five percent of the respondents identified "encourage start-ups" as one of their top three economic development strategies. In fact, it was the most popular strategy, ahead of retaining or attracting biotech firms, supporting basic science, or promoting technology transfer (see Table 3).

Although the survey showed a general policy orientation toward supporting home-grown biotech firms, the incubation concept admittedly does not provide sufficient ground for discriminating between state actions. A more useful categorization is to look at varying levels of intensity or commitment in implementing the incubation concept based on the portfolio of programs a state actually adopts. We have distinguished three such levels: incubation policies, incubation programs, and incubation places. The levels are cumulative so that states pursuing an incubation-place strategy will also have a supporting network of policies and programs (Table 4). Each level of incubation is described below and illustrated with state examples.

TABLE 3
Ranking of State Biotechnology Strategies

Type of Strategy	*Ranked Top 3*	
	Number of States	*Percentage*[a]
Enhance the knowledge base of biotechnology research	20	63
Encourage the start-up of dedicated biotechnology businesses	28	88
Support the scaling-up of small biotechnology firms	17	53
Retain biotechnology firms already located in the state and encourage in-state expansion	21	66
Attract branch manufacturing plants of firms headquartered elsewhere	19	59
Attract complete firms presently headquartered elsewhere	10	31
Transfer new bioprocessing techniques to existing firms	17	53
Pursue general economic development (not specific to biotech)	15	47

SOURCE: BIRG Survey of State Biotechnology Policies and Programs. See Edward J. Blakely and Nancy Nishikawa, "The Search for a New Golden Goose: State Strategies for the Biotechnology Industry" (Working Paper 500, Institute of Urban and Regional Development, University of California, Berkeley, 1989).
NOTE: States were asked to rank the strategies listed with "1" being most important; strategies of equivalent importance could be given the same numerical ranking.
a. 38 states responded, of which 6 states marked "no answer." Percentages, therefore, are based on $n = 32$.

TABLE 4
Matrix of Incubation Levels

Level of Incubation	*Major Differentiating Characteristics*		
	Promote Commercial Biotech	*Assemble Regional Assets*	*Maintain Magnet Infrastructure*
Policy	X		
Programs	X	X	
Places	X	X	X

Table 5 fits selected states into this classification scheme. The assignments are based on responses to the BIRG survey, and supplemented by agency brochures and information published in industry periodicals. In addition, we show how these strategies array against the population size of dedicated biotech firms in each state. Below, we illustrate these different strategic formulations by discussing several state cases.

Incubation Policy

An incubation policy is an official statement or policy position endorsing biotechnology as a desirable type of economic activity. In this sense, it is a species of industrial policy, where the intent of industrial policy is to express preferred patterns for the allocation of private resource allocation. According to Margaret Sharp, industrial policy "reorients resources, provides bridging mechanisms for industry to access the research base, and has a catalyzing effect on industry – making it willing to invest money more readily, to think about longer term strategic considerations."[22]

Although the incubation policy may be backed by considerable expenditure of public resources, the cost factor need not be large. The core element is a reliance on government policy signals to spur market initiatives. Organizationally, the state usually provides at least a minimal staff through a contact person or a small office within or attached to the commerce department or the high-tech agency. Given a small staff, large-scale biotechnology promotional effort is difficult. Rather, personnel time is likely to be channeled into rational coordination of the many programs that are administratively fragmented.[23] Staff may also provide mediation between pro-industry interests

TABLE 5

Incubation Strategy of Selected States

Incubation Policy		*Incubation Programs*		*Incubation Places*	
States	*Firms*	*States*	*Firms*	*States*	*Firms*
California	111			Massachusetts	54
Connecticut	13			Maryland	38
Texas	13			New Jersey	24
				New York	20
Oregon	5	Wisconsin	16	Pennsylvania	9
Montana	2	Colorado	9	North Carolina	6
Arkansas	1	Florida	8	Ohio	5
Delaware	1	Minnesota	6	Michigan	4
Hawaii	1	Illinois	4		
New Mexico	1	Kansas	4		
Rhode Island	1	Indiana	3		
South Dakota	1	Georgia	2		
Idaho	0	Missouri	2		
Kentucky	0	Iowa	1		
Mississippi	0	Tennessee	1		
Average number of firms (lower group)	0.9		5.1		6.0

SOURCE: U.S. Congress Office of Technology Assessment, *New Developments in Biotechnology: U.S. Investment in Biotechnology*, OTA-BA-360. (Washington, DC: U.S. Government Printing Office, 1988), Tables 4-6, p. 68.
NOTE: The OTA Inventory identified a total of 402 dedicated biotechnology firms (DBFs) in 50 states. The 33 states listed above contain a total of 363 DBFs, that account for over 90% of the total.

and other government functions, such as regulation and education. The state that pursues the incubation-policy approach is more likely to depend on a trade association to coordinate the needs of its corporate members and to provide a more-or-less unified voice to which government offices can respond.

Texas provides an example of a state at the *incubation-policy* category. Promotion of biotechnology is the responsibility of the Office of Advanced Technology (OAT) within the Texas Department of Commerce. Official state interest in the biotechnology industry came relatively late, and its first project was a 1988 survey of firms involved in or related to biotechnology. Many of the firms are clustered in metropolitan areas, such as San Antonio and Houston. Although the state has deemed it important to document the extent of biotechnology in Texas, there is expected to be limited follow-up. At the time of the survey, the OAT Director noted that biotechnology groups within the state were forming their own network. It was hoped that the database being compiled from the state's survey could be turned over to the new industry organization. Because of limited resources, the office works best with groups that have "their own infrastructure."[24] This position was echoed by the head of the Houston Economic Development Council:

> There's already such a strong grass roots movement that we didn't see anything we could do in a formal plan that isn't already happening. The best we've been able to do is add our voice to tell anyone who will listen that it's time for Houston to be recognized as a serious research center.[25]

California officials also take a low-intervention approach in the business of biotechnology. The Project Coordinator for Biotechnology estimates that his office is "probably aware of only 10 percent of what's going on" in negotiations involving California biotechnology firms.[26] Given the high profile of biotech in the state, former Governor George Deukmejian convened an interagency task force for which the Project Coordinator provides staff support. Among its accomplishments, the task force has clarified and streamlined state regulations affecting biotechnology, and it has developed guidelines that local communities can adopt in formulating policies on environmental

testing and zoning. The task force's structure provides a regular forum for interested parties from industry, government, and education to air—and to anticipate—issues of concern and to devise appropriate public responses. By removing the obstacles that might impede biotech's expansion, the state seeks to send encouraging signals to industry.

Where the development of biotechnology is neither self-evident nor expected to be spontaneous, regions are more likely to develop a strategic plan. Plans fall into the incubation-policy category to the extent that the formality of the approach views government and industry in a formal, arms-length relationship. The purpose of the plan is to rationalize dispersed resources (venture capital fund, R&D grants, management assistance programs, training programs, etc.). The plan may also recommend expansion of, or marginal adjustments to, programs originally designed for all high-technology companies (or even small businesses in general) so they will better address the specific needs of the biotech client.

An example of the *plan-based policy* is Oregon's "Enhancement and Diversification: Biotechnology in the Oregon Economy, 1988-2000" which was prepared in 1988 by the Biotechnology Industry Advisory Committee of the Oregon Economic Development Department. The recommendations are being implemented using the report as indicative planning to steer a clear path for biotechnology. The report calls for formulating and marketing biotechnology through a "well thought-out plan [that] is fundamental to orderly economic growth."[27] Some Oregonians have pointed to the unanticipated and ad hoc development of Oregon's Silicon Forest as an example to be avoided. The plan does not recommend the establishment of new economic development programs. Rather, it seeks to marshal existing resources and direct them toward biotechnology promotion by setting up a precise agenda and a list of objectives to be achieved.

Incubation Programs

Incubation programs go beyond policy statements that are intended to influence investment by the private sector. As we have broadly defined them here, incubation programs also go beyond one-to-one counseling in the economic development office. Rather, the purposes of incubation programs are to cross-fertilize ideas and to bring together people and resources that can realize the commercial potential of innovations. If the intent of an incubation policy is to generate or adjust signals for private-sector investment, then the intent of incubation programs is to involve the state directly in quickening the pace of innovation, sharpening the ability to bring new ideas to market, and increasing technological sophistication.[28] These are programmatic elements that can be grouped under the rubric of moving products "from the laboratory to the marketplace." For this reason, incubator programs seek to assemble a soft infrastructure: to facilitate information networks and exchanges and to marry product innovations and business savvy, researchers and venture capitalists, start-ups and corporate sponsors.[29] A prime example is the research grant that stipulates a requirement of matching funds or in-kind contributions from an industrial partner. The states are engaged in institutionalizing interactions that occur sporadically and disjointedly between the academic and industrial communities. Incubation-type programs that exploit university-industry linkages are usually established within the state university system, but often there is explicit encouragement of collaboration between two or more campuses, and with private universities located in the state. A university-affiliated organization may change its legal status to encourage flexible interactions, such as more permissive stances toward investments, equity positions, or contract negotiations. University-industry arrangements may also take the form of partnership schemes that give member-contributors privileged access to certain academic resources. Finally, incubation programs may include a variety of structured communication channels, such as newsletters, symposia, and conferences.

Incubation programs have become increasingly popular in universities across a wide range of technologies, including biotechnology. One example, Colorado, is a typical case. In 1984, the Governor's Cabinet Council on High Technology initiated a strategic planning program that focused on all of Colorado's high-technology industries. Early in the process, biotechnology was recognized as a major "homegrown" industry with relationships that could be traced to university

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research. At the heart of Colorado's biotechnology initiative lies the Colorado Institute for Research in Biotechnology (CIRB). It provides a single point of entry to broad-based biotechnology activities occurring throughout the state's higher education system. It is a vehicle for faculty researchers to discuss their individual needs, strengths, and research interests. A primary objective of CIRB is to promote interdisciplinary, multi-campus, and industry-university collaborative research. By enhancing research capability, for example, through a seed grant program, the state hopes to become more competitive in receiving large federal and foundation grants. By filtering the research proposals – delineating subareas of "research excellence" and directing (if implicitly) further research toward these areas – Colorado institutions are working to consolidate their expertise and develop prestige in specific fields.

Incubation Places

Incubating policies and programs stress coherence and coordination. Still, these approaches often amount to what Donald Haider calls a kind of faddism where "similar to Noah's Ark, some states have 'one of everything' in the name of economic development."[30] Incubation places cut across a variety of state functions. Instead of imposing a coordinative structure over existing programs, incubation places bring that coordination into a single agency and stress venue enhancements.

As the name indicates, incubating places offer permanent physical facilities. Although conferences are important places for interpersonal exchange, they are not incubating places because they convene occasionally and in different locations. Further, what distinguishes incubating places as defined here is the offering of economic development *and* technical assistance programs at the same site. Thus, whereas some universities are incubating places, others are limited to scientific interchange and lack the important quality of comprehensiveness. This strategy does imply a certain amount of duplicated services and costs. At the same time, many of these organizations are working toward becoming independent, self-funding organizations.

We identify three types of incubating places that meet the criteria: a physical structure populated by people and organizations involved in both scientific research and economic development. The first type is the traditional incubator facility that is designed for start-up companies.[31] Firms have private space for R&D and small-scale production, but they often share a common administration area, pool overhead services, and have access to experts for assistance with business development. These facilities can be valuable incubating places; however, we turn to two other types that are not usually recognized as incubation places. The integrated biotechnology center is described first, followed by the entrepreneurial agency.

Integrated Biotechnology Center

States with integrated biotechnology centers administer a wide range of programs and commit considerable resources to the promotion of biotechnology. The North Carolina Biotechnology Center (NCBC) is a "full-service" center devoted to biotechnology, housing a wide variety of services for start-up and growing companies. NCBC was created in 1981 as a division of the State Board of Science and Technology. In 1984, the center was made a private, nonprofit corporation to increase its flexibility. It carries out no scientific research of its own, although it awards grants and seed monies to scientific investigators and new companies conducting biotech R&D. One of NCBC's key functions is to assist universities in putting together recruitment packages that will attract world-class scientists and promising young scientists. At other levels of education, it has developed biotechnology curriculum for the community college system and high schools.

Another feature of the integrated center is the importance of physical facilities – a communications hub that regularly brings together researchers, entrepreneurs, and public officials to foster the formal and informal interchange of ideas. NCBC's information division maintains several databases and hosts conferences and workshops, as well as ongoing symposia. The spirit of the center is captured in the Information Director's statement that "the Plant Molecular Biology

Program meets at the center monthly to exchange ideas over pizza and soda and to hear a lecture . . . numerous university-industry collaborations have evolved from the meetings."[32]

Besides North Carolina, several states, including Pennsylvania, New York, New Jersey, and Maryland, have recently constructed or are planning to spend millions of dollars in brick-and-mortar projects dedicated to biotechnology. A major attraction of these biotechnology centers is the availability of sophisticated equipment that may be rented on a time-share basis, thereby allowing small firms to defray high fixed costs. This type of strategy has also been implemented at the Illinois Institute of Technology by the federal government. Frank Young, director of the Food and Drug Administration, explains the rationale of magnet infrastructure as follows:

> In the United States, we've done a very unusual thing, relative to other parts of the industrial world, by making our investment in fermentation pilot plants and scale-up plants before the product is actually ready for production. Typically, the product arrives when the plant is a minimum of four years out of date, in some cases as much as eight. By making fermentation technology available to industry and university scientists through our consortium, on what amounts to a turn-key rental basis, we'll help companies delay their investment in state-of-the-art technology until their products have actually proved themselves in later-stage clinical trials. This should save enormous amounts of money.
>
> Instrumentation in molecular biology becomes obsolete in something like two and a half years. If each of us — academia, industry, and government — buys state-of-the-art equipment and underutilizes it through its brief period of high performance, we're in effect lowering the productivity of capital in the nation. The FDA's initiative is a capital-sparing strategy.[33]

This type of structured place-making provides a new stimulus to the incubator model in an effort to enhance the "hatching" process.

Entrepreneurial Agency

Some states have established institutions that participate directly in technology development and commercialization. Rather than simply promoting seedbed conditions favorable for start-ups, these entrepreneurial agencies are planting the seeds themselves. Industry analysts (either on staff or hired as consultants) scan the market to identify appropriate market niches, and in-house scientists conduct the requisite research to develop novel products. The agency may commercialize the product on its own or it can license the production and/or marketing rights or it can form a joint venture to perform these functions. Michigan (described below) and Ohio provide two examples of the entrepreneurial agency. Neither is self-supporting yet, but their ultimate goals are to earn sufficient income to operate independently of state financing.

The Michigan Biotechnology Institute (MBI) was founded in 1981 as part of a statewide strategy to revitalize and diversify the economy. Located in Lansing, close to Michigan State University, MBI was chartered as an independent, nonprofit corporation. The Michigan Strategic Fund, Kellogg Foundation, and Dow Foundation provided initial capitalization of $29 million for operations. A for-profit subsidiary, Michigan Biotechnology Ventures, was set up to provide economic return to MBI and assure commercialization of Institute-developed technology.

MBI's research agenda is set by combining information on markets and industry trends with analysis of technological feasibility, and assuring development of technology with high commercial potential. The Institute is located in a new 120,000-square foot building with a 20,000-square foot industrial-scale pilot plant designed to promote interaction of biologists and engineers. The pilot plant is also available to industry for a fee. Research projects are started at an earlier stage than industry, but carried farther toward commercialization than universities. Commercialization is achieved via licensing, formation of joint ventures, or creation of spin-off companies.

Besides carrying out its own research and development, MBI has programs to help focus university research on commercially important problems, to assist entrepreneurs in developing

marketable technology, and to perform contract research for industry. If a company funds research at MBI, scientists can work alongside MBI staff during the course of the project.

CONVERGENCE OF INDUSTRY NEEDS AND PUBLIC POLICY

As commercial biotechnology has matured, the number of actors involved and the complexity of relations among them have increased significantly. Firms are embedded in networks at varying levels. Earlier we discussed the growing importance of strategic alliances but that the content of those alliances is subject to negotiation. Although *co*-activities are one of the major avenues available to build value in the company, negotiations are often biased against small biotechnology companies that operate under financial constraints and must give up some rights to production and/or markets. It is critical not to lose sight of the fact that the locus of manufacturing is a critical issue for the biotech firm's long-term viability. The CEO of a Seattle biotechnology company stresses the

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> importance of hanging on to some manufacturing as a means of developing facilities and people and expertise. Because we've done this, we've been able to invent some proprietary expression systems and a number of proprietary manufacturing technologies. These things may be as important as the creation of the molecules themselves because they make us cost-competitive.[34]

Management is more and more inclined to wait it out until the potential value of a product has been demonstrated in order to structure the best terms in a strategic alliance.[35] Meanwhile, during the delay, say, until the Phase 2 clinical trials, a company will continue to use up its own financial and human resources. Clearly, the choice of strategic partners is out of the policymaker's hands. Nonetheless, one implication of our research is the role of a successful incubating environment in enabling biotechnology firms to build up the value of its technology before it enters negotiations with a financing partner. An economizing development strategy cannot be overlooked. The prototypical incubation place, therefore, would contain a mix of technological stimuli, opportunities for interpersonal exchanges (i.e., exposure to a large number of prospective national and local partners), and contributions to fixed cost.

One means of supplying resources to new biotech firms is through state economic development policies. Yet a slate of poorly defined programs, all of which are nominally related to economic development, can be counterproductive and can waste limited public resources. The incubator model can shape a plausible role for economic development. By looking closely at the stages of growth through which a biotech firm passes, the model helps to discriminate the types of interventions suitable for those stages. As has traditionally been the case, state government can best intervene early in the product life cycle: in education and technology development, and in supporting commercialization and new firm starts. The good news is that increased fragmentation within commercial biotechnology is creating new niches for business development. This trend warrants notice by economic development policymakers because it means that firms can make different choices to position themselves competitively. Many new products will continue to evolve from scientific work conducted at academic and research institutions. At the same time, technical and product ideas will flow to firms from hospitals, medical schools, and suppliers in the larger bioscience community. Important lessons are still to be learned about how existing biotechnology programs can facilitate linkages within this community.

It is true that some start-ups will emerge in unexpected places and informal networks may flourish without any overt public assistance. The incubator metaphor does not claim otherwise. What interests us here are the more modest contributions to technology-based economic growth. The argument for the incubator approach is that by pushing at the boundaries of economic viability, public policies can broaden the field in which new firms can take root. As Benjamin Chinitz discussed many years ago, the type of policies in a region combined with industry type and

structure can influence the development of firms in particular locales irrespective of otherwise similar regional economic factors.[36] Casting the incubation concept as a yes-or-no policy issue can be misleading; there is room for improvisation. Therefore we have proposed a typology that is arrayed against "degrees of incubation," that is, levels of effort ranging from minimal tending to more extensive cultivation of commercial biotechnology. A particular configuration of policy and programs should be considered not only in terms of stimulating new industrial development, but also enhancing and reinforcing the environmental assets of place. Economic development is not a science but a process. And it is in this light – as a process model – that the incubator metaphor is helping to understand and to shape policy choices.

NOTES

1. This industrial form is articulated especially clearly in the work of Annalee Saxenian. See Annalee Saxenian, "Regional Networks and the Resurgence of Silicon Valley" (Working Paper 508 Institute of Urban and Regional Development, University of California, Berkeley, 1989); "The Origins and Dynamics of Production Networks in Silicon Valley" (Working Paper 516, Institute of Urban and Regional Development, University of California, Berkeley, 1990).

2. The search for promising high-technology industries usually occurred in the context of more comprehensive efforts to understand the workings of state economies to identify sources of strengths and vulnerabilities, and to plan directions for the future. Examples include Pennsylvania's "Choices for Pennsylvanians," Michigan's "Path to Prosperity " and California's "Report of the Commission on Industrial Innovation."

3. Allen J. Scott and Michael Storper, "High Technology Industry and Regional Development: A Theoretical Critique and Reconstruction," *International Social Science Journal* 112 (1987): 215-32.

4. As used here, metaphor is similar to Kaplan's concept of informal narrative. He points out that this form of discourse is appropriate for resolving dilemmas when there are no clearly accepted external criteria. It allows policy analysts to think globally about who should do what, and how, when, and why they should do it. It would be a mistake to construe metaphors or narratives as "proof." Instead, these methods view policy-making as an interactive process, moving back and forth – between fact and a "conditioned idea." Thomas J. Kaplan, "The Narrative Structure of Policy Analysis," *Journal of Policy Analysis and Management* 5 (1986): 761-78. See also Martin Landau, "On the Use of Metaphor in Political Analysis," *Social Research* 28 (1961): 331-53.

5. Edgar M. Hoover and Raymond Vernon, *Anatomy of a Metropolis* (New York: Anchor Books, 1962); Raymond Vernon, *Metropolis 1985: An Interpretation of the Findings of the New York Metropolitan Region Study* (Cambridge, MA: Harvard University Press, 1960).

6. Office of Technology Assessment (OTA), U.S. Congress, *New Developments in Biotechnology: U.S. Investment in Biotechnology,* Special Report, OTA-BA-360 (Washington, DC: U.S. Government Printing Office, 1988), p. 3.

7. Most of our references to specialized biotech firms include those operating in all sectors. However, when discussing the industrial structure of biotechnology, our referent is the human diagnostics/therapeutics sector. This simplification is necessary as a practical matter to render the discussion more manageable. But it is also the case that the diagnostics/ therapeutics sector is the largest within biotechnology (with an approximate 50% share) and it is the most advanced, both in terms of the technology and commercialization efforts (OTA, *New Developments in Biotechnology*, p. 10). There is also diversity among the diversified corporations, mainly those belonging to the oligopolistic industries of pharmaceuticals, chemicals, food processing, and agricultural supplies. Consistent with our focus on diagnostic/therapeutic biotech firms, our main referents are their closest allies – the pharmaceutical companies. To the extent that dedicated biotech firms (DBFs) and diversified corporations (DCs) with biotech interests share common structural characteristics within their respective strata our generalizations will be less distorted.

8. Amy Glasmeier, "Factors Governing the Development of High Tech Industry Agglomerations: A Tale of Three Cities," *Regional Studies* 22 (1988): 287-301.

9. Stephen R. Barley and John Freeman, "The Strategic Analysis of Interorganizational Relations in Biotechnology" in *Strategic Management of Technological Innovation*, ed. R. Loveridge and M. Pitt (West Sussex, U.K.: Wiley, 1990), pp. 127-56.

10. OTA, *New Developments in Biotechnology*.

11. Francesca Lunzer, "Cash Crisis Creates Biotech Alliances," *High Technology Business*, April 1988, pp. 18-23.

12. Mary Jean Pramik, "Biotech Companies Use OEM to Speed Up Entry to Market," *Genetic Engineering News* 10 (September 1990): 1, 39.

13. Walter Stohr, "Regional Innovation Complexes," *Papers of the Regional Science Association* 59 (1986): 29-44.

14. Outright equity acquisitions are the exception in biotech partnerings. Several reasons are given for the lack of greater merger and acquisition activity. For DCs, larger equity shares increase their risk of liability. Moreover, acquisition is no guarantee that DCs will get the scientific talent and creative R&D environment being sought. Managers and scientists of entrepreneurial biotech firms often resist the unavoidable bureaucracies of large houses. Many of the original key personnel at Hybritech, a company acquired by Eli Lilly in 1985, and at Genetic Systems, bought by Bristol-Myers the same year, have since abandoned the ventures. Large corporations are finding that they can selectively purchase access to technology

through strategic alliances, and avoid having to put up a lot of capital up front. Paradoxically, a DBF with a series of strategic alliances with different organizations has in place a "poison pill" against takeovers because technology could very well be tied up with one's competitors.

15. In a random sample of 200 relationships from their data base, Teece, Pisano, and Shan found that the vast majority, 62%, were between a DC and a DBF, 10.5% were between DCs, and 5% were between DBFs (the remaining arrangements involved universities, research institutions, and government agencies). David Teece, Gary Pisano, and Weijan Shan, "Joint Ventures and Collaboration in Biotechnology," (Working Paper No. IB-8, Center for Research in Management, University of California, Berkeley, 1987). A similar pattern was reported in Ernst & Young's survey of biotech firms, with over two-thirds of respondents involved in strategic alliances, ranging from 61% of small companies to 87% of large companies. G. Steven Burrill with the Ernst & Young High Technology Group, *Biotech 90: Into the Next Decade* (New York: Mary Ann Liebert, Inc., 1989).

16. David Ernst and Diana Mackie, "Fighting the Financing Frenzy: What Next for Biotechnology Companies?" *Bio/Technology* 6 (1988): 495-500.

17. Stephen R. Barley and John Freeman, "Technical Report: A Preliminary Analysis of Strategic Alliances in Commercial Biotechnology" (Cornell University, Ithaca, NY, 1990).

18. OTA, *New Developments in Biotechnology*.

19. Ibid.

20. Comments made at the National Conference on Collaborative Initiatives in Biotechnology, November 1-3, 1987. See Conference Proceedings, prepared by the Montgomery County High Technology Council and distributed by NTIS as PB88-173521.

21. The survey was conducted in 1988-89 by the authors through the Biotechnology Industry Research Group, University of California at Berkeley. Questionnaires were mailed to agencies in the 50 states that are charged with development of commercial biotechnology, or whose jurisdictions are related most closely to this field. The respondents were directors of biotechnology centers, high-technology agencies, or general economic development departments of state government. Thirty-eight states returned usable questionnaires or participated through a telephone interview version, for a response rate 76%. Most states sent supplementary literature describing various programs, and this information was integrated into the analysis. In addition, follow-up telephone calls and/or in-person interviews took place in a limited number of cases. A more complete analysis of the survey data may be found in Edward J. Blakely and Nancy Nishikawa, "The Search for a New Golden Goose: State Strategies for the Biotechnology Industry" (Working Paper 500, Institute of Urban and Regional Development, University of California, Berkeley, 1989).

22. Quoted in Mark Ratner, "Examining Biotech's Global Economic Role," *Bio/Technology* 7 (1989): 750.

23. Harvey Goldstein, "Why State and Local Industry Policy? An Introduction to the Debate," in *The State and Local Industrial Policy Question*, ed. H. Goldstein (Chicago: APA Planners Press, 1987), pp. 1-15.

24. Personal communication with Karen Ware, April 18, 1989.

25. Quoted in Fred Gebhart, "Houston, Former Oil Capital of America, Now Sees its Future in Biotech," *Genetic Engineering News* 9 (April 1989): 14.

26. Quoted in Mark Ratner, "Regional Development: The Role and Effectiveness of Governmental Agencies," *Bio/Technology* 7 (1989): 671-83.

27. Oregon Economic Development Department, Biotechnology Industry Advisory Committee, "Enhancement and Diversification: Biotechnology in the Oregon Economy, 1988-2000" (1988), p. 25.

28. David Osborne, *Laboratories of Democracy: A New Breed of Governor Creates Models for National Growth* (Boston: Harvard Business School Press, 1988).

29. Edward J. Blakely, Brian H. Roberts, and Phillip Manidis, "Inducing High Tech: Principles of Designing Support Systems for the Formation and Attraction of Advanced Technology Firms," *International Journal of Technology Management* 2 (1987): 337-56.

30. D. Haider, "Economic Development: Changing Practices in a Changing U.S. Economy," *Environment and Planning C: Government and Policy* 4 (1986): 451-69.

31. For a review of the literature on incubator facilities, see Candace Campbell and David N. Allen, "The Small Business Incubator Industry: Micro-Level Economic Development," *Economic Development Quarterly* 1 (1987): 178-91.

32. Mark D. Dibner and Janet E. Hafer, "Biotech Centers Catalyze Government/University/Industry Interactions," *Genetic Engineering News* 9 (August 1989): 22-29.

33. From an interview in G. Steven Burrill, *Biotech 90: Into the Next Decade*, p. 154.

34. Ibid., p. 196.

35. Ibid., p. 164.

36. Benjamin Chinitz, "Contrasts in Agglomeration: New York and Pittsburgh," *American Economic Review* 51 (1961): 279-87.