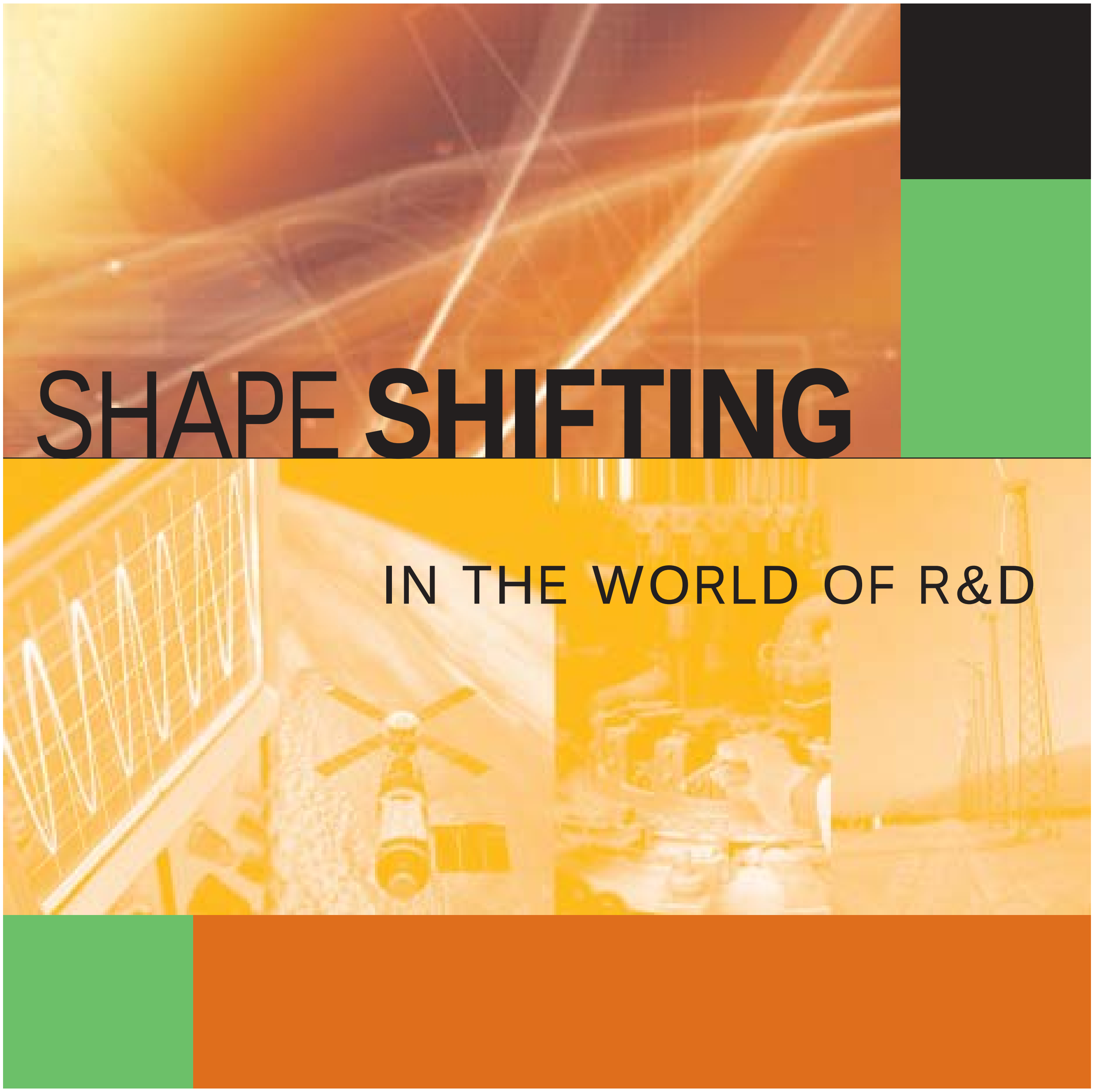
SHAPE SHIFTING IN THE WORLD OF R&D



Institute for the Future

September 2002

SR-773

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About the …

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Table of Contents

List of Figures and Tables	vii
Executive Summary	ix
Introduction	1
Chapter I How Did We Get Here?	3
Chapter 2 A Cambrian Explosion of R&D Forms	11
Chapter 3 The Cambrian Explosion in Different Industries	19
Chapter 4 Social Networks Will Support New R&D Forms	33
Appendix Research & Development in America, 1865–2010	43

List of Tables and Figures

Table	I–1	The Next Ten Years Will See an Explosion in R&D Forms	2
Figure	1-1	Rise of Corporate R&D Labs	4
Figure	1-2	Corporate R&D Patents Outpace Independent Inventors	5
Figure	1-3	The Rise of Federal R&D Spending	6
Figure	1-4	Growth in Science and Technology Talent	8
Table	2-1	SRI International and Sarnoff Spinoffs	14
Table	3-1	Venture Funding for Energy Sector on the Rise	23
Figure	3-1	More Patents Awarded to Smaller Biotechnology Firms	27
Figure	3-2	Pharmaceutical Companies Will More Than Double Their Share of Outsourced R&D	28
Figure	3-3	Market Exclusivity Period Is Shrinking	29
Figure	4-1	Random Networks Versus Scale-Free Networks	35
Figure	4-2	Networks Take on Different Forms	36
Figure	4-3	Soda Straw Links Connect Different Universes	38

Executive Summary

Shape-Shifting in the World of R&D

In the next ten years we will witness an explosion in R&D forms. This will be a period of large-scale experimentation in which many R&D forms will co-exist, often under one corporate umbrella. Today, the world of R&D is experiencing the equivalent of the prehistoric Cambrian Explosion when the earth saw a huge number of new life forms appear and spread over the planet. In approximately the last 100 years, a combination of forces, from government policy to scientific culture, have re-shaped the landscape of R&D. From early domination by individual inventors at the end of 19th century, R&D has moved into large-scale corporate and government R&D labs, and in the last ten years increasingly outside of internal organizational boundaries into innovation networks, bringing together internal and external resources to solve problems or pursue common passions.

In the next ten years, we will see many organizational forms co-exist side by side. Some R&D forms will die out, others will adapt and re-shape to the new environment, producing mutants or hybrids, and some new forms will emerge. No one organization will have a monopoly on the right form of structuring an R&D organization. "Experimentation" will be the buzzword of the next ten years.

The explosion will not spread evenly or equally across industries. The speed and depth at which it will be felt will depend on several industry characteristics, among them its capital requirements, regulatory environment, and the available talent pool.

In this fertile and changing environment, companies will need to:

- Manage different R&D structures simultaneously—organizing for diversity and complexity.
- Learn to value intangible assets, such as relationships and access to the right people, ideas, places, and processes.

- Strive for hybridization—build processes that encourage cross-fertilization between disciplines, functions, and geographies and hire hybrid thinkers.
- Create, facilitate, and participate in the right types of networks and manage them to maximize innovation. Having a well-managed network will be a key source of competitive advantage in the next ten years.

This report, *Shape-Shifting in the World of R&D*, begins with an overview of the history of R&D over the last 100 years. This overview sets the stage for the pending "Cambrian Explosion" in R&D forms that will hit over the next ten years. The report describes some of the adapting, new, and hybrid forms of R&D that are likely to emerge, and then delves deeper into what the explosion means for business by analyzing how these forces will shape the R&D environment in four key industries: information and telecommunications, energy, biotechnology and pharmaceuticals, and consumer products. The report includes a graphic map charting R&D in America from 1865-2010 and concludes with a discussion of the key element of the R&D organization in the future—networks.

Introduction

For over two billion years, life on earth consisted of single-celled organisms, floating in primeval oceans or massed in giant colonies. Then, beginning approximately 570 million years ago, came the Cambrian Explosion. In the next 40 million years—in the blink of a geological eye—a phenomenal, bewildering array of complex creatures evolved at high speed: five-eyed, hose-nosed creatures, like *Opabinia*, or the amored slug known as *Wiwaxia*, as well as the charmingly named *Hallucigenia* wandered the sea floors. Most of them went extinct, but they left behind the building-blocks of all future life —complex biological mechanisms, sensory organs, shells and skeletons. Enormous innovation emerged from creative chaos.

The life story of research and development (R&D) in the United States has reached such a point where there is the potential for an explosion in R&D forms. The potential explosion is the result of two intersecting trends. First, with global voice, text communications, and computing power now as ubiquitous as oxygen, the technological environment has hit an inflection point. Second, many of the traditional large R&D organizations like Bell Labs and Xerox PARC are dying out, and a new "adaptive space" is emerging that is creating opportunities for large-scale experimentation in R&D forms and practices. In fact, the "genetic material" of R&D has grown far more complex of late, and has already started to generate new organizational forms, such as dispersed networks of researchers, knowledge spot markets, and small but intensively focused R&D labs.

In the next ten years we will witness this explosion in R&D forms. This will be a period of large-scale experimentation in which multiple R&D forms will co-exist and support each other, sometimes under the same corporate umbrella. Some of the existing forms, such as large internal R&D labs will survive by adapting to the new environment, while many other large-scale labs will die out; some new forms and hybrids will emerge but will be transitory, others will become the mainstays of the new era (see Table I–1). The speed and depth of the transformation will be uneven across industries but are likely to affect most as lessons from one sector diffuse and become adopted in others.

Though there will be many R&D forms in the next ten years, most of these will incorporate network relationships, which will be formal or informal, within organizational boundaries or outside, virtual or incorporating physical presence. These networks will shape many of the experimental forms and adaptive practices in R&D over the next ten years. Companies will increasingly have to bring together combinations of internal and external resources to help them reach across boundaries and stay on the forefront of innovation. Creating, facilitating, and participating in the right types of networks and managing them to maximize innovation will be a key source of competitive advantage for companies in the next decade.

Table I–1
The Next Ten Years Will See an Explosion in R&D Forms

Adapting species	*Networked R&D labs*	IBM Intel
Hybrids	*Crossover organizations*	MIT Media Lab SRI International Stanford Bio-X
New species	*Passion-driven ventures*	Intellectual Venture Packet Design
	IP Shops	General Patent Corporation
	Knowledge spot markets	InnoCentive

Source: Institute for the Future

Chapter 1

How Did We Get Here?

Corporate strategy, government policy, the state of universities, and the culture of the scientific community have all shaped the organization of R&D over the last century. A look at this history alerts us to the forces we should pay attention to as we map out the future (see Appendix, Research & Development in America, 1865–2010 on page 43).

The Era of the Heroic Inventors, 1865-1893

In the decades following the Civil War, the United States industrialized, creating an unprecedented outpouring of inventive activity driven mainly by independent inventors. Industrial facilities could not compete with heroic figures like Alexander Graham Bell, Thomas Edison, and Elmer Sperry. The best 19th-century inventors struck an enviable balance between independence and connectedness. They used backing from wealthy patrons to buy freedom to work on promising problems, used journalists to cultivate a public image emphasizing (usually overdrawn) hardscrabble origins and naïve genius, and built companies around their inventions.

Independent inventors also didn't have much competition from other sectors. Government support for science after the Civil War was sporadic and focused on aiding settlement of the Western frontier. Federal dollars went to geological surveys, agricultural research, and other kinds of applied science, not basic research.

Academic research was in its infancy. Johns Hopkins, the first university dedicated primarily to graduate training and research, opened in 1876. Older universities like Harvard and Columbia opened professional schools and doctoral programs between 1880 and 1900. Still American science was regarded as decidedly provincial, with a few world-class minds brightening an otherwise bleak landscape.

Organized Large-Scale Research, 1893-1989

Beginning in the 1890s and through the late 1980s, research and development became a large-scale endeavor—first as innovation became industrialized and then as science became a matter of national security in light of the Cold War.

Industrializing Innovation: 1893-1940

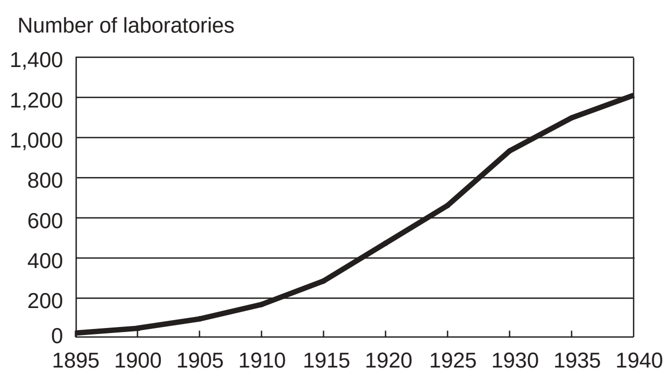
The structure of R&D began to change in the 1890s. General Electric, DuPont, AT&T, and other companies opened autonomous research laboratories, often growing them from older testing and production troubleshooting centers (see Figure 1–1). Put simply, invention became synonymous with corporate R&D.

Several factors encouraged this trend.

- A number of key basic patents—for the electric light, telephone, and industrial chemicals—expired in the 1890s, forcing companies that had enjoyed virtual monopolies to develop new products.
- Antitrust law encouraged innovation by preventing companies from pooling patents and sharing intellectual property.
- The theoretical bases of electronics and industrial chemistry were still poorly understood. Targeted investments in basic science offered the prospect of dramatic improvements in products.
- The drive for efficiency led to the late 19th-century American businesses' obsession with mechanizing, managing, and controlling information. The most familiar tools of the modern office—the typewriter, telephone, file cabinet, and printed form, even the skyscraper and corporate headquarters—were invented in this period. R&D was just another thing to organize and manage efficiently.

In this environment, many companies concluded that invention and innovation were too valuable to be left to independent inventors. Consequently, from the 1900s until World

Figure 1-1
Rise of Corporate R&D Labs
(Total number of laboratories in operation)



Source: Arnold Thackeray, et al., *Chemistry in America 1876-1976: Historical Indicators*, D. Reidel, 1985.

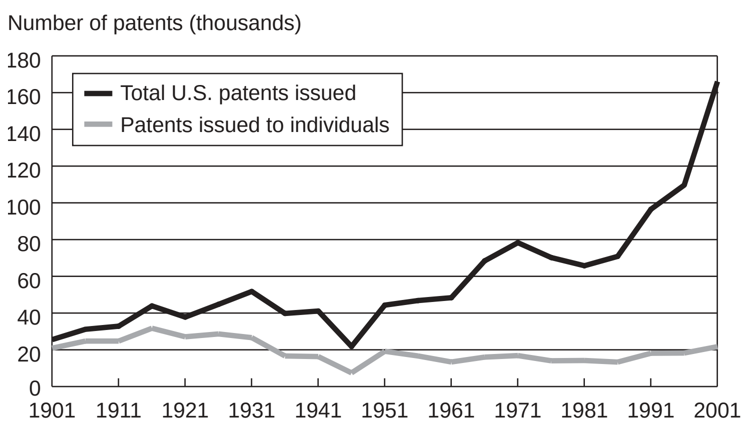
War II, industrial laboratories dominated American R&D, and changed its character and direction. Corporate R&D was essentially conservative in its mission: its purpose was to improve technologies and products, and develop new ones that served current markets, not to engage in the "creative destruction" of existing systems. Independent inventors, the heroes of the previous era, became increasingly marginal in this one. Their importance (as measured by the number of patents awarded to them) hit its peak around 1916—just as industrial R&D centers were picking up speed (see Figure 1–2).

University and government research became more substantive in this period, but did not compete with industrial research. Universities became the gatekeepers of scientific and engineering talent, as more scientists trained at home rather than abroad, and as engineering societies made college degrees a requirement for membership in the profession. But academic culture kept professors focused on education and research: competing with corporate R&D was unthinkable. Government laboratories, meanwhile, expanded slowly but remained service-oriented, focusing on routine work like testing, establishment of standards, and enforcement of food and drug laws.

Cold War, Big Science: 1941-1989

In the 1920s and early 1930s, American science lagged behind Europe. That began to change in the mid-1930s, as scientists fleeing Nazi Germany took up posts in American universities and colleges. But it was World War II that transformed America into a world leader in science and technology. The federal government sponsored the building of new laboratories to conduct military research at universities like MIT, University of California, Berkeley, CalTech, and dozens of state universities. During the war the government also built a matching network of government-owned facilities for atomic physics, aerodynamics, and other specialized sciences.

Figure 1–2
Corporate R&D Patents Outpace Independent Inventors



Source: Historical Statistics of the United States.

These facilities developed radar, penicillin, the digital computer, operations research, synthetic rubber, sulfa drugs, and the atomic bomb, among others, and became the foundation for a new government-funded infrastructure for science. The war had convinced policymakers that in a world of large-scale war and high-tech weapons, science and technology were critical tools for national security, and the government could not afford to not support it. Wartime projects also showed that mission-oriented, federally funded projects could be directed to specific social and political ends.

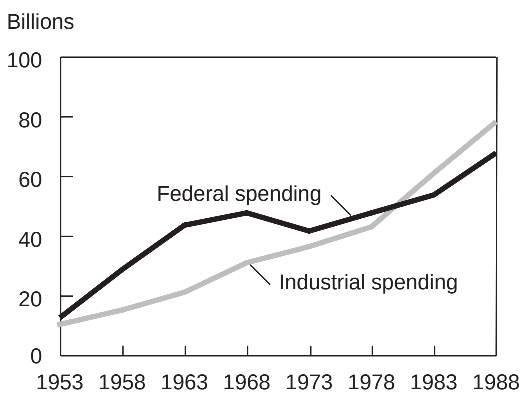
With the onset of the Cold War in the late 1940s, the government's role as patron of academic and industrial research grew (see Figure 1–3). In selected areas like nuclear physics and space science, it was a direct participant, organizing and managing institutions like the Los Alamos National Laboratory and NASA. Through the late 1970s, government funding supported the lion's share of R&D, and lead to the rise of a new kind of academic science, defined by huge teams of researchers, vast arrays of instruments, and multi-year experiments.

Large companies also benefited during the Cold War era. Many used government contracts to support their cutting-edge work. Development of early-warning radar systems funded IBM's early work in time-sharing and real-time data processing; NASA's Apollo project drove innovations in microelectronics, materials science, and computers. In this environment, savvy corporations like AT&T and IBM used R&D to maintain their market dominance. Their near-monopolies also made it possible for them to establish advanced research laboratories that rivaled the best universities in talent and independence.

The Era of Innovation Networks, 1990-Today

In the last dozen years, R&D and innovation have increasingly moved away from large companies into networks of individuals and companies—so-called "innovation networks." Such networks take many forms—they may be collections of individual innovators banding together to pursue a passion, an idea, or a potentially commercially attractive venture. Other types of networks may be created and

Figure 1–3
The Rise of Federal R&D Spending
(Spending on R&D by sector, in billions of dollars)



Source: National Science Foundation

based within existing organizations, tying them to needed skills and resources outside their own walls.

What's Changed?

It appears that we are once again seeing the rise of independent innovators. But you shouldn't confuse today's innovation networks with networks around innovators at the end of the 19th century. As Mark Twain said, "History does not repeat itself but it does rhyme." The innovation networks that have emerged today, while giving greater power to individuals, are clearly different from the 19th-century model in several important ways.

- They take many different forms. Some include individuals, others are formed around organizations or on their periphery, some are strictly online, others include physical presence, and many are hybrids.
- They are made up of people who are not self-taught entrepreneurs but highly educated professionals—scientists, engineers, researchers, and entrepreneurs with technical backgrounds.
- They are not local but highly global, and tap into resources from many places. Silicon Valley's innovation networks extend into far-flung places such as Taiwan, China, India, and Nordic Europe.
- They cross ecological boundaries, incorporating innovators and researchers from academia, large and small companies, government labs, and non-profit organizations. The early innovators simply did not have the luxury of this rich ecology of institutions to tap into.
- They have uncovered an abundance of funding sources—from venture capitalists to technical entrepreneurs who have been successful in their previous ventures and who increasingly fund new ideas—often those that they are passionate about.

The Drivers

So, why did the model of large-scale industrial research, epitomized by large R&D labs inside corporations give way to the new, networked-innovation model? Several drivers were responsible for the shift.

- *Explosion of new technologies.* New technologies and new fields of science have proliferated. Many, like nanotechnology, did not even exist 20 years ago. Corporate R&D labs, which used to specialize in a few technologies or science areas, simply do not have enough resources to keep up with a pace of change and invest in all the areas that might have a significant impact on their product lines or completely disrupt their existing position in the marketplace. The food industry, for example, will have to re-invent itself as a result of breakthroughs in genomics and the new level of understanding about the connection between food and health. To participate in this revolution, food companies will need to have an understanding of agriculture, chemistry, genetics, and biology, among other disciplines. Such a range of resources is often difficult to build internally.
- *Emphasis on return on investment.* Pressed by growing competition, managers are calling on internal R&D departments to account for the money put into research—that is, how productive these investments are and what returns they generate for the company. Although the problems of measuring return on investment (ROI) are significant, it is clear that the single

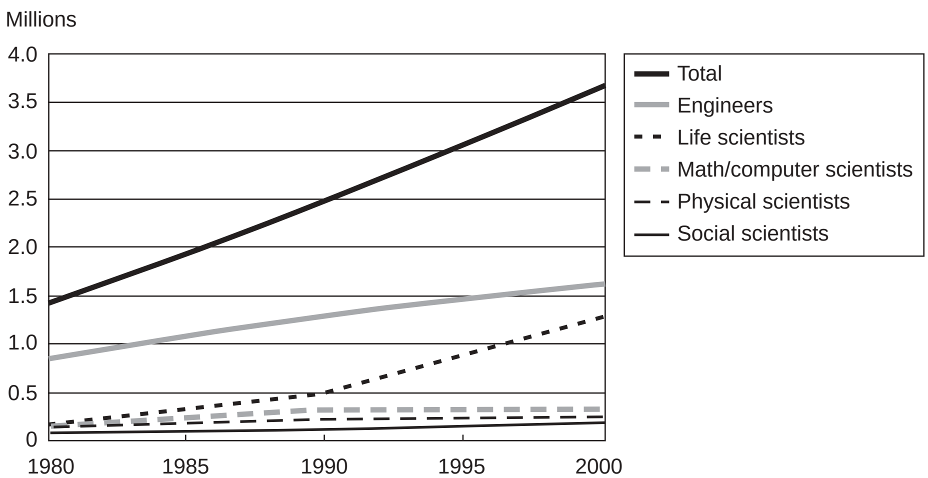
mindedness, dogged determination, and less bureaucratic organizational structures of many small companies can produce results superior to those achieved in larger R&D labs mired in internal organizational processes and often shielded from direct market forces. For every example like nylon (which DuPont successfully shepherded from laboratory to market), there are a dozen counter-examples like the transistor (developed at Bell Labs, but commercialized elsewhere).

- *Entry of academic R&D.* The Bayh-Dole Act of 1980 allowed universities to privatize research done with public funds. When budget cuts hit in the late 1980s, ambitious schools began to establish ventures with industry, develop licensing programs, and encourage faculty to start their own companies—turning universities into competitors with corporate research. Academia has increasingly been drawn into innovation networks, with many professors and students pursuing both academic research and commercial applications simultaneously.

- *Highly-skilled labor force.* The growing number of science and technology workers in the United States and abroad, combined with the scarcity of academic and government lab science positions, has resulted in the flow of Ph.D.s into commercial ventures, particularly entrepreneurial ones where financial rewards are higher (see Figure 1–4).

- *Widely-distributed IT infrastructure and new research tools.* Ubiquitous IT infrastructure has facilitated collaboration between individual researchers, scientists, entrepreneurs, wherever they may be located around the globe. New sophisticated computer tools, such as 3-D modeling,

Figure 1–4
Growth in Science and Technology Talent
(Millions of college graduates in various science disciplines)



Source: National Science Foundation, *Science and Engineering Indicators*, 2002.

advanced analytics, and data mining, make it possible for individuals and small groups to design and test new products without substantial capital resources and the benefit of large scale research labs' infrastructure.

The Next Era

In sum, the kinds of resources and infrastructure once provided by large organizations and government departments—financing, technology, support services, and skilled labor—are now widely available outside large organizational boundaries. It is increasingly clear that no company or organization has the breadth of knowledge and expertise to guarantee it a leading-edge position in the future. To survive, one must be involved in many different fields, bring together people from different backgrounds, and give them direct incentives for innovation rather than bury them in large organizational bureaucracies.

Chapter 2
A Cambrian Explosion of R&D Forms

R&D is moving into a new era. It will be an era in which R&D will be conducted in a variety of organizational forms that take advantage of both physical and social networks in increasingly cross-disciplinary and cross-organizational explorations. It will be an era of wide-scale experimentation, with no one company having a monopoly on the "right" formula for structuring an R&D organization. It will be a time of changes in the R&D ecology—we will see some R&D organizations simply die out, others adapt and re-shape to the new environment, producing mutants or hybrids of existing ones. We will also see the emergence of new forms, some temporary, others becoming mainstays of the new ecology. Co-existence of multiple forms, often within the same organization, will be the defining feature of the R&D landscape in the next ten years. The following are examples of adaptations of existing forms and emergent new ones that give us hints of what the R&D ecology is likely to look like in the coming decade.

Adapting Species

We will see a few existing large-scale R&D organizations successfully adapt to the new environment by extending their reach, or tentacles, to outside sources of innovation, while at the same time, sharpening their internal focus by concentrating on what they do best. But don't expect all large corporate R&D labs to disappear. There are still inherent efficiencies in having a diverse set of resources under one roof and these large organizations will build on such efficiencies in their efforts to reach outside the organization. Two companies known for their large R&D organizations are already adapting—IBM Research and Intel.

IBM Research

IBM Research may be one of the last diversified large-scale research labs to have survived and thrived. IBM's first research lab was created in 1945 in New York. In 2001, almost 3,500 employees were engaged in research at eight labs around the world. The lab is responsible for several key computing and storage technologies. It is the largest industrial research organization in the world conducting leading-edge research in a wide variety of technical disciplines including chemistry, computer science, electrical engineering, materials science, mathematics, and physics, as well as applied research in areas strategic to the future of the company.

Through the years, the lab has survived by transforming itself and opening up to collaborative research with customers and suppliers, as well as university labs. It is highly networked, with researchers engaging in joint research and publications with universities, professors, and graduate students working at the lab as fellows. IBM researchers also serve as adjunct professors at various universities and university professors in turn work in IBM labs.

This academic cross-fertilization is perceived to be essential to the continuing development of scientific and engineering disciplines in universities by exposing students and faculty to areas of exploration most relevant to industry. In turn, the industrial labs gain access to younger and fresher talent and approaches to development that are not necessarily tied to the immediate corporate needs, yet which would have a potentially significant long-term impact on products.

Intel's Lablets

Intel is adapting in a couple of ways. First, it is growing tentacles outside of its own R&D lab to university scientists and other researchers. It is also making investments in "disruptive research" in areas beyond its current core competence in semiconductors. These disruptive research efforts are concentrated in potential new business areas such as ubiquitous computing, wireless networking, and biological computing. The program works like this. A small group of program managers identifies and funds projects inside and outside the company that are beyond the scope of its existing business lines and research. These projects are located within Intel's existing labs or in universities and nonprofit research organizations working in conjunction with Intel scientists. If and when the project matures, it will be brought into the main R&D pipeline.

In another effort to adapt, Intel created the first of a series of what chief technical officer, Pat Gelsinger, called "lablets" located near major research universities in 2001. Each lablet is headed by a university professor on a 1-2 year leave and is staffed by about 25 Intel scientists and student interns working in collaboration with visiting university faculty and other academic researchers.

The first of these lablets were near Carnegie-Mellon University in Pittsburgh, PA with a focus on widely distributed storage systems; the University of Washington, Seattle, WA with a focus on technologies and usage models for ubiquitous computing environments; and the University of California, Berkeley, CA with a focus on extremely networked systems of very small and very numerous devices. At the end of May 2002, Intel announced a similar arrangement with the *Universitat Politecnica de Catalunya*, Barcelona, Spain, to conduct microprocessor research.

Hybrids

Hybrids will bring together elements of several different organizations, crossing ecological boundaries between academia, business, and government. We expect more and more of these types of organizations to emerge in the next ten years. Three have already arrived on the scene—the MIT Media Lab, Bio-X at Stanford, and SRI.

MIT Media Lab

The MIT Media Lab, established in 1986, is a multi-disciplinary research organization operating at the intersection of technology, media, and art. It was one of the first examples of a hybrid—an academic research organization set up to meet the educational needs of its students and also an industrial consortium trying to balance the conflicts and tensions between academic openness and the development of proprietary intellectual property for its industrial supporters and financial success. Because 90% of the Lab's $35 million budget comes from corporate sponsorship, a great deal of time and effort is devoted to fundraising and interaction with sponsors.

From its beginning, the Media Lab has been supported by a consortium of technology, media, and manufacturing companies who currently pay more than $250,000 per year for the privilege of gaining access to research, researchers, and students at the Lab. Members also receive exclusive, royalty-free licenses to the lab's intellectual property. Non-subscribers need to wait several years after initial availability to sponsors to license Media Lab patents. In addition, the Media Lab executes a few contracts for directed research for specific tasks requested by corporations. In general, lab researchers have the freedom to explore longer-term innovations.

As the value of intellectual property rights has increased, this model has created conflicts for staff and students who want to exploit their work for financial gain through the creation of their own companies. Faculty, staff, and students need to carefully maintain a separation between what they do for the lab and its sponsors and what they may do for themselves or future employers. This tension will continue to play out at universities and other academic institutions as government-funded, unrestricted, open research grants in the public interest are replaced by business sponsorship.

Bio-X at Stanford

Many of the most interesting developments in science and technology are taking place at intersections of existing disciplines, especially the combinations resulting from various permutations of information, physical, material, and biological sciences. For example, the mapping of the human genome, which will result in advances in medicine, would not have been possible without the use of data processing and networking technologies. Micro-electromechanical sensors and actuators, and nanotechnologies will require the participation of specialists from a variety of disciplines capable of understanding and communicating with their colleagues.

A number of universities have created programs to consciously encourage cross-disciplinary research and education. One of the most ambitious is the Bio-X department at Stanford University. Its leaders have recognized the challenge involved in bringing together faculty, students, and researchers with diverse cultures and languages. Among its first projects is the development of cross-disciplinary curricula to teach graduate students in biological sciences and engineering more about medicine, along with projects that consciously include participants from the biological, physical, information sciences, and several engineering disciplines.

Similar efforts are taking place at institutions like MIT and the University of California, San Francisco, which is developing a new, multi-billion dollar campus. Its layout includes space for commercial laboratories and there are plans for biotechnology businesses to locate near the campus.

SRI International

SRI International was spun-off from Stanford University in 1946 to perform independent client-sponsored research. Its researchers created many innovations including the computer mouse, onscreen windows and hypertext, dodecyl benzene (the basis for the first successful household detergent—Procter & Gamble's Tide), mobile robots, and drugs for treating malaria. Because much of SRI's funding came from government contracts, particularly the Department of Defense, it was unable to commercialize many of these technologies.

This all changed with the passage of the Bayh-Dole technology transfer act of 1980, which allowed SRI and many other government and government-sponsored research organizations to commercialize their inventions. Shortly thereafter SRI established a commercialization office. Technologies developed internally and at its subsidiary, Sarnoff Research Lab (a former internal R&D lab for RCA Corporation which affiliated with SRI International in 1987), are screened for commercial applications. Instead of doing only contract research, SRI now reaps rewards from the many companies it has spun off since 1980 (see Table 2–1). To fund spin-offs, SRI raises outside venture funding. Some of SRI's scientists and researchers move into spin-offs, allowing them to realize financial gains from their research.

New Species

The shifts in the R&D environment will produce new types of organizational forms, which will emerge from the "adaptive spaces" created as a result of the die-off of older forms and ubiquity of the communications infrastructure.

Table 2–1
SRI International and Sarnoff Spinoffs

Discern Communications	Automation of deployment and operation of customer services and support centers
Intuitive Surgical	Computer-enhanced system for minimally-invasive surgery
Nuance Communications	Natural language speech interfaces
Pangene Corporation	Rapid gene cloning and phenotyping of disease gene drug targets for the pharmaceutical and biotech industries using proprietary technology platform
PolyFuel Inc.	Proprietary, direct methanol fuel cell that provides up to 10 times the energy of rechargeable batteries
Delsys	Pharmaceutical drug delivery
DIVA	Interactive video on demand (VOD) products and services
E-Vue Inc.	Next generation solutions for streaming multimedia over networks
Lamina Ceramics	Design and manufacture of low temperature co-fired ceramic on metal

Source: SRI

Some of these new creatures will be transitory—short-lived opportunistic responses to environmental changes, while others will become mainstays of the new era. Some new species have already emerged including passion-driven ventures, Intellectual Property (IP) shops, and knowledge spot markets.

Passion-Driven Ventures

A new generation of technology entrepreneurs, enriched by money made in previous ventures, is applying their passions and insights developed in earlier work to fund new companies. Unlike traditional venture capitalists, they use their own money to support these interests.

For example, Nathan Myhrvold, who was a chief technical officer at Microsoft for many years, is using some of his wealth to establish an investment company, Intellectual Ventures. He says it is not a venture capital firm since it will fund his ideas rather than those of others. "I'm excited about biotech in the way I was excited about the PC industry [in the late 1970s]. My analogy is that biotech is in the same stage when Intel shipped the first microprocessor in 1971." Even with his interest in biotechnology, his expertise in information technologies is vital because of the importance of computational power on generating discoveries.

Steve Perlman started out in traditional R&D organizations at Atari and Apple where he was frustrated by his inability to get some of his most significant ideas transferred to product development groups. He left Apple with the rights to some of these ideas. He continued to develop these ideas with other colleagues into what later became WebTV. After Microsoft acquired the company, Steve created a new venture—a largely self-funded research lab, Rearden Studios. The first product developed at Rearden was Moxi Digital, which was sold to Paul Allen and merged with Digeo, a digital television system.

The founders of Packet Design, Judy Estrin and Bill Carrico, are experienced techno-entrepreneurs who left Cisco to pursue their passion of solving fundamental infrastructure issues of the Internet. Their new company fills an important vacuum created by lack of sufficient commercial and academic research in the field. To allow the team to pursue their research and at the same time to create revenues to enable its operation, Packet Design has created a two-layer structure—it is creating spin-offs and internal enterprises which actually get commercial products out the door, while the research group is freed to work on an open-ended timetable. Their first spin-off, Vernier Networks, offers control and security products for wireless networks. Their next enterprise, Packet Design CNS, will focus on building tools and technology to enable large-scale service providers and telcos to boost IP traffic analysis, traffic engineering, and traffic management. This venture will not be spun out of Packet Design but instead run as a business unit within the main company, closely tied to its research team.

This hybrid model—part research organization and part product company—allows Packet Design to also play an important role in setting standards for the wider Internet community through its participation in the open Internet Engineering Task Force (IETF). Senior Packet Design researchers lead key IETF committees. Thus, the company has a voice in a larger Internet community despite its small size. While this work is donated to the community, the value accrues to Packet Design's commercial spin-offs and products.

The key to survival of these passion-driven ventures is in building institutions that are not simply personality-driven—that is, whose existence is highly dependent on the vision and leadership of one key individual—but have a business rationale and an infrastructure that endure beyond one person. Recently we have seen a number of personality-driven ventures quickly rise and just as quickly fade out of existence. The most notable of these is Interval Research, which started out with much fanfare, propelled by the vision of Paul Allen, one of the founders of Microsoft. However, in its three years of operation, the venture failed to deliver actual products and ultimately went into bankruptcy.

IP Shops

It took a century to issue the first million patents; it took half as much time to issue the next million; it will take only five years to issue the next million patents. Have we seen an explosion in innovative ideas and a speeding up of our creative capacity over the last two centuries? Maybe, but there are other forces at work as well.

Today, intellectual property (IP) is not only viewed as an asset to be bought and sold, but also to be used in various competitive battles—to force a competitor to negotiate, to arrange a licensing deal, to prevent a new competitor from entering a potentially lucrative market, or to increase company value in an IPO or acquisition. Competitive forces, rather than pure advances in innovation, drive companies to legally protect their intellectual property.

New organizations whose main purpose is the mining of value from registration and exploitation of IP are emerging. These "IP shops" attempt to create liquid markets in protected IP by negotiating licensing deals between inventors and larger companies, or by the threat of infringement lawsuits.

General Patent Corporation specializes in helping cash-strapped independent inventors pursue their patent claims against the big guys. Recently it secured a licensing agreement between General Motors and an independent entrepreneur who claims to have invented a die-casting process that greatly reduces waste in the manufacture of machine parts. General Patent Corporation works in partnership with law firms to help entrepreneurs and small companies patent their inventions and pursues lawsuits in their defense. Such IP shops also use data-mining technologies to search large corporate patent portfolios in order to transform idle patents into royalties or arrange technology swaps.

More IP shops are likely to continue to emerge in the near term, but we think that in the long run they are transitory phenomena. Openness, trust, and idea and knowledge exchange are necessary rules of engagement in increasingly networked research environments. No matter how many legal barriers one creates around sharing, social networks are deeply personal in nature and open exchanges are a pre-requisite for their survival.

Knowledge Spot Markets

Information and communication technologies are enabling new kinds of knowledge communities and organizational forms. These "knowledge spot markets" are bringing together those who seek problem resolution and those with the solutions wherever they may be located geographically. The only requirement is access to the Internet.

Knowledge spot markets greatly extend the pool of resources available to companies or individuals for solving problems. They also allow them to access such resources in a just-in-time manner, when a particular problem arises, or when a particular solution is necessary.

Anyone with access to the Internet can participate, from a highly paid researcher at Stanford to a struggling scientist in Russia. Knowledge spot markets are created by organizing talent in diverse areas from the sciences including biology, information technology, engineering, and chemistry into pools of resources ready to be tapped for projects that are up for bid as they are posted by corporations, research labs, and others. The key innovation here is the enhanced ability of companies to access external knowledge without the constraints of geography and time.

InnoCentive is perhaps the best example to date. Launched in 2001 by Eli Lilly, it uses the power of the Internet to create and enhance open-source R&D by creating a collaborative community of seekers and solvers. It does this through a global incentive-based solution network where a community of innovative scientists (solvers) find and solve challenging problems posted by seekers. InnoCentive seeks to expand the innovation capacity of companies by posting scientific challenges that need to be solved and connecting them with talented scientists worldwide for the most innovative solution.

InnoCentive, however, is not alone. There are several similar Web sites that connect talent in a range of disciplines and expertise to projects, problems, and consulting work in a just-in-time manner. A2Zmoonlighter is an example. Launched in 1998, then as SOFT-moon-lighter, its mission is to directly connect moonlighting professionals with businesses that have short-term needs without the hassles of going through body shops, recruiters, consulting companies, and other middlemen involved in finding IT talent.

Today the company has over 200,000 professionals in its database and 10,000 corporate clients and has expanded the concept into other areas spawning several other efforts including CREATIVEmoolighter, BIZmoonlighter, and OFFICEmoonlighter.

Although expanding the innovation capacity of its clients is not part of its mission, A2Zmoonlighter represents an emerging model for organizing talent in the new world of networked innovation. Already there are other players, such as 2 Rent A Coder and a similar spot market for IT problems being offered and organized under the Google search engine.

The Lesson: Experiment or Die

With the explosion of R&D forms and processes, now is the time for most large companies to engage in large-scale experimentation by setting up different types of structures, engaging in many types of relationships, and having a willingness to cross functional and organizational boundaries. IFTF's Paul Saffo's management imperative, "Ready, Fire, *Steer!*" (rather than "Ready, Aim, *Fire!*"), is particularly apt for the new world of R&D. Without such experimentation and adaptation, large companies may find their R&D arms withering and being left behind by their competitors. Experiment or die becomes a byword for success in the future. In the next decade, as companies experiment with new forms and combinations of forms of R&D they will need to keep the following in mind.

- *Learn to manage different structures simultaneously.* Companies will increasingly need to manage many different kinds of R&D forms under one roof. This will require differentiated and flexible management approaches, varying with the kinds of relationships, the types of people involved, and the objectives of the venture.

- *Value intangible assets.* Many companies readily assess the value of tangible assets such as manufacturing facilities, inventory, and real estate. In innovation networks, the key feature of R&D structures in the next decade, intangibles such as relationships, access to the right people, ideas, places, and processes for diffusing ideas quickly throughout the organization are of paramount importance. While new technologies are challenging traditional notions of intellectual property, companies are becoming obsessed with putting a numeric value on their intellectual assets. Patents and licenses are very important to companies' survival and we will see an increasing preoccupation with these as a result of divergent and often conflicting regulations in different countries. However, companies should not lose sight of the fact that in the networked environment the open flow of ideas is the currency of exchange. Valuing such exchanges and creating processes for encouraging them will ultimately help companies succeed.

- *Strive for hybridization.* Innovation will continue to come from cross-fertilization of different disciplines and industries (biology and information technologies; biology, new materials, and IT; energy and materials). This means that companies will need to hire hybrid thinkers—people with deep expertise and training in one area but who are able to cross disciplinary, geographic, functional, social, and organizational boundaries and apply their skills in another arena. Companies will also need to create organizational processes that encourage cross-fertilization between disciplines, functions, and geographies.

Chapter 3
The Cambrian Explosion in Different Industries

While we expect that the emergence of new forms of R&D will affect nearly all industries, the timing and pervasiveness of change will vary according to the characteristics of the innovation environment in each industry.

Industry Characteristics

Seven industry characteristics will drive the speed and depth of change over the next ten years: capital requirements, time to market, regulation, competitive environment, technology impact, collaboration, and the available talent pool.

Capital Requirements

It can take a vast amount of capital investment to create, develop, and commercialize innovations. For example, new pharmaceutical products cost around $800 million to bring to market. Intel's Pentium microprocessor and Gillette's Mach3 razor each cost approximately $1 billion. At the other end of the scale, a software company can build a new application with a few PCs, a broadband connection, and some highly skilled programmers with little capital investment. Innovative areas with low capital requirements are fertile ground for networks of innovators. Where capital requirements remain high, look for emergent forms to find niches in the R&D process and for niches where these forms can add value with limited investment.

Time to Market

In general, shorter product development times reduce risk and lower the amount of capital needed to support development before payoff. They also allow for iteration, the ability to make incremental changes to design in response to new technology, feedback from consumers, or shifts in consumer demand. In general, the shorter that the time to market is, the easier it is for new players to come in and for new R&D forms to emerge.

Regulation

Regulation often influences the proliferation of new forms by its impact on competition and time to market. For example the deregulation of the telecommunications industry was followed by the emergence of new devices (mobile phones) and services (caller ID). Depending on the type of law, regulation can be either a driver or barrier to the emergence of new forms. In some cases, regulation mainly affects the role in the R&D process that small innovation organizations play. For example, the drug approval process limits smaller biotech firms to a technology out-licensing role because they are too small to run the complicated and expensive clinical trials required by the Food and Drug Administration.

Competitive Environment

New organizational forms thrive in competitive environments. Where competition is limited, new forms are likely to emerge in small niches. These, however, may foster disruptive innovations that will ultimately displace existing products and firms. For example, the creation of WiFi (short-range wireless) networks by small groups of individuals is in part a response to the limited competition among large telecom players.

Technology Impact

Innovation may be tightly linked to changes in base technology (ITC) or to changes in design and packaging (consumer products). Industries experiencing rapid technological changes are usually most supportive of new species of innovators. It is not surprising that many new networked types of organizations first originated in the IT industry, where technological changes were most pronounced.

Collaboration

A corporate environment that supports collaboration on many levels is a necessary condition for the emergence of new types of R&D organizations. The biotech industry, for example, has traditionally had very close ties to academia, with many top biotech researchers wearing two hats—serving as lead scientists or executives in companies while continuing to teach and sometimes do research at universities. The more open the industry is to cross-boundary collaborations, the more likely it is to see emergence of new R&D forms.

Talent Pool

The size and quality of the available talent pool can have a positive or negative impact on innovation. For example, a shortage of highly-skilled talent can encourage new organizational forms as companies reach outside their boundaries to find the necessary resources. Shortage of engineering talent, for example, has led many companies to establish collaborations and alliances with universities, where they get access to students and professors in relevant fields.

The combination of these key characteristics inside industries will likely determine the speed and extent of changes in R&D over the next ten years. Here, we look at these variables for four key industries—information technology and telecommunications (ITC), biotechnology and pharmaceuticals, energy, and consumer goods.

Information Technology and Telecommunications

The ITC industry has created more new forms of innovation than any other industry. Furthermore, ITC itself has become such a critical underpinning to the creation of innovation in other industries, that it now pervades the research, development, and innovation processes of almost every firm. As a result, the biggest impacts of the emerging new forms in ITC may be on companies outside the traditional ITC industry such as biotechnology, nanotechnology, advanced materials, and social and economic modeling.

ITC Characteristics

ITC began to display an explosion of forms early in the industry's development. Large, formalized research organizations were complemented by such successful efforts as the standards communities of the early Arpanet and Internet, the after-hours hackers and home brewers who begot the personal computer revolution, and even government sponsored labs that gave away the tools they produced for their own research. The characteristics of the industry today make it more suited than ever for the creation of new types of innovation-generating organizations.

Capital

Relative to other industries, innovation in ITC is not capital intensive. Lack of capital is rarely the limiting factor for the development of software or hardware innovations. ITC development is comprised of a combination of low-cost software and higher but still low-cost hardware. These already low barriers to innovation are likely to decrease further in the next five years as the lowest-development-cost component of ITC, software, becomes dominant. In addition, the combination of ITC with innovations in other industries is bringing this "capital-lite" innovation approach to other industries. For example, in 2002 the bioinformatics community began to adopt freely distributed software tools. These tools, developed inside of universities, corporations, and consortia, are being released under open source licenses and supported by publications in the ITC press.

Time to Market

A hallmark of the ITC industry has been its unique ability to bring complex products to market very quickly. The increasing prevalence of open-source software development will accelerate this speed significantly as it reduces development times for software. Having witnessed the success of open-source projects like Linux and Mozilla, small, agile organizations are finding that open-source and source-available software models speed up both time-to-fix and time-to-distribute.

Regulation

ITC today is among the least regulated industries. ITC's free hand is due in large part to the ability of some of the most innovative organizations to find application areas that are, as yet, unregulated or those where technology is advancing faster than regulators. For example, the debates around privacy regulation that arose with the popularization of the Internet have failed to keep up with the advent of new technologies such as e-commerce, Web services and smart cameras. Similarly, intellectual property law is being increasingly circumvented by new consumer technologies such as peer-to-peer file sharing, and inexpensive compact-disc burners. While these issue areas will remain important, feedback from customers will continue to be more important than legislation in affecting the ITC industry.

Competitive Environment

Due to its dependence on innovation and rapid product cycles, ITC is an inherently competitive industry. The top-10 firms in ITC markets are in constant flux, with almost complete turnovers in some sectors every decade. This churn will continue as many large firms become victims of the telecom and dot-com busts and as small groups of innovators rush in to create the new dominant models. Despite the presence of two large players with near monopoly power—Microsoft and Intel—dominating the industry today, in the future, innovation is as likely to come out of large firms as small garage-type operations. Low product-development costs and networked-based innovations such as open source will drive this trend.

Technology Impact

New technology and innovation are more essential for the ITC industry than for any other industry. Rapid speed to market, less regulation, and rapid obsolescence of new products makes every ITC organization highly dependent on their ability to access new innovations. The progress of Moore's Law and the similar 15-18 month doubling times for memory, storage, and bandwidth have been the key enablers of technological advances in ITC.

Collaboration

The collaborative model of innovation is core to the foundation of the ITC industry—for example, the Homebrew Computer Club in the 1970s produced several companies including Apple Computer. Open source software development has created a powerful new model for collaborative innovation for this decade. With it, program managers can concentrate on developing those features that are unique to their current task and avoid re-thinking and re-writing codes already developed by others. In the words of Jim Herriott of the Bios Group, "Knowing too much actually slows down problem solving. It is more efficient to have multiple groups working on pieces of the problem."

Talent Pool

The top talent of the future in IT is unlikely to be willing to work exclusively in large, or even single, organizations. As Generation Y (1979-1990) enters the workforce they bring with them a conversant, comfortable, and demanding knowledge of ITC that is qualitatively different from previous generations. While corporations may look to this tech-savvy population to replace a retiring generation of researchers, they may have a hard time hiring, inspiring or retaining them. Members of these generations are instilled with a strong sense of personal achievement, desire for creativity, and drive for entrepreneurship that makes it hard to hire and retain them in large, hierarchical organizations.

Implications

For the past three decades ITC has been on the leading edge of the creation of new models of innovation. The characteristics which are shaping the industry's future, such as the open source movement, issues in IP regulation, and the increasing importance of software, will push it further still. The long and protracted investment slowdown in the technology sector provides an additional important driver for innovators to come up with novel solutions for generating innovation that may produce new models of discovery.

Perhaps the biggest impact of the ITC industry's continuing speciation and experimentation will be the export of this model to other industries. First, as other industries begin to experience some of the characteristics that in the past have been unique to IT such as relatively low capital costs and high competition, they may begin to learn from the successful models of the IT industry. Second, the infusion of ITC technology into innovations in other fields such as biotechnology, pharmaceuticals, and energy will bring these industries face-to-face with innovators in the ITC industry and the models they bring with them.

Energy

While the innovation environment in the energy sector has so far been unsupportive of the new forms of R&D, fundamental changes in the industry are gathering momentum. Over the next five years, these changes could lead to the type of explosion of new, networked models that we are beginning to see in other sectors. Extensive regulation, the absence of competition, and big, long-lasting, and expensive technology have limited energy R&D to large established players—primarily electric utilities, power plant equipment manufacturers, and federally-funded national laboratories. However, the characteristics that have supported the stability of this regime for decades are looking increasingly unstable today. Three key drivers of change—new technologies, market liberalization, and climate change—have the potential to reshape the characteristics of innovation in this industry. The way these drivers play out over the next five years will determine the extent to which the energy industry produces its own Cambrian Explosion.

Energy Characteristics

The characteristics of the energy industry have tended to discourage change and have limited small organizations to a peripheral role in innovation. However, due to the drivers mentioned earlier, almost all of these characteristics are likely to change significantly in the next few years, bringing new R&D forms to the industry.

Capital

The equipment, scale, and complexity of power generation have traditionally limited energy R&D efforts to those with monopoly profits (electric utilities), and those with immense scale (equipment manufacturers like Westinghouse). However, advances in the price and performance of new technologies such as fuel-cells and thin-film photovoltaics could be extremely disruptive to current system and could enable new R&D players organized around social networks to emerge. Required capital investments in these new technologies are relatively small (compare a $3 billion nuclear power plant to a $10,000 fuel cell) and may well change the economics of the industry, opening it up to new players. In addition, venture capital (VC) funding of new energy technologies has grown at an annual rate of 51% in the last five years (see Table 3–1). The existence of this new funding mechanism for energy R&D could be instru-

Table 3–1
Venture Funding for Energy Sector on the Rise (Venture capital investment in energy, in millions of dollars and percent of total VC investments)

	Millions	***Percent***
1995	20	0.3
1996	98	1.2
1997	145	1.2
1998	204	1.5
1999	442	1.5
2000	1,200	1.8
2001	775	2.1

Source: Nth Power, PricewaterhouseCoopers MoneyTree.

mental in generating new types of small, networked R&D organization as markets liberalize and technology gets cheaper.

Time to Market

Regulation and the complexity and scale of power generation projects have traditionally made time to market longer in energy than in most other industries. However, this characteristic is showing signs of changing driven by increasing competition, the entrance of VC money into the industry, and the emergence of smaller power plants. Crossover technologies that have direct consumer applications—such as fuel cells for mobile phones—represent one of the most fertile areas for emerging R&D forms while the energy industry goes through its transition. The longer deregulation stagnates, the more likely innovation in energy will be shifted toward crossover applications that address more competitive markets like consumer electronics and healthcare devices.

Regulation

The lack of competition and fixed prices in the energy sector in the past have essentially blocked the way for new R&D players and created the most essential barrier to innovation. But much like it did for the telecom industry in the 1980s, the process of deregulation begun in the mid-1990s holds the promise of increasing competition and opening up new markets for innovation. New players, instead of selling to a few dozen electric utility companies, will begin selling to thousands of businesses and eventually millions of households. In light of increased competition, the traditional big players will feel pressured to adapt or partner with smaller ones—some will simply die out. Also, as individuals begin to witness the effects of global climate change and in some cases experience them directly, social, and political organizations may begin to take actions including providing stronger incentives for conducting energy R&D and implementing a carbon tax.

Competitive Environment

Despite the current deregulation efforts, very little real competition exists among utilities today. The future of deregulation will be the main driver of competition in this sector. The fallout from the California energy crisis of 2000-2001 and Enron's collapse makes the near-term future of deregulation uncertain. However, in the longer term (5-10 years) energy markets will be more liberalized than they are now, which will allow new types of players to enter the market and enable new collaborations between them and existing players.

Technology Impact

Technology has always been an important component of the energy industry, but the shift from large systems to small, smart, integrated systems will make it even more important in the future. Not only are power generation technologies advancing and diversifying, but software and other information technologies are becoming increasingly essential as energy generation becomes more distributed.

Collaboration

Energy has traditionally seen high levels of collaboration among the government, utilities, and equipment manufacturers. The big change is that collaborative activity is beginning to broaden to include new players as competition increases. For example, cooperative research and development agreements (CRADAs) now allow federal laboratories to work together with private businesses.

Talent Pool

Looking ahead, one of the biggest problems for energy R&D is a demographic one. The average age for members of the energy workforce is higher than in other industries. For example, one major international energy company expects to see half of its workforce retire in the next five years. An aging workforce will be one of the key drivers for large companies to partner outside their organizations.

Implications

Because the energy industry is still primarily based on large, expensive, long-lived assets, new models will emerge more slowly than in other industries. However, with the development of smaller technologies, deregulation, and increased political activity associated with climate change happening simultaneously, new forms of R&D are likely to appear over the next five years. The emergence of new forms will initially manifest itself with an increase in external R&D, spin-offs, and venture-funded start-ups. Ultimately, energy will become more connected to other industries. The move to distributed generation will greatly increase the importance of data and IT for the energy industry. Furthermore, advances in power generation at the micro level will enable new applications in both the IT and medical devices industries. These connections will lead to the emergence of cross-industry R&D forms, which include both energy and other technologies such as those from the ITC and health care industries.

External R&D, Spin-offs, and Start-ups

Among the largest global energy companies, BP has been the most externally focused and is pursuing innovation throughout a broad portfolio of energy sources. On the other hand, Exxon Mobil, the largest energy company in the world, focuses on innovation in its core technology—drilling for petroleum—and relies almost completely on its internal R&D. Watching the progress of innovation at these giant companies over the next few years will shed light on the value of the network model as it is applied at the global level.

Astropower, now one of the largest developers of photovoltaics, was spun off from its parent, PG&E. This is an indicator that the beneficial attributes of small scale, speed, and flexibility are increasing and may be a recognition of how hard it is to grow an innovative business within a large organization. Polyfuel, a spin-off of SRI, is developing micro-fuel cells for mobile phones and laptops. As a start-up it has attracted venture funding and plans to bring a product to market in 2003 by focusing on a consumer application and circumventing the regulatory structure of the energy industry.

Energy as a Connective Technology

The shift from “hard R&D” (devices) to “soft R&D” (software) in the energy industry suggests that energy may become a “connective technology” that crosses boundaries and finds applications by working with other technology sectors such as ITC and health care. This may make places where energy, ITC, and health care research are located near each other prominent hot-spots for network hubs.

Consumer Goods

The industrial world over the past 50 years has moved from a world of scarcity to a world of abundance—an abundance of products and choices about these products. As a result, people no longer look exclusively for functionality when purchasing things; instead, they look at such intangibles as the product's symbolic meaning, the experience associated with it, and its value in one's social network. This can be true whether people are buying cars, soap, or washing machines.

This world of abundance is forcing consumer goods companies to compete not only on the basis of lower-cost quality products but on the basis of intangibles—creating excitement about the product, ability to capture consumers' attention, novelty, design, and experience associated with the product, ability to deliver the product or experience to the customer through the right channel and at the right time.

At the same time, consumer products companies, more than many others, are particularly affected by technologies coming from outside of their sector. As mentioned earlier, food companies will increasingly need to understand advances in genomics and the connections between food and health. Advances in ITC have had powerful effects on communication channels between brand manufacturers and consumers. Developments in radio frequency identification (RFID) technologies promise to revolutionize the whole supply chain. Advances in biometrics and sensors offer new techniques for understanding consumers. The Nike shoe, which relies on innovations from a variety of sciences—aerodynamics and chemistry, to name just a couple—is a classic example of the need for innovation from a variety of disciplines in the consumer sector.

What all this means is that innovation for many consumer goods companies has increasingly broadened outside of the internal R&D organization to include other companies and universities, as well as other parts of the organization, such as product design, consumer research, services, and IT.

In the next ten years, many consumer goods companies will have to look outside their R&D organizations to stay abreast of innovations and will need to bring them inside their companies. Not surprisingly, companies such as Procter & Gamble expect 50% of their R&D budget to be spent outside the company. Such money will fund research at universities, start-ups, and independent research organizations. These outside investments will allow companies to access a wider range of ideas and will often result in quicker introductions of new products.

Implications

- Lines between marketing, R&D, and IT will become increasingly blurred. For consumer goods companies, the center of innovation will shift from R&D to design, new technologies, and methodologies for understanding consumers and reaching them, and new ways of understanding the masses of data that are available about consumers.
- There will be more opportunities for independent inventors, designers, and innovators to work with large consumer goods companies through various types of licensing arrangements, seed funding, online market places, and other collaborative arrangements.
- There will be more cross-industry collaborations, with consumer goods companies increasingly partnering with IT, biotech, and materials companies and research organizations.

Biotechnology and Pharmaceuticals

The pharmaceutical industry is in the midst of a shift in product development focus that will result in the introduction of revolutionary pharmaceutical products. The mapping of the human genome and the application of information technologies to R&D are the significant initial steps into a new era of drug discovery and development. Information technologies have enabled greater data creation, collection, and manipulation and rapid parallel processing throughout the R&D process, resulting in groundbreaking discoveries, such as the sequencing of the human genome. Proteomics (the study of how proteins are coded for and expressed and how they interact with other molecules) and functional genomics (the study of how genes and their products interact with each other and the environment) will define the structure and functions of proteins and identify gene and protein interactions with other genes and gene products. A decade from now, structural and functional understanding of new and existing chemical entities, such as proteins, will inform the development of much safer, much more efficacious, highly targeted—even individualized—pharmaceutical treatments.

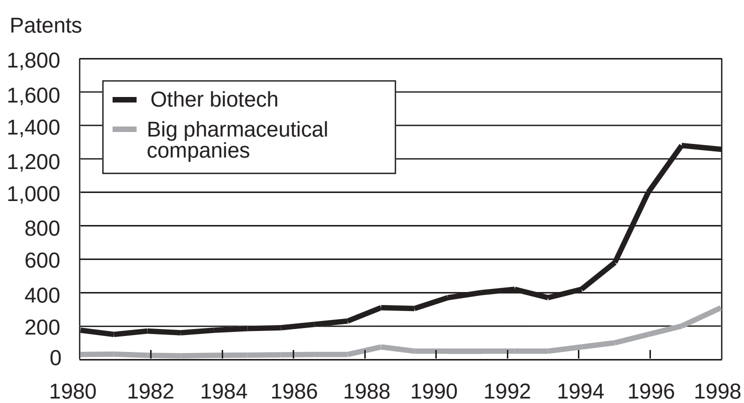
Biotechnology and Pharmaceutical Characteristics

For more than a decade, the R&D engines that bring pharmaceutical and biotech products to market have been dependent on networks of innovation. Pharmaceutical companies tapped into and began seriously developing ideas generated in the patent-rich biotech sector in the 1990s (see Figure 3–1). And, pharmaceutical companies are increasing their investment in work with contract research organizations and others to bring products to market (see Figure 3–2 on page 28). New research models and ways of organizing researchers will be critical to effectively integrating developments in science and technology into new products.

Capital

Drug development is capital intensive. The cost of bringing a pharmaceutical product to market has risen from $500 million in 1990 to $800

Figure 3–1
More Patents Awarded to Smaller Biotechnology Firms
(Percent of all biotechnology patents awarded)



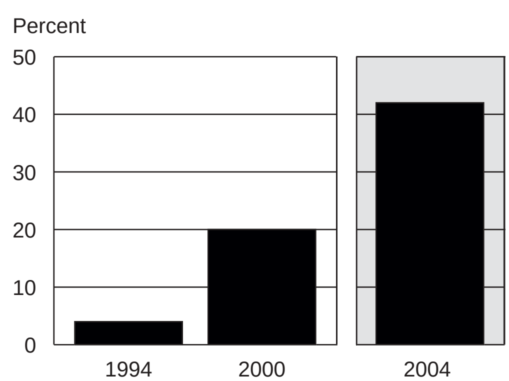
Source: U.S. Patent and Trademark Office, and Sanford Bernstein & Company analysis, 2000.

million reported in 2002. Lengthy time to market (approximately 12 years), forecasted increases in R&D investment of between 8% and 13%, and greater investment in promotion, including direct-to-consumer marketing activities, will continue to drive cost increases. Alliances between large companies and research-intensive biotech organizations allow them to join forces and increase the efficiency of bringing new products to market. New alliances and ways of conducting R&D, such as sharing the costs of health treatment across research-based and insurance-reimbursed pro-viders, are likely to emerge as concern about the increased costs of health care could limit the capital available to support R&D. If successful, any of a number of current legislative proposals to manage low-cost access to and availability of drugs, especially for the elderly, could, in effect, set price controls on pharmaceuticals, shaping the structure of private industry funding and research for years to come.

Time to Market

Overall, we expect the length of time to market to increase in the medium-term as regulatory issues are worked out, but it should decrease in the long term as collaboration proves successful and information technologies improve the development process. On the regulatory side, the expected increase in the development of new combination products that have both drug and device functions will pose a significant challenge to regulators. Currently, regulators are poorly prepared to review such hybrid products. In time, this problem should be resolved; for example, there is a proposal to create an office to regulate combination products that should speed up the approval process. Industry is also likely to work with regulators to ease this problem through such mechanisms as joint filing or industry fees to hire and support a regulatory staff with hybrid-product expertise. But beyond regulatory issues, there are several factors that can influence time-to-market in the biotech/pharma sector. A lack of appropriate clinical trial participants is likely to

Figure 3–2
Pharmaceutical Companies Will More Than Double Their Share of Outsourced R&D
(Percent of R&D that is outsourced)



Source: Advancetech Monitor, Frost & Sullivan, *The Pink Sheet*, April 3, 2000.

increase time to market, at least in the short- to medium-term. Collaboration among companies has the potential to speed up time-to-market as it pools appropriate and varying resources into development efforts. Successful application of information technology to product testing should decrease time-to-market in the long-term as in-silico testing becomes the norm.

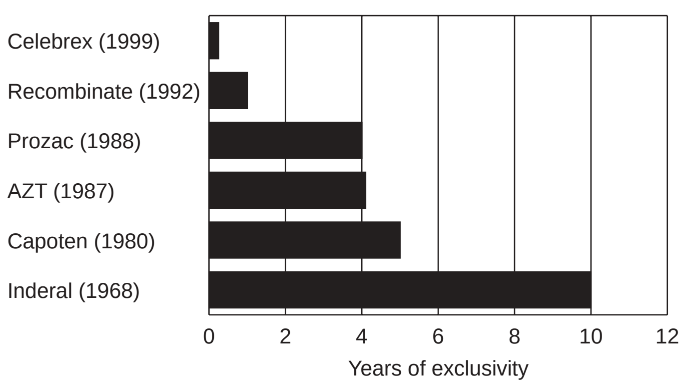
Regulation

The pharmaceutical and biotech industries are and will continue to be highly regulated by the federal government, as the need to ensure the safety of drugs and other biotechnology products will remain. In addition, the regulatory environment will continue to be complicated by such issues as intellectual property and privacy. Some countries and companies will continue to challenge intellectual property and patents, while some developing nations refuse to adhere to the World Trade Organization's Trade-Related Aspects of Intellectual Property Rights agreement. Intellectual property is the basic resource that is being exchanged in collaborative relationships and companies evaluate one another on the basis of complementary intellectual assets and skill sets. Realistic assessment of the value of intellectual and intangible assets will remain a major business issue for partnerships, and may lead companies to favor fewer, longer-term relationships built on trust rather than engage in multiple, short-term partnerships.

Competitive Environment

In 2000, only three of ten approved drugs recovered their R&D investment through sales, despite more than 10% annual increases in R&D spending in most years since 1980. In addition, the period of market exclusivity is shrinking for most investments (see Figure 3–3). These competitive pressures have led the pharmaceutical industry to consolidate through mergers and acquisitions as well as to partner with the patent-rich biotechnology industry to bring new products to market and are likely to lead to even more collaborations in the future.

Figure 3–3
Market Exclusivity Period Is Shrinking
(Years of market exclusivity enjoyed by various prescription drugs after their initial release date)



Source: Pharmaceutical Research and Manufacturers of America, 2000; The Wilkerson Group, 1995.

Technology Impact

New tools and technologies are transforming drug discovery and development processes. The identification of critical drug targets and the application of high-speed, powerful computer processing capabilities to drug discovery are transforming the way potential targets are identified and examined. Experts believe early "clinical" testing will occur *in silico* using computer-based modeling to simulate how a chemical would interact in the body rather than testing with human subjects. Taking this forecast to the extreme, we can imagine a drug for which all of the clinical testing has been simulated without touching a patient. This would allow a whole new generation of entrants, without substantial capital resources to pay for expensive human trials, to enter the market and make it easier for smaller research organizations to occupy various market niches.

At the same time, the convergence of four key sectors—materials, energy science, biology, and information technology—will create a whole new universe of products that leverage advances in these areas to create pharmaceutical products that stretch our imagination. For example, will a closed-loop diabetes sensor and insulin releaser be considered a drug or a device? Industry and regulators will need to collaborate in some areas to define new categories that balance the demands of a competitive market and consumer safety. Combination products are just one example of new products that will require physician education and enhanced regulation. Other examples include the soon to come gene-based products, such as genetic testing, gene therapy, and biologic treatments, that have the potential to revolutionize how health care is delivered.

Collaboration

Collaborative, cross-organizational, and cross-disciplinary efforts will become more important as distinct fields collide (for example, materials science and biology, biology and IT). Research-intensive universities are already promoting hybrid organizations in their own research facilities, such as Bio-X at Stanford, to facilitate new connections across disciplines. Over time, what we currently consider "boundary crossing" fields, such as bioinformatics, will become established and carve out their own disciplines. Facilitated by geography and communication technologies, collaboration and formal organizational affiliation will remain fluid. Despite initial forecasts that co-location would be irrelevant due to communication technologies, we've seen the development of strong regional centers for biotechnology and pharmaceutical R&D, such as Oyster Point south of San Francisco and in the San Diego area. These regional collaboration nodes will continue to be of importance in the R&D efforts in the industry.

Talent Pool

The biotechnology sector is becoming more and more information intensive. In addition, the intersection of biotech with other areas, energy and materials for example, will require more hybrids—people with knowledge and skills in IT and biology, energy and biology, materials and biology. These people are very much in short supply because universities have traditionally provided training in just one discipline. Because of shortages in these types of hybrid workers, we will see more collaborative efforts and new organizational forms created to fill in the gaps.

Implications

The pharmaceutical industry will face a difficult business environment for R&D in the next 5-10 years. The blockbuster profit model that counts on the broad application and sales success of a few drugs to support the R&D costs of future developments is expected to diminish in importance as companies move toward developing customized drugs. Advances in genetics and genomics will enable the development of such drugs, but incorporating these advances will be challenging in the short term. Established companies will struggle to extend and repurpose patents as their products lose their patent protection (approximately $39 billion in brand-name sales will be vulnerable to competition between 2002 and 2010) to remain competitive.

To combat such troubles, companies will continue to merge and partner to achieve economies of scale and improve their pipelines. Collaborative relationships with biotech companies and academic labs will be extremely important for pharmaceutical innovation. In short, the pharmaceutical and bio-technology industries, early protagonists of collaborative R&D models will both spend the next 5-10 years digesting major scientific ad-vances. In this period we are likely to see the creation of larger companies as current players expand their existing R&D labs through mergers and acquisitions. We are also likely to see emergence of new niche players as a result of the advent of new technologies allowing for clinical trials *in silico*.

While large and small companies will continue to partner in the pre-clinical phase of the research process, many biotech companies will look to mid-sized pharmaceutical collaborators, rather than large firms, in order to direct and maintain greater ownership of the results of their research efforts development.

Chapter 4

Social Networks Will Support New R&D Forms

We forecast in Chapter 2 that the next ten years will be an era of great experimentation in R&D, with many new organizational forms emerging—some transitory, some longer lasting. One element will provide critical support for many of the organizational forms—networks. Networks will come in a variety of forms—formal or informal, within organizational boundaries or outside, virtual or incorporating physical presence. Networks have been playing a key role in the organizational structures and dynamics of some innovation regions and industries for nearly 30 years. The Silicon Valley, for example, can best be viewed as a network of innovators who move freely among organizations transferring ideas and knowledge. Similarly, the fashion industry of Northern Italy has retained its innovative spirit despite competition from many cheaper overseas producers because it has a highly flexible networked industry structure consisting of many small specialized manufacturers expert in one particular part of the process—dyeing, weaving, cutting, and so forth. Networks allow flexibility, they open up organizational boundaries to new ideas, facilitate quick diffusion of ideas and processes, and promote adaptability to changes in the business environment.

In the next ten years, creating, facilitating, and participating in the right types of networks and managing them to maximize innovation will be a key source of competitive advantage for a growing number of companies and industries. In this chapter we outline some of the key lessons from our research that will help companies create and manage their innovation networks.

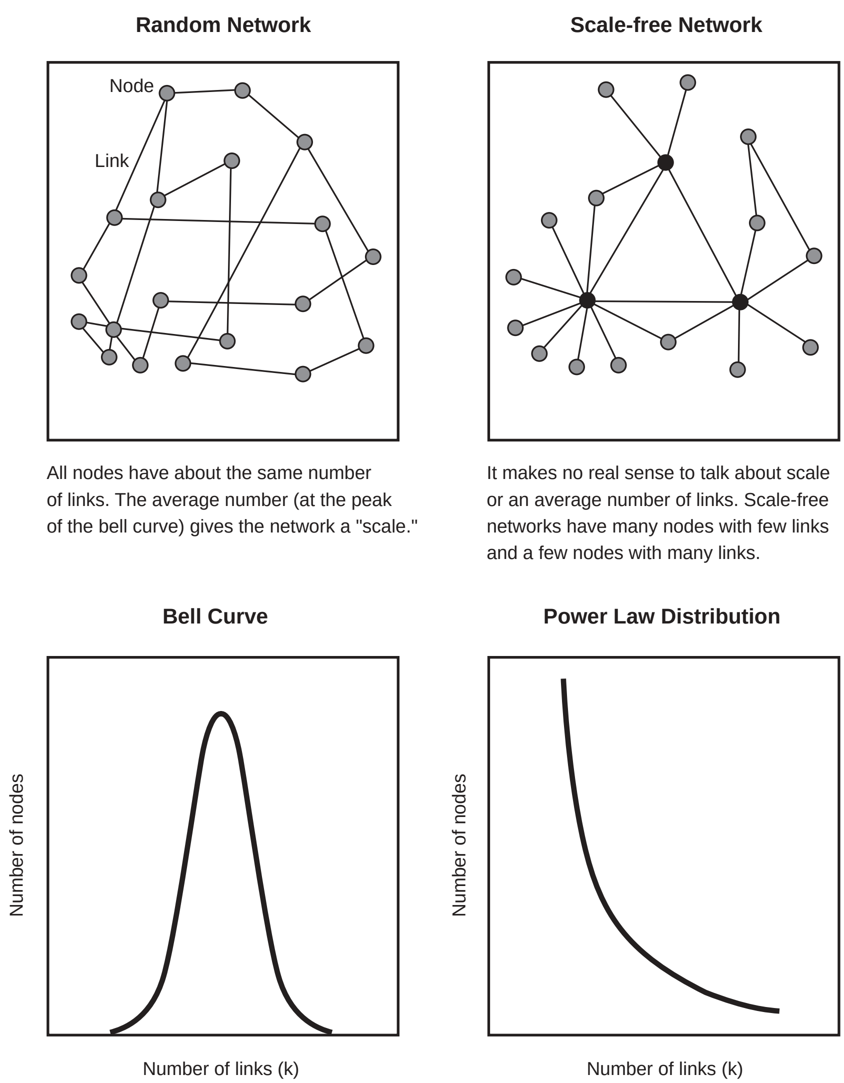
Network Principles

New technologies such as flow tracking, modeling, advanced analytics, and web crawling facilitate better ways of understanding networks. What's more, the evolution of World Wide Web, the grandest of networks that connected millions of computers and users from around the world, gave scientists a unique laboratory for studying nodes and links. Although much of this research is still new and there isn't complete agreement on the emerging findings, some are worth exploring.

Among the most important findings is that networks follow fundamental rules or organizing principles, which apply equally to the World Wide Web, social networks of friends and acquaintances, biological systems, gene networks, and food webs in nature. Recent research by Albert-Laszlo Barabasi, a professor of physics at the University of Notre Dame in Indiana, has found that all networks—social, sexual, professional, biological, or the Internet—are similar in that they follow the same mathematical laws. The following are some of the basic principles of naturally occurring networks.

- *Natural networks are scale-free*. Unlike in a random network in which nodes on average have about the same number of links, with natural networks, it makes no sense to talk about scale or average number of links. These real-life networks follow a power-law distribution—the majority of nodes have only a few links and these numerous tiny nodes coexist with a few big hubs—nodes with an anomalously high number of links that keep the networks from falling apart (see Figure 4–1).
- *Hubs dominate network topology*. Hubs are nodes with a very high concentration of links—think people, institutions, and regions with an unusually high capacity for connecting and maintaining numerous relationships and links. Hubs are key to the distribution or diffusion of information, ideas, or other resources from one place in the network to the other.
- *The highly connected tend to become even more connected, or "the rich get richer."* According to Barabasi, networks are dynamic and growing, as networks constantly need to add new recruits. New recruits show some form of preference as they attach to the network. For example, new Web sites want to be picked up by popular sites, such as Yahoo!, to increase their traffic. New scientists want to work with established, well-known scientists rather than unknown ones. As a result, when deciding where to link, new nodes prefer to attach to the more connected nodes. This preferential treatment results in a few highly connected hubs with a disproportionate ability to establish links with new network entrants.
- *Physical spaces and face-to-face interactions are important to network formation and maintenance.* Abundant connectivity and substantial growth of online interactions does not abrogate the importance of personal, face-to-face interactions in creating networks and keeping them vibrant. IFTF research shows that young people, even enriched with various technologies and online resources, spend most of their time in the real physical world, in face-to-face interactions with friends, family, teachers, neighbors, and others in their social network. In fact, their online activities often serve to support and maintain these face-to-face relationships. Also and not surprisingly, most innovation networks tend to be regionally or place-based (Silicon Valley, Boston area, Bangalore, and others). If innovation is iterative, face-to-face, and network based, then it is not surprising that is also place-based. Talented and creative people want to be where the action is, where their ideas stand the best chance of coming to fruition.

Figure 4–1
Random Networks Versus Scale-Free Networks



Source: Barabasi, Albert-Laszlo, *Linked: The New Science of Networks*, Perseus Publishing, 2002.

Although one can design different kinds of networks—hierarchical, centralized, decentralized or distributed—each with its own distinct architecture, naturally occurring networks facilitate the processes that are critical to innovation (see Figure 4–2). Companies should not underestimate the role of the informal connections that naturally emerge within designed hierarchical or centralized structures. Thus, it is better for companies to design infrastructures and processes that support these naturally evolving network connections and structures rather than discourage their development.

Implications

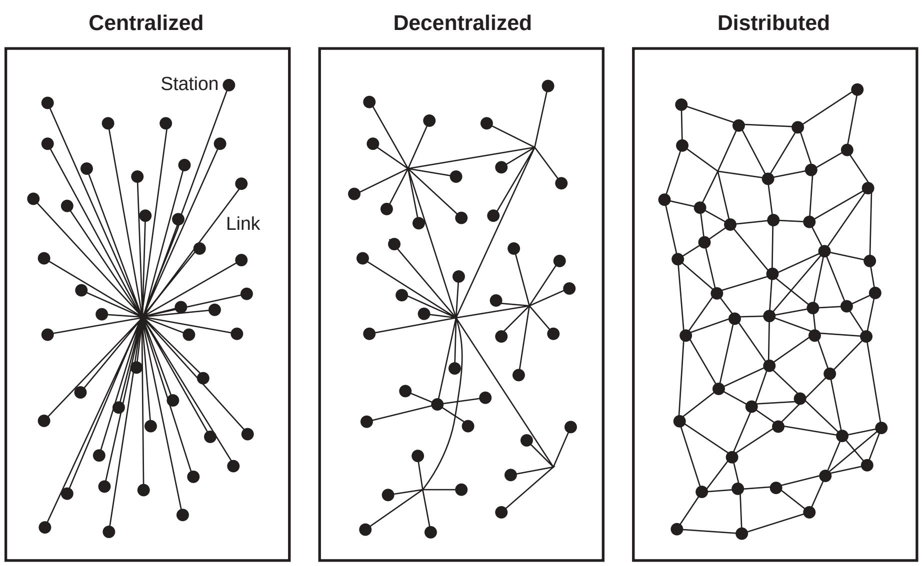
These basic principles have profound implications for business organizations and how they create, facilitate, and participate in innovation networks as well as how they manage networks to capture their full value.

Think, Live, and Breathe Hubs

Think in terms of creating hubs—centers of activity and magnets for relationships and ideas. And understand and support naturally evolving hubs. This means bringing in people and creating spaces that attract others to them. Hubs may be formed around opinion leaders, around key scientists whose work is exciting and generates a lot of interest and desire to collaborate, and other interesting individuals that serve as magnets.

Hubs play an important role in diffusing information and ideas in larger groups. Many organizations suffer from a delusion that they need to communicate and diffuse information to every single individual. Such communications may be quite inefficient and costly. The beauty of hubs is that they make it possible for very few people to connect and communicate ideas to a very large number of others in the

Figure 4–2
Networks Take on Different Forms



Source: Barabasi, Albert-Laszlo, *Linked: The New Science of Networks*, Perseus Publishing, 2002.

network. Thus to transmit ideas and to communicate efficiently, companies should use hubs as key communication channels.

Hubs are often the equivalent of the "early adopters" in traditional diffusion theory. It is important to remember, however, that hubs are not necessarily innovators themselves. It is their acceptance of an innovation that is the key. If there is resistance among hubs, the product or the idea fails to diffuse. If the hub accepts a new product or service, it can influence a very large number of people in the network. By targeting hubs, ideas and information can spread very quickly through a network as information passing each hub reaches a phase transition and all the hubs and nodes are affected.

Build Redundancies to Reduce Risks

The hub structure is an important asset as well as the Achilles' heel of scale-free networks. It is the Achilles' heel because if one hub is disabled, communication to a large part of the network may falter and ideas that normally flow through that hub may come to a stop. For this reason, it is important to build redundancies into the system—if one hub is disabled, another one can take its place. IFTF's ethnographic research on networks indicates that young people build multiple redundancies into their social networks to reduce such risks—if one person goes away, there is someone else to take that person's place, supplying necessary the resources, such as technical assistance or travel advice.

All Nodes Are Not Created Equal

Networks require individuals to perform different roles in order to survive and run smoothly. Concentrating exclusively on individuals who are magnets or hubs may put an organization in jeopardy. The following are some important roles (in addition to hubs or magnets) that we have identified in our research.

Experts

Experts provide specific content expertise when needed. People continuously scan their networks to figure out who has a certain type of knowledge. The practice of informal knowledge outsourcing enables members to access different types of expertise as needed much faster than they could on their own.

Technical Support

Given the centrality of technology to network communications, these people are essential to keeping the network connected.

Brokers

Brokers connect people or ideas that otherwise might not come together, typically by connecting together different hubs within the same network or outside of it. As such, they serve a critical role in the diffusion process. By connecting different worlds and bringing ideas from one world to another, they often ignite the creative spark that drives true innovation. These people serve as "long links" connecting different worlds together and moving ideas between them.

Organizers

These members of the network orchestrate and plan activities for other members. The organizer may specialize in certain kinds of activities, or know everything that is going on, serving as a resource for others.

Innovators

Innovators may not necessarily be the hub or the magnet, but they come up with new ideas for just about anything—activities, connections, projects, and partnerships. The innovator keeps the hub humming.

Need to Create Small-World Effect

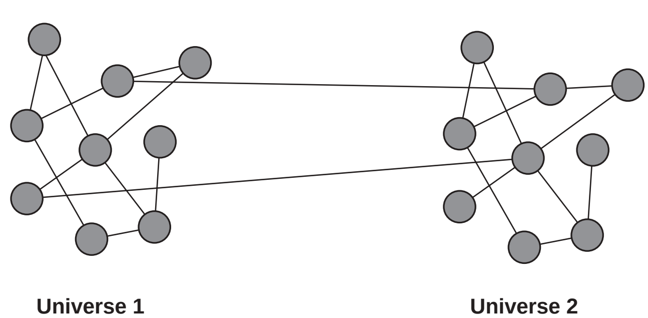
People usually form close network links that require little effort to maintain such as those with family, neighbors, or people with similar interests. These local networks are very efficient—the costs of communicating are low since there is little need for "cultural" translation, and the homogeneous ties tend to reinforce key ideas held by members of the local group. On the other hand, diverse networks tend to be less efficient at communicating ideas and coming to a common understanding because it usually requires more time and effort. At the same time, diverse networks tend to be more creative because innovation is often the result of joining together previously unconnected ideas, practices, or people. This is why port cities and other places that are situated at the crossroads of different cultures and people are usually innovation hot spots. As Peter Hall points out in his book *Cities in Civilization*, "by accidents or geography, sparks may be struck and something new comes out of the encounter."

To achieve the best of both worlds—efficiency of homogeneous networks and creativity of heterogeneous ones—companies need to create small-world effect—tightly-knit homogeneous networks linked by a few "soda straw" links (sometimes referred to as "weak links") in between (see Figure 4–3). They serve the very important function of transferring ideas and knowledge between more homogeneous networks, thus infusing each with innovation.

Tap into Regional Innovation Hubs

Our research shows that not all geographic regions are created equal. Certain regions serve as innovation poles, creating combinations of people and institutions that produce innovations on a scale unmatched by others. They possess unique ecosystems or, in the words of Manuel Castells, professor of regional planning at University of California, Berkeley and author of many books on innovation and networks, "innovation milieus," consisting of dense networks of personal relationships which transcend the boundaries of individual companies, universities, venture capital firms, and other institutions. The drivers of innovation in such regions are dense but open networks based on personal relationships, within which ideas move freely, and are quickly taken up, re-invented, and adopted.

Figure 4–3
Soda Straw Links Connect Different Universes



Source: Jim Herriott, Vice President, Bios Group.

The importance of personal and face-to-face interactions in such networks is key to their success. One of the experts we worked with summed up the advantages of Silicon Valley, "In one day, I can talk to a professor at Stanford, meet with a big venture capitalist, talk to a bunch of colleagues in a start-up, come by and talk to people at IFTF [Institute for the Future], and all within a radius of five miles." As pointed out above, most innovation networks are place-based and require face-to-face interactions. Thus, becoming an insider in regional innovation networks is a critical competency for companies. This means not only establishing an office, or physical presence in key places, but being intimately involved in the dense networks of personal and professional relationships in it. It is easy to live in a place but not be a part of it.

Leverage Connectivity to Expand Breadth and Reach of Social Networks

Abundant connectivity, resulting from both the diffusion of information and communication technology and greater mobility across geographic borders, is having profound effects on social networks. The web of relationships an individual participates in crosses more boundaries and reaches into more communities than ever before. As people cross boundaries they are exposed to other ideas and influences. Information technology facilitates this expansion and reach by helping people build new global ties with others who share their passions, lifestyles, or professional interests, while at the same time helps them strengthen ties with those they already know. It also allows these relationships to be activated or de-activated as needed.

IFTF research shows that one important function of many communication technologies, such as the World Wide Web, wireless phones, and e-mail, is to allow people to have portfolios of just-in-time relationships that can be activated and de-activated as needed. They enable individuals to extend their reach and gain necessary resources, knowledge, and relationships in an extremely efficient and just-in-time fashion. Technology does not substitute for face-to-face interactions but acts as a means for extending and maintaining them.

Overlapping Relationships Promote Loyalty and Open Exchanges

One of the distinguishing features of the Silicon Valley's innovation environment is that there is little distinction between personal and professional networks. People actively use personal networks for establishing new ventures, finding jobs, raising capital, or obtaining information quickly and efficiently. Personal networks serve the dual ends of fulfilling purely expressive or emotional and instrumental needs—that is, they are filled with emotional content and at the same time are used as tools for accomplishing clear goals. IFTF's ethnographic interviews with entrepreneurs in Silicon Valley point to this tight interweaving of personal and professional relationships. Indeed, for most individuals, social networks are highly valued assets. They ensure that no matter what happens to companies or other institutions in one's professional life, one can always fall back on them. This confers the freedom to take risks. In other words, extensive networks give one the freedom of the wealthy—who choose to do things because they are interested in them and not because they need the money.

While companies want to encourage mixing social and professional interests in order to promote cohesiveness and creativity within networks, they need to understand that it is very difficult to keep intellectual property within formal organizational boundaries. Personal and work networks are intertwined—

how do you not talk about work or new ideas with your friends? Companies need to be ready to play by the rules of Silicon Valley, which thrives on open and dense personal networks in which information flows freely.

Passion Drives Innovation Networks

It is remarkable how much free advice, free work, even tools and equipment are exchanged in innovation networks. Our interviews indicate that innovators driven by passion for tinkering with technologies, ideas, and commitment to their social relations often spend extensive amounts of time working on projects without a clear financial payoff simply because they are close to people involved in the project, because it is technically interesting to them, or they are emotionally committed to the idea. Working in social networks is for many a hobby or entertainment. One of the entrepreneurs, when asked if there is a difference between his work routine and his weekends, was surprised by the question. On weekends he basically continues tinkering with technologies he works with during the week.

New Tools for Network Analysis

New tools for understanding networks are surfacing every day. Two particularly promising techniques to look at include: social network analysis and agent-based modeling.

Social Network Analysis

Social network analysis (SNA) is the mapping and measuring of relationships and flows among people, groups, organizations, computers, or other information processing entities. It uses systematic analysis and representation of quantitative data to understand the interactions, relationships, and flow of resources between individuals. The result is a visual and mathematical presentation of a structure of connections within which actors are embedded. Rather than looking at individuals' demographic, behavioral, or psychological attributes, SNA looks at the relationships or the structure of relationships between actors or nodes as the unit of analysis. SNA has found important applications in organizational behavior, interorganizational relations, epidemiological studies, and work on mental health, social support, exchange of information, and the diffusion of innovations.

Agent-Based Modeling

Agent-based modeling (ABM) is a simulation technique and tool for studying and modeling emergent phenomena that result from the interactions of many individuals or independent agents. ABM models the behaviors of individuals by using collections of autonomous decision-making entities called agents. Agents may execute various behaviors that are appropriate to the system they represent (for example, producing, consuming, or purchasing). Each agent individually assesses its situation and makes decisions based upon programmed rules; in addition, agents may be capable of evolving, allowing unanticipated behaviors to emerge. Sometimes neural networks and genetic algorithms are incorporated to allow agents to realistically learn and adapt. ABM can increase understanding in four main application areas.

1. *Flows and swarms* (e.g., to decrease waiting times in supermarkets or design safety exits).
2. *Markets* (e.g., to predict stock market fluctuations).
3. *Organizations* (e.g., to identify optimal organizational structures for particular functions).
4. *Social networks* (e.g., to predict innovation adoption and diffusion).

ABM works best when the interactions among agents are complex, nonlinear, and involve learning and adaptation; when space is crucial and the agents' positions are not fixed (e.g., in a theme park, supermarket, or highway); and when the population is heterogeneous.

Conclusion

We are entering a new era in R&D—from dominance of one organizational form to the explosion and co-existence of many different types of R&D organizations and processes. Although the speed and scope of change will vary among industries, the phenomenon is likely to affect most industry sectors and to migrate from one to another. In the next ten years, the landscape is likely to include a great variety of R&D forms—large-scale research labs within corporate boundaries are likely to co-exist side by side and compete with loose and flexible networks of researchers banding together to pursue ventures they are passionate about, for example. Innovation in this coming era is as likely to come out of the large R&D lab as out of a garage operation comprised of a few talented people. Experimentation with multiple forms and different processes will be the signature of the new era.

One element will continue to underpin many of the organizational forms in the next decade. This element is networks, both within organizational boundaries and outside, tying the organization to outside sources of ideas and innovation. Ability to create and manage internal and external innovation networks will be the enduring source of competitive advantage for companies over the next decade.

Appendix

Research & Development in America, 1865-2010