TECHNOLOGY TRANSFER

1. The Emergence and Evolution of Technology Transfer

Technology transfer is at the same time both a recent addition to the global business lexicon and a process that has informed the entire progress of the United States. During the early years of the Republic, pragmatic interests of nation building shaped the growth and application of technical knowledge, and the American social and political environment provided a climate that made innovation and its transfer possible. By the end of World War II, the Manhattan Project's success had clearly demonstrated that the three pillars of research– the university, industry, and the government—could collaboratively solve problems that no single institution could solve alone.

The recent history of technology transfer, as understood by today's practitioners in the United States, is generally acknowledged to have emerged as a direct result of several seminal events, primarily the legislative acts that established the land grant colleges and the legislation in the 1980s that opened university research and federal laboratories to greater access by industrial corporations. Because that history continues to affect the current development of technology transfer in practice, we begin this article with a brief overview of the salient legislation and the related influences that have shaped the evolution of technology transfer in the United States (see ENDNOTE 1).

1.1. The First Pillar of Research: The University. Today technology transfer practitioners are actively engaged in the promotion of collaborations with scientists and engineers in university. But the traditions that shaped the American university did not anticipate collaboration outside the university, and in a variety of ways those traditions continue to influence contemporary academic perspectives toward technology transfer. Thus, practitioners who seek to employ best practices approaches when developing research projects with university partners will find it useful to understand the university context.

Initially, colleges and universities in the United States contributed little to the creation of the scientific intellectual capital required to develop technology. This lack of contribution stemmed directly from two factors. First, in establishing the colonial colleges, America's founders transferred the European university's primary mission– to educate future professionals in medicine, law, and the ministry– to their own charters. And second, as Jencks and Riesman (1) observed, "until the late nineteenth century there had hardly been an academic profession at all" (Ref. 1, p. 160). Indeed, higher education required some 130 years of internal investment, from the first endowed professorship in mathematics in 1720 to the mid-1800s' launch of the first scientific schools, to create the faculty specialization necessary to reshape the original mission of the colonial colleges. Given their roots in professional education and the magnitude of their investment in building their own institution, it is not surprising that some universities remain cautious, even skeptical, when considering partnerships with those outside their traditions.

The influence of the German universities provided an additional impetus to the evolution of science and engineering in the United States. German university education of this period differed from the scientific training at the European and American institutions: It was technical in nature, grounded in experimentation,

Kirk-Othmer Encyclopedia of Chemical Technology. Copyright John Wiley & Sons, Inc. All rights reserved.

directed toward advanced study, and informed by a “unity of research and teaching” (Ref. 2, p. 1635). According to Ben-David, “Until about the 1870s, the German universities were virtually the only institutions in the world in which a student could obtain training in how to do scientific or scholarly research” (Ref. 3, p. 22). By the 1850s, “nearly 300 Americans are known to have matriculated in the leading German universities” (4)– a direct example of technology transfer in the form of intellectual capital from Europe to the United States– with at least some of these Americans turning their newly minted German Ph.D.’s into faculty appointments at colleges in the United States.

The Morrill Act of 1862. It was in this environment of an already rather robust interest in science and engineering education that Congress passed the first Morrill Act in 1862. The Act provided a permanent endowment to establish in each state

. . .at least one college where the leading object shall be, without excluding other scientific and classical studies and including military tactics, to teach such branches of learning as related to agriculture and the mechanics arts. . . in order to promote the liberal and practical education of the industrial classes in the several pursuits and professions in life.

Passage of the Morrill Act has been characterized variously as “the decisive enabling event provoking the expansion of United States engineering education” (Ref. 5, p. 1107); “as confer[ing] legitimacy on vocational and technical studies (Ref. 6, p. 1680); and as the worldwide model for the “integrated (i.e., teaching, research, and extension) agricultural university” (Ref. 7, p. 1063).

While some technology transfer practitioners view passage of the Morrill Act as the defining event in the emergence of technology transfer, the historical evidence argues for greater modesty when linking the Morrill Act to the present environment for technology transfer. In fact, American colleges instituted formal training in civil engineering in the 1820s, and 13 U.S. institutions had awarded approximately 300 degrees in engineering by 1866. As for the legitimacy of vocational and technical studies, we have already documented the influence of the German universities on the United States and the shift in curricula and mission that infested even the colonial colleges as a result.

Finally, with regard to the Morrill Act’s influence on the model for agricultural research, three caveats come immediately to mind. First, it was not until the Hatch Act was passed in 1887 that Congress authorized an annual appropriation to fund an agricultural experiment station at each land-grant college, completing the “integrated model.” Second, as Goldman (5) reported, “It is noteworthy that until some years after the Hatch Act of 1887 assigned federal funds for agricultural research, the study of science and engineering at the land grant colleges substantially outpaced the study of agriculture” (Ref. 5, p. 1108). Finally, prior to the Morrill Act, a number of colleges had already been founded for the study of agriculture.

The Hatch Act of 1887. The Hatch Act of 1887 added the research component to the land grant formula, and transfigured the model farms of many land grant institutions from centers of learning into teaching aids and experimental stations. Under the Hatch Act, Congress pledged to appropriate funds annually to each state for an agricultural experiment station and made federal support available for state research staffs for natural science investigations related to agriculture:

> From the inception, experiment stations prevented a sharp delineation between education and research, By . . .setting standards for the expenditure of resources, these research pioneers set the ground rules for themselves and their progeny in other fields and disciplines utilitarian problem focused, housed apart from resident instruction, and accountable to a sponsor (Ref. 8, p. 1454).

With its emphasis on research and the utilitarian application of that research, the Hatch Act both increased the presence of the science specialists within the university and redefined the university as a "social service station" (1,6,9). In further shifting the mission of the university, the Hatch Act added depth to the breadth contributed by the Morrill Acts. Moreover, its successful application in states like Wisconsin became the model for university-government partnerships at the federal level.

The Smith Lever Act of 1916. Passage of the Smith-Lever Act in 1916 cemented the relationship between governmental and university institutions by creating and funding the Agricultural Extension Service to disseminate. . . the research findings of the land grant institutions to the agricultural and rural interests within their respective states (Ref. 8, p. 1454).

In adding a dissemination component to the teaching component of the Morrill Act and the research component of the Hatch Act, this last piece of legislation made formal the tri-part mission of the land grant university (7). Thus, it is with the Smith-Lever Act that what we today know as technology transfer was launched (8).

1.2. The Second Pillar of Research: Industry. Although some corporations and universities initiated linkages following passage of the Smith-Lever Act, the contraction in both business income and government revenue precipitated by the Great Depression severely limited both corporate grants and government funding to universities for research.

Some basic research continued in the university during the 1920s and 1930s-notably research in atomic physics and in chemistry; research on the principles underlying the behavior of semiconductors; and research by Crick and Watson that later led to their identification of the structure of DNA. But as Williams (10) noted:

> If technology transfer is defined as the transfer of knowledge that might be turned to practical account, institutions of higher education generate much more new knowledge to transfer [now] than before the second World War. The transfer is more effective when firms in the business sector have research workers who are able to identify the results of research [that] have practical potential (Ref. 10, p. 853).

Manhattan Project. World War II "permanently altered the funding, organization, and style of academic research" (Ref. 8, p. 1454). While the Manhattan Project brought researchers from the three pillars of research—government, academic, and industrial spheres—together at an unprecedented level, the goal was to affect the outcome of the war rather than to produce a commercial product (although the research ultimately led to the development of an entirely new industry). Importantly for technology transfer practitioners, the success of the Manhattan Project demonstrated that scientific research could address interdisciplinary problems and could be executed through the collaboration of government, industry, and the university.

The model of collaborative partnership exemplified by the success of the Manhattan Project influenced how government and industry viewed university access after World War II ended: Government required access to researchers who could develop new knowledge to address the challenges posed by Sputnik and to ensure defense needs, while industry desired practitioners with a sufficient grounding in theory to translate the new knowledge into applications and systems. Moreover, "with the advent the Kennedy Administration in 1960, constantly advancing technology was explicitly identified as the cornerstone of future national prosperity as well as of national security" (Ref. 5, p. 1111), thus adding commercialization to industry's rationale for fostering technology transfer.

Corporate Access to Scientists and Engineers. Government programs, including the G.I. Bill, sought to increase the numbers of engineers and research scientists prepared for either industry or academia. Because industry ultimately had to produce the defense machinery resulting from university government collaboration for Cold War defense purposes, the private sector provided grants-in-aid to universities to ensure access to the university's graduates. Confirming the private sector's use of this strategy, in 1988 Powers and colleagues learned from their study of why corporations collaborate with universities that three-quarters of the companies surveyed cited labor force access as the main reason for collaboration, leading Williams (11), to observe, "The best prospects of efficient technology transfer occur when business enterprises are able to employ large numbers of high quality graduates" (Ref. 11, p. 864).

Indeed, the government's effort to increase the numbers of engineers prepared for university research produced a significant increase in the number of engineers who entered the private sector with theoretical, rather than with applied, training. Still, according to Goldman (5) by 1985, "One-third of all United States scientists and engineers were directly employed either by federal agencies with a military mission, or by primary defense contractors" (Ref. 5, p. 113), suggesting that a large part of the nation's intellectual capital in technology fields remained in government hands, either directly or indirectly.

Shift to Applied Research. During the decade of the 1970s, the Vietnam War, Watergate, the energy crisis and stagflation, and the leveling off of student enrollments in higher education "resulted in fluctuations in federal funding of academic research" (Ref. 8, p. 1453). By the late 1970s, governments in Great Britain and the United States increasingly questioned government funding of basic research and pressured universities to increase their applied research. In part, the new emphasis on applied research reflected government frustration with economic stagflation. In part, it reflected declining tax revenues and the perception that universities should contribute to their financial support. Regarding this second point, governments had noticed the successful spinoff of the multi-disciplinary government research laboratories into start-up companies (for example, at M.I.T. and at Stanford University) and viewed these successes as part of the solution to funding the universities (10).

At the same time, the private sector significantly increased its university grants and contracts (12). According to Williams (10), there were three reasons for the increase in corporate spending on university-based research. First, discoveries in some scientific fields, notably in the biological sciences and information technology, held broad promise for commercialization, and corporations risked competitive decline if opportunity were missed. Second, the deepened knowledge base within corporate laboratories made it possible for industry to more quickly identify those discoveries that, with further corporate R&D, would lead to viable products. And third, as government funding declined, university researchers had “a stronger incentive than hitherto to seek research grants and contracts from the business sector” (Ref. 10, p. 857).

For their part, university scientists, engineers, and administrators were keenly aware of “the speed with which some of the discoveries from research in electronics, semiconductors, and materials were followed by process or product innovations and improvements” and were likewise aware of “offers of lucrative employment for the key research workers in this field [i.e., genetic engineering], and the ready supply of capital for new companies established with the objective of exploiting the inventions” (Ref. 10, p. 858).

Bayh-Dole Act of 1980. It is in this climate of increased interest in the fruits of strategic research by university researchers, of rising competitive pressures within the business sector, and of renewed efforts by government to reduce costs and stimulate economic development that Congress passed the Bayh-Dole Act in 1980.

Because the primary mandate of the land grant institutions was to teach, conduct research, and disseminate new knowledge, faculty career advancement promoted publication while ignoring—and in some cases, discouraging—patenting. Without a recurring revenue stream from patent royalties, universities had little incentive to pursue applications research prior to Bayh-Dole (13). For example, neither penicillin nor synthetic estrogen stilbestrol, despite their obvious commercial value, were patented by their discoverers. Thus, for many years universities did not transfer their research results to those companies in the private sector with the capacity to produce new products and services for consumers.

However, the disinterest in patenting within the university culture was not entirely an outgrowth of university credentialing protocols. Earlier, we noted Williams' (10) observation about the significant increase in new knowledge with practical application that universities created after the Second World War ended, an observation conditioned by how technology transfer is defined. Williams added a second possible definition:

> If technology transfer is defined as the practical art of production, institutions of higher education do not have much technology to transfer. The transition from discovery of knowledge to product and process innovations is frequently costly and financially risky, and at least the later stages of design and development are best conducted in organizations that will undertake the production and marketing (Ref. 10, p. 853).

Bayh-Dole addressed this second definition— production and commercialization— and in so doing recognized the essential role of business and industry as the second pillar of research. In its Preamble, Bayh-Dole explicitly linked university, government, and industry through the nexus of patenting:

> It is the policy and objective of the Congress to use the patent system to promote the utilization of inventions arising from federally supported research or development; ...to promote collaboration between commercial concerns and nonprofit organizations, including universities; ...to promote the commercialization and public availability of inventions made in United States by ...industry and labor.... (14)

In granting universities the first right to elect to and to license inventions resulting from federally sponsored research (15), Bayh-Dole likewise opened routes to the intellectual property that had accumulated as a result of federal funding of high expenditure R&D projects in domains deemed by the government to be critically important to the economic hegemony of the United States: aerospace, atomic energy, pharmaceuticals, and electronics (10). It is not difficult to imagine the economic value of these newly opened routes, especially for smaller firms. Less obvious, but perhaps of greater import, is the potential for synergistic leveraging brought about by the Bayh-Dole Act. According to Williams (10), by the mid-1980s, the allocation of business R&D spending among research sectors was 5% for basic research, 20% for applied research, and 75% for development; while the distribution in higher education was virtually reversed at 65%, 30%, and 5%, respectively (Ref. 10, p. 856).

1.3. The Third Pillar of Research: Government. As we have demonstrated thus far in our review of the emergence of the university and the emergence of the business sector as partners in technology transfer, it is impossible to disentangle the influence of the third pillar of research— government— from the evolution of the other two pillars. Having integrated much of the government's role in technology transfer into the preceding discussion, we can now briefly retrace our steps.

We have related how government acted as a facilitator through its use of the bully pulpit, through its policy initiatives, and through its mandate to legislate. Specifically, government action promoted technology transfer through legislation that included the Morrill Acts, the Hatch Act, the Smith-Lever Act, and the Bayh-Dole Act of 1980. Government participated in defining the models for the development of intellectual capital through the G.I. Bill and through its influence on the engineering curriculum, as well as through the policy instruments of various government departments and federal agencies. And government demonstrated the feasibility of engaging universities and businesses in multidisciplinary research partnerships to address national defense and to promote economic development.

Indeed, using the twin levers of legislation and funding, government soon became the invisible gorilla in basic research and technology development: By 1968, "federal government agencies awarded more than 70% of all university research and development grants," and "between 1958 and 1968 academic research and development expenditures more than tripled from less than $2 billion to more than $7 billion in 1988 constant dollars (Ref. 8, p. 1455). Likewise, the distribution of government dollars reflected the huge capacity of the federal sector to employ its public policy initiatives as catalysts in shaping a national research agenda. For example, according to National Science Foundation data, "The life sciences, especially medicine, the physical sciences, and engineering have consumed roughly 80% of the funds [distributed to universities] for many years [i.e., 1980-1988]" (Ref. 8, p. 1457).

Stevenson-Wydler Act of 1980. Still, although the Bayh-Dole Act of 1980 and the cross-sector research centers facilitated new links between universities and industry, they did not address research conducted within government entities. As Cold War perspectives receded, Congress facilitated those links through passage of additional enabling legislation. For example, the Stevenson-Wydler Act, also passed in 1980, authorized federal laboratories to actively seek cooperative research with state and local governments, academic institutions, and private industry and to disseminate information through a new Center for Utilization of Federal Technology. Under Stevenson-Wydler, Congress established an Office of Research and Technology Applications at each federal laboratory and mandated that each laboratory's budget include "sufficient funding to support technology transfer activities" (Stevenson-Wydler, as amended).

Trademark Certification Act of 1984. In 1984, Congress revisited the role of the federal laboratories in technology transfer. Under Bayh-Dole, 1980, universities and small businesses could elect title to the intellectual property they developed through research funded with federal dollars. However, Bayh-Dole did not extend the same right to elect title to managers and operating contractors of federal laboratories. Congress passed the Trademark Clarification Act to close this gap, providing licensing, patenting, and royalty rights to contractors; enabling laboratories to make decisions regarding licensing (including retention); and enabling private companies of any size to obtain exclusive licensing.

Technology Transfer Acts of 1986, 1987, and 1989. The Technology Transfer Acts of 1986 (16), 1987, and 1989 (17) completed the legislative series. The 1986 Act held scientists and engineers specifically responsible for ensuring the transfer of technology out of the government laboratory; set a minimum 15% royalty floor for inventors working in government owned and operated laboratories; and allowed federal employees, both current and former, to participate in commercial development (barring conflicts of interest). According to the NIMH Technology Transfer Office (Bethesda, MD), under the Act of 1987, Congress provided assurances that federal laboratories could enter into "cooperative research and development agreements with other federal laboratories, state and local governments, universities, and the private sector." Together, these acts brought the United States National Laboratories (USNL) into the technology transfer equation (and altered the USNL's mission) by creating structures for government participation similar to those created through passage of Bayh-Dole for the private sector.

One caveat. Although this article incorporates, from time to time and as appropriate, information about the U.S. National Laboratories and other federal research agencies, for a number of reasons, any critical review of technology transfer as an emergent field will necessarily focus on industry–university partnerships as the primary theater for such transactions (see Endnote 2).

Although the focus here is not on the government sector, it can be noted that collaborative research agreements negotiated with national laboratories and federal agencies follow the same general patterns with regard to matchmaking, negotiations, and execution of the research agreement. Therefore, while we acknowledge the importance of the government's research institutions, and while we recognize that as practical matter much of this review is applicable to the government laboratories, our primary focus is the university–industry relationship.

1.4. Bringing the Pillars Together. Today, technology transfer can take place among all three pillars of research—universities, government laboratories, and industries—and the prospects for technology transfer have never been greater. Universities and government laboratories now have the incentives required to participate. At the same time, increased corporate emphasis on maximizing shareholder value has led corporate America to reexamine its intellectual property assets and its internal R&D expenditures, creating additional incentives for industry–university links (13). Enabled by the Bayh-Dole Act, the Stevenson-Wydler Act, the Trademark Clarification Act, and the Technology Transfer Acts, universities, government, and industry can now routinely engage in the kinds of collaborative initiatives that have proven so powerful in times of war or national crisis (see ENDNOTE 3).

Notwithstanding the increased incentives and efficiencies that this evolution brings, some barriers remain. The greatest barrier is often the attitude of "going it alone." Those who embrace the "going it alone" attitude make the claim that partnering does not help the project or its management and that partnering is expensive, cumbersome, and time consuming. The challenge for the technology transfer manager is to refute these misperceptions by demonstrating with success stories and best practices that collaboration and technology transfer can indeed improve the effectiveness of the internal R&D organization (19). As Roussel, Saad, and Erickson (20) have observed in *Third Generation R&D*, many companies never reach third generation R&D status—that is, they never achieve the ability to leverage internal R&D with external resources (Ref. 20, Chapter 3).

Technology transfer can occur through licensing, gifting, or collaboration. It was envisioned to integrate with, and thus to extend, the research and development process. Typically, a corporate technology transfer organization will acquire technology from an external R&D source, will facilitate collaborative research agreements for joint development of new technology, and will out-license technology developed through internal R&D. In some models, a technology transfer organization oversees all three of these efforts; in other models, the work is split among separate organizations. The range of activities and goals under the technology transfer umbrella can include college recruiting; promoting new businesses, economic growth, and employment within the community; integrating research with educational objectives; increasing the domains for collaborative research; and introducing intellectual asset management and knowledge intensity (see Endnote 4).

Research collaborations offer many benefits for university, government, and company partners. Working with government, outside experts can significantly improve the quality and comprehensiveness of the research at hand, while also reducing its costs and development time. In addition, as we noted in discussing the lessons learned from the Manhattan Project, many of the scientific advances of the previous decade occurred at the interface between traditional fields, and this trend is expected to continue and strengthen as knowledge increasingly converges. As also previously observed in discussing the evolution of the industrial pillar of research, industry-sponsored research enables universities to secure additional financial resources for educational and research missions (although corporate funding of university research and licensing of university technologies cannot replace federal funding for research). An added benefit of university–industry partnering is that university research is informed by real world situations, a benefit of especial value to engineering schools.

Thus, the impact of 20 years of technology transfer following Bayh-Dole has been significant both in changing how universities and industry work together and in enlarging how research is developed and distributed. While contemporary technology transfer efforts at many universities (including at the Massachusetts Institute of Technology, the University of Wisconsin, and Stanford University) were in place well before 1980, passage of the Bayh-Dole Act expanded the nascent effort underway, extending it to include many more universities, and bringing attractive new dimensions to the dominant model for corporate support of university research. From the business perspective, prior to Bayh-Dole the model embraced by the overwhelming majority of companies with basic research interests resembled more of a gentlemen's agreement than a business development model: The corporate partner brought money to the table in exchange for access to the university to recruit new graduates and to hire key faculty as consultants. Although this model served both parties quite well for more than 80 years, given the knowledge intensity required in the global business environment today, a new model is required. As shown in Figure 1, in addition to financial assets, industry now provides equipment, access to successful researchers and corporate facilities, and access to corporate intellectual property through licensing, equity stakes, or gifts. In return, universities continue to credential graduates and to offer access to their faculty as consultants and practitioners (see Endnote 5).

But new approaches to the licensing, sale, and co-development of basic science (and services to facilitate research projects) are changing the role of industry R&D directors and chief technology officers. University presidents, state governors, and congressional members have not failed to grasp the implications of these new research partnerships. The transformation of basic science into technology applications with commercial value creates jobs and sustains economic growth. The focus on commercialization generates discussion and expressions of concern within universities about the university's perceived propensity to "sell out to industry" (although at most universities, a balanced technology transfer strategy is much valued by university researchers). In fact, to recruit top faculty, many universities have found it necessary to showcase the success of their technology transfer initiatives, including their support for faculty involvement in start-up companies. Finally, in a global economy, technology transfer is likewise a global enterprise, with world scale corporations seeking expertise through university partners in other nations. It is not unusual to find that such international partnerships open doors to government officials, to funding, and often to new business opportunities. In today's competitive and fluid environment, no one nation, university, or corporation is exclusively positioned to capitalize on a technology.

2. Using Technology Transfer to Invent, Develop, and Extract Value

Over the last 50 years, modern society transitioned from the manufacturing economy of the post-industrial Revolution to a new economy that is information and knowledge based. This transition has dramatically increased the value of basic knowledge and innovative technology and has led to the need for more organized systems and approaches for determining the value of technology. Indeed, because technology development incurs substantial costs, it is important that business and university partners capitalize on their technology through effective methods of intellectual asset management, valuation of intellectual property portfolios, and technology transfer (13).

To manage the technology transfer process effectively, several key elements must be in place: an organization with the requisite competencies; a framework for identifying and evaluating value creation and extraction opportunities; disciplined procedures for analysis and negotiations; effective external interface management; and a portfolio of high value intellectual property. Underlying these processes is an important skill set that includes possession of traditional technology transfer capabilities (including the capability to identify and acquire external technologies of value to the company), collaborative and partnering skills, and skills surrounding outplacement strategies through sales, licensure, or donations (the latter for potential tax and other benefits).

2.1. Organizational Competency. The first order of business is to ensure that professionals are specially trained to sift through existing patents—and the technology knowledge base underlying those patents—to identify those with promising properties and to ensure that each beneficial patent is used. The process by which a technology transfer professional reviews hundreds of available patents to find those that are most promising is referred to as *tech mining*. Tech mining benefits industry by promoting efficient use of intellectual property portfolios and by assuring that the high costs involved in the research and development of new technology are not wasted. In most organizations, only a third (or less) of the patent portfolio (including the related knowledge base) is ultimately used. Untapped, the other two-thirds represents potential opportunities that are unrealized and, as such, are sunk costs. It is critically important, therefore, that each patent be managed successfully and with an eye to its full potential. Likewise, universities interested in technology transfer need to view their patents and licensing activities opportunistically. Gruetzmacher, Khoury, and Willey (21) point out that revenue captured from university licensing reduces the expenses associated with patenting and contributes resources that support the university's primary missions of teaching and research, and the authors suggest that it is "irresponsible" for the university to ignore these revenue opportunities (Ref. 21, p. 122).

Through proper training, individuals can become innovative technology miners, unlocking the benefits of technology transfer. To do so, the individual must understand the overall concept of intellectual asset management. A company's intellectual assets are comprised of its accumulated knowledge, information, intellectual property, and experience—with the synthesis of the whole exceeding the sum of the parts. While the key component of an intellectual asset's value is the intellectual property itself (the patents and copyrights), it is important to recognize that there are other components that may be utilized as a venue to extract the full value of the technology. For example, the experience of the researcher behind the invention is a valuable component of any patent. In today's knowledge intensive society, any invention worthy of the time and cost to be patented deserves a second look by its inventor(s), and their supervisors and managers. The ability to bring inventors together with new team members who might envision different applications or prospective markets increases the capacity of the technology transfer team, adding the power of leverage to the toolbox of an effective technology transfer organization.

2.2. Framework for Development and Extraction of Value. When the business of technology transfer is well managed and nurtured, those involved in the development and commercialization of the technology benefit. Therefore, the second order of business is to maximize technology transfer opportunities. At DuPont, managers have developed and implemented a general framework to conduct this analysis (see Fig. 2). The framework is divided into two distinct parts: *value creation* and *value extraction*. Value extraction can take many forms: internal utilization to support manufacturing and product development; creation of an equity position in a 100% owned or shared ownership arrangement; or generation of a revenue stream from selling, licensing, or donating the technology to a nonprofit organization.

As the framework indicates, there are many ways to extract value from technology. The most common model—that of inventing a new product or process—describes what is still the prime objective of industrial R&D. But quite frequently, the research is aborted or otherwise delayed for strategic business reasons, effectively terminating the project before it has developed to commercialization. Moreover, as Gruetzmacher and his colleagues (21) observed, "The R&D landscape is changing rapidly. Companies are under significant pressure to improve the success rate of commercialization and to reduce the cycle time from idea generation to product commercialization" (Ref. 21, p. 119). Thus, as Figure 2 indicates, in addition to the owners' use of the technology patent, the owner(s) can choose to realize value by creating a spin-off of the patent with 100% equity; by forming a joint venture with external partners to achieve full patent utilization; by selling or licensing the technology; by trading the patent for an equity position; by cross-licensing, gifting, or donating the patent to a research university; by publishing the patent; or simply by placing the patent in the public domain.

2.3. Disciplined Procedures for Analysis and Negotiations. The ultimate value of a technology depends on what the licensee is willing to pay for it and what the licensor is willing to accept for the license. Several models exist for determining the value of a technology, and the model that works best depends on the specific technology and its markets. Often the goal of the licensor is to determine the fair market value of the research by quantifying the R&D costs that would be incurred to replace the technology or by simply tallying the sunk costs associated with the technology. Analysis of these costs (and their related terms) is informed by assessing the property's potential technological and competitive market position. This assessment includes consideration of the features, advantages and benefits, and degree to which the technology is either evolutionary or revolutionary. However, while Gruetzmacher and his colleagues (21) agree that using this approach is common and sometimes appropriate, the authors suggest: "In most cases, the value of a patent [or] technology, in terms of the future economic benefit it generates, bears no resemblance to the cost expensed to produce the asset" (Ref. 21, p. 116).

Rather, the pricing model developed by Gruetzmacher and his co-authors (21) is based on the expected economic benefit of the patent or technology. In this model, from the corporate perspective "the value of a license is proportional to the cash flow it generates, whether as a result of an incremental increase in sales or a reduction in costs or both" (Ref. 21, p. 116). The authors note that the university may take a "broader view" of valuation, looking beyond profitability measures alone to include any benefits to society, whether or not measurable in dollars.

The differences in perspective between the university and the corporation result from two factors relevant to the valuation process. The first factor arises from the differences in missions that inform the objectives of the corporate, for-profit perspective versus the university, non-profit perspective, and we discuss these differences and perspectives later in this article. The second factor stems from the need to distinguish between *value* and *price*, a distinction that traces back to Adam Smith's Diamonds and Water Paradox in the *Wealth of Nations*. Because this distinction continues to confound non-economists, it is useful to revisit it. In his analysis of economic behavior, Smith (22) observed that while life depends on ongoing access to water, water was for all practical purposes free, while diamonds, which had no life-sustaining importance, were expensive. It took economists several decades to sort out this question by recognizing that utility and rarity are factors in determining value, while price is a derivative of a market transaction that reflects the level at which a willing buyer and a willing seller have agreed to exchange one asset (currency) for another asset (a good or a service). The application of this lesson for technology transfer practitioners, whether from the corporate or the university perspective is the knowledge that

> A patent provides its owner with the right to exclude others from practicing the patented invention for a specified period of time. While that may block (legally) an unauthorized use, *that in itself has no value unless* (*1*) the patent owner or legitimate licensee has the wherewithal to reduce the invention to commercialization and/or (*2*) the patent(s) can be used defensively to control or starve off competition. [italics added] (Ref. 21, p. 116).

Thus, while *value* and *price* are often used interchangeably, technology transfer practitioners seeking to "extract value from the technology portfolio" are really looking to set a price for use.

Arnold (23) identified at least 100 factors that affect price, with different factors coming into play in different situations. Gruetzmacher and his co-authors distilled the list to encompass six general categories of factors for consideration by practitioners seeking to devise a disciplined procedure for analysis and negotiation: technology, markets served, complementary assets, legal position, license terms, and risk. (We make brief reference to each of the six categories below and refer the reader to the text for a full description of each of these factors.)

According to Gruetzmacher and his colleagues (21), developing a model for determining a technology's price requires an understanding of (a) the industry sector, (b) the economic lifetime of the technology, and (c) where the technology is in its timeline to commercialization. The authors note that proven technology at or near commercialization can garner a higher price (because development risk has been reduced) than can earlier-stage technology where technical and developmental hurdles may remain. However, a guiding principle in assessing any technology, whether innovative or incremental, is the anticipated economic benefit of the technology. The authors suggest that without an anticipated profit enhancement, "There are few, if any, reasons why a company would enter into a license. . ." (Ref. 21, p. 118).

A second element to include in a pricing model involves a market analysis. Technology transfer practitioners will need to identify the market to be served (i.e., new or existing) and project the market's size; will need to define the technology as high, low, or even no tech; will need to identify and assess competing products and their promoters; and will need to adjust expectations to reflect differences in anticipated royalty rates across industry sectors. Gruetzmacher and his colleagues caution that

> Industry norms suffer the 'chicken and egg' syndrome in that it is difficult to discern if a particular royalty range for a specific sector is a result of the market forces within that sector or rather the tendency to base fees, royalty rates, and price structure on historical comparable transactions within that sector (Ref. 21, p. 118) (see Endnote 6).

Complementary assets are "the unique capabilities belonging to the enterprise, tangible or intangible, that bridge the link between innovation and commercial success" (Ref. 21, p. 118). Complementary assets include development, manufacturing, and marketing capabilities; access to capital; name recognition and reputation; access to other intellectual property rights; and external relationships. While a licensor's hand in pricing is strengthened by virtue of holding the legal rights to the patent, the licensee's position is likewise strengthened through ownership of the complementary assets that are essential for commercialization (Ref. 21, p. 118).

The strength of the patent's legal position ". . .can have a significant impact on the price of a license" (Ref. 21, p. 119) and such strength should be identified in the valuation assessment process. Determinants here include the number (both domestic and foreign) of patents licensed; the nature of the patent (e.g., whether it dominates a key process or design across an industry sector); litigation history (i.e., whether challenged and upheld as valid); and penetrability (e.g., whether competitors can work around the patent, whether held in a portfolio of patents which together create barriers to entry).

Licensing terms (discussed more fully in a subsequnt section,) can encompass literally scores of factors, and each factor or combination of factors will differently affect price determination. For example, exclusive versus non-exclusive use will engender different price expectations, as will obligating a licensee to abate any infringement that occurs during the term of license.

Finally, risk assessment is probably the analysis that is at once the most difficult and yet the most critical when pricing intellectual property. For the corporate partner who brings complementary assets, including capital, to the negotiating table, assessing the risk of failure is critically important. Failure can result from many factors, ranging from external events in the global marketplace to political risk at home arising from federal and state shifts in priorities. Risk analysis cannot be limited to the usual analysis of business, industry, market, and consumer factors alone if a pricing model is to be meaningful. Moreover, most corporations include in their risk analysis a yardstick for achieving minimum revenue thresholds—and for the most part, these revenue thresholds for commercialization set the bar high. According to Gruetzmacher, Khoury, and Willey (21), "Large companies typically establish thresholds in excess of $200 million, while medium size companies have thresholds that are in excess of $20 million" (Ref. 21, p. 121).

Once the factors that are relevant to valuing an intangible property portfolio have been identified, the challenge becomes to convert those factors to quantitative terms. Because there are so many variables involved in valuation, practitioners do not yet have a quantitative construct in place for making pricing decisions. However, some academics are attempting to develop theoretical frameworks for valuation models that extend beyond the customary discounted cash flow analysis. One new approach for tackling this quantitative analysis is based on the Black-Scholes formula for valuing stock options. Readers seeking a quantitative tool for valuing intangible assets may want to explore this literature.

2.4. External Interface Management. External interface management is likewise essential when dealing with technology transfer. Membership in such leading associations as the Licensing Executive Society (LES), the Commercial Development and Marketing Association (CDMA), the Association of University Technology Managers (AUTM), the Council for Chemical Research (CCR), and the Industrial Research Institute (IRI) is recommended. Active involvement in these and similar organizations establishes companies and universities as leaders in the field of technology transfer, builds individual skills, and creates invaluable networks with other technology transfer professionals, academics, and consultants.

3. Barriers to Collaboration Among the Research Pillars

With vastly different cultures and missions, corporations, universities, and government entities often encounter barriers in their efforts to collaborate. For corporations, the tasks are economic in nature: customers must be served successfully enough to produce profits and build shareholder wealth. Alternatively, for universities the tasks are scholarly in nature: to develop new knowledge and to disseminate it, including through the education of future generations. For government, the tasks are political and sociological: to promote a well-ordered society through mechanisms that safeguard and defend the nation, its citizens, its institutions, and its interests and that ensure the integrity of the Constitution. The differences among institutional missions can create a challenging environment for nurturing and cementing partnerships. In this section, we describe barriers associated with two of the three pillars of research—the university and the corporation—and we discuss those barriers through two lenses: conflicts of interest and N.I.H. (i.e., Not Invented Here).

It should be noted, however, that while we use the term "barriers" in the heading for this section, we do so because "barriers" is the descriptor commonly employed by stakeholders in discussing institutional differences, and not because we believe that those differences are insurmountable. For example, we believe that the barriers associated with the N.I.H. perspective are in fact smokescreens. We also believe that overcoming differences begins with an understanding of the historical context, and for this reason, we have already traced the emergence and evolution of the three pillars of research (See sections 1.0–1.4).

While the perception of barriers remains, at the same time, some institutional barriers have become increasingly porous and some institutional specializations have begun to overlap in response to modern complexities. This is not a new development. Six established universities radically changed their missions during the period 1860 to World War I. While the new models created by each of these universities were distinctly American, importantly, each university reorganized with its own unique mission and (competitive) priorties. Likewise, the Manhattan Project, and later the National Aeronautics & Space Administration (NASA), relied on re-configured institutional interrelationships and these relationships evolved as purposes changed: For example, while the government took oversight responsibility for the Manhattan Project, the private sector took on oversight of NASA's performance. The point is that while institutions have traditional roles and missions based on shared beliefs, these roles and missions are not static, and they are not unilateral within an institution. Rather, they are emergent and responsive, working to create new relationships to deal with new needs. Among those new relationships are those at the intersection of public and private interests in what Drucker (Ref. 24, p. 358) called the "mixed economy;" those resulting from the effects of globalization on the nation state and the national economy; and those resulting from the extraordinary capital and human energy required to manage the business of innovation, whether in the university, government, or corporate laboratory.

Institutions do not always enjoy the luxury of enlightened leadership (as was the case with the universities noted above) or government policy shifts (as was the case with the Bayh-Dole Act and the Technology Transfer Acts). Although such abrupt influences on missions occur, often they raise more questions than they answer. From the university perspective, the important questions are those about relationships, and we discuss those questions under the moniker *conflicts of interests*.

Conflicts of interest are not legal constructs (although they can alert practitioners to legal issues); they are social constructs. They reflect the values of institutional stakeholders. Some of these values are so fundamental that they have changed very little over time: businesses seek profits; universities seek knowledge; governments seek to preserve and protect. Other values continue to emerge, while being shaped by the underlying principles on which the institution rests.

Often, the processes for dealing with barriers raised by conflicts of interest will involve articulating the objectives of each institutional partner, as well as the objectives of the partnership as a venture separate from either parent. The guiding question is "What is right?" It is not, "Who is right?" Acknowledging conflicts of interest, their historical roots, and their practical implications is the first step for technology transfer practitioners seeking to develop cross-institutional partnerships.

From the corporate perspective, N.I.H. can be, and has been, a barrier inhibiting corporate participation in cross-institutional research, despite legislation promoting technology transfer. In a free society, government cannot (except in time of war) use its power to force one institution to take up the tasks of another, "even though they are sanctioned and even encouraged by governmental policy" (Ref. 24, p. 350). Each institution can choose to narrowly define the relationships that promote its self-interest. Barriers arise when the N.I.H. perspective becomes an excuse that is used to avoid cross-institutional research, often under the mantle of protestations about who will control the patent and how other details of the collaboration will work in practice. Thus, the practitioner will want to be aware of how the corporation views its interests and what can be done to overcome the N.I.H. barrier.

3.1. The University Perspective. From the university's perspective, there are four factors that can inhibit university–industry research collaborations. *Implicit in each of these factors is some form of perceived, potential, or actual conflict of interest*. The four factors are (a) the conflicts related to the practical difficulties of negotiating and managing a collaboration; (b) the conflicts related to fear of deleterious effects on faculty and students; (c) the conflicts related to the perceived impact on the mission, reputation, and financial resources of the university; and (d) the conflicts related to expectations held by state or local officials about the university's contribution to regional economic development. We highlight each of these factors in a general sense below and discuss them further in relation to specific issues in later sections of this report.

In weighing these factors against potential benefits, the Association of University Technology Managers (25) cautioned decision makers about the importance of maintaining appropriate balance when considering collaborations: "Few campuses benefit from patents for 'blockbuster' products. Of the reported 20,968 active licenses in fiscal year 2000, only 125 (0.6%) generated more than $1,000,000 in royalty income" (Ref. 25, p. *i*).

Practical Difficulties Negotiating and Managing Collaboration. Practical difficulties associated with negotiating and managing university–industry collaborations often stem from issues related to what are now widely recognized conflicts of interest, both real and perceived.

Most of the current conflict of interest policies in United States universities follow patterns established by federal regulations (although university adoptions of federal protocols vary significantly in the depth of the disclosures they require and in their thresholds for examining personal conflicts). At the same time, there are different strategies that can be employed for managing various types of conflicts, depending on the details of each individual case. These strategies include procedures for independent review and transparent disclosure of significant financial support in published reports. More radical interventions might include divesting questionable assets, terminating consulting arrangements, or withdrawing the researcher from the project. A useful strategy for preventing potential conflicts of interest involves continuous education for both faculty members and graduate students who aspire to become practicing scientists.

Effects on Faculty and Students. The economic value of new knowledge has significantly increased the specter of potential conflicts of interest on the part of university researchers. As a result, virtually all research universities now have policies in place to monitor and manage relationships and to prevent abuses. The purpose of these policies is to anticipate, prevent, and limit situations that might lead to the appearance of wrongful interest or conflict. It is important to note that the U.S. national innovation system requires close cooperation to succeed. Therefore, it must be recognized that while potential conflicts cannot be fully eliminated, they can be controlled and contained by an emphasis on managing ahead of the situation.

Commitment conflicts are generally defined as anything that might interfere with a faculty member's full-time duties. One example of such conflicts relates to the time spent by faculty developing, launching, and administrating start-up companies. To prevent this type of conflict, many universities have formal policies limiting the amount of time that a faculty member can spend on outside activities.

A related, and as yet unresolved, issue is that of students as inventors and generators of new knowledge. State laws are unclear (or, more often simply mute) about the ownership of intellectual property developed by students through work on research projects under grants to the university. In addition, university protocols differ widely on this issue and may or may not align closely with state laws. Some professors and their universities afford graduate students a "collegial" status, while other universities view graduate students on research grants as university employees. The push on some campuses by graduate students for union affiliation further clouds the landscape. The increased benefits and remuneration that unionization promises may be won at a price that negatively impacts students' claims to status as professionals and thus may work against students' participation as full partners in the development of new knowledge, including its patenting and licensing.

Impact on University Mission, Reputation, and Financial Resources. - Some university leaders, as well as faculty members, express the concern that university–industry collaborations threaten the mission and reputation, and thus the integrity, of the university as an autonomous social institution. Burgess (in Ref. 26, p. 843) describes the autonomous status of university as "see[ing] education, especially higher education, as an activity with its own values and purposes, affecting the rest of society obliquely and as a kind of bonus."

This concern goes to the heart of the university as an autonomous academic institution. Traditionally, the university has been viewed as a generator, conservator, and transmitter of knowledge. But recent interpretations of these roles have translated into three discretely different views on the relationship of the university to society:

> One is the idea of the university as a self-governing community or college of scholars; the second treats the university as a public service corporation provided by government; and the third sees the university as an enterprise in the knowledge industry selling whatever mix of academic services it is most profitable to produce to whomever is willing and able to buy them (Ref. 26, p. 844).

Examples of the first interpretation continue, particularly in Great Britain with Oxford University and Cambridge University, whose royal charters ensure the strongly held premise of autonomy found within their mission statements. Alternatively in the United Kingdom, the polytechnic institutes comprise traditions that fall under the second interpretation. According to Burgess (in Ref. 26, p. 843) polytechnics are “responsive, vocational, innovating, and open. Institutions in this tradition do not think it right to hold themselves apart from society: Rather that they should respond to its needs.”

The third interpretation is most often associated with universities in the United States, where “the idea of the university as an economic enterprise, selling academic services to the federal and state governments, to business and to households, is much more widespread… than in any other country” (Ref. 26, p. 844).

We cannot conclude, however, that because many U.S. universities model the third interpretation, these institutions of higher education have sold out to industry. Rather, American universities may be viewed as having responded to new realities as they have emerged. For example, while the traditional explications of research divide research into basic and applied domains, there are significant areas of research—commonly referred to as development research—that fall in between these two traditional endpoints. Such research, while concerned with applications, nevertheless actively creates new knowledge in the pursuit of those applications. It is not uncommon for development research to produce pure knowledge that finds no practical purpose for decades. Nor is it uncommon to find that the growth of multidisciplinary interfaces among the traditional disciplines within the university applies as well to the blurring of boundaries between basic and applied research. As a pragmatic matter, the development of information technology and the creation of new materials have profoundly impacted how industries design, produce, and maintain products and how they customize products for markets. Thus in some sectors, industrial practice has led the academic sector in conceptualizing and addressing complex, multidisciplinary problems (12).

Given the model prevalent in the United States, in practice, therefore, universities often compete with one another to attract industry partners with significant financial and intellectual resources. However, the appropriate response to concerns about the integrity of the university’s mission and autonomy is to institute effective systems and safeguards within the university. Such systems will enable the university to guard against devolving into a contract research organization that is indebted to its sponsors and dependent on revenues from sponsored research and licensing fees.

Financial conflicts of interest arise when scientists’ private financial interests and their research converges in a way that might call into question their ability to make unbiased decisions related to their work. Perceptions of any conflict of interest can delegitimatize the research enterprise itself by weakening public trust. This is a particular concern for research universities, as they depend heavily on federal research funding.

Conflict of interest policies regarding research with living subjects, while always a concern in laboratory situations with human subjects, have garnered growing attention from the public and the press as such research is increasingly conducted by private sector ethical drug companies in partnership with universities, by biotechnology start-up companies spun out of university research efforts, or by private sector funding to the university to determine the efficacy of a new treatment. These policies differ from other conflict of interest policies and must be regarded as a special case. While substantive protocols exist to safeguard human subjects trials, the array of protections is now under re-evaluation in many universities and private sector laboratories. Conflict of interest policies are but one element of the human subjects concerns that surround clinical trials, but these policies comprise an extremely important element. Clinical trials depend on the willingness of patients to take part in the trials, which in turn depends on the patient's trust that the clinical researchers who are conducting the trial will remain at arm's length and will do no harm.

Contribution to Regional Economic Development. Institutional conflicts of interest are a recent source of concern. These conflicts relate to the role that universities can play in local economic development. In the United States, this role traces back in part to the establishment of the land grant colleges and universities and to the linkages implied or associated with their founding. Among the benefits promised by the Morrill Acts were direct benefits, primarily in agriculture and mining, to the state and the local community in exchange for public funding. As a corollary, the local economic environment provided something of a natural laboratory for applied research. Thus the local context often played "a key role in determining industrial linkages" (Ref. 12, p. 937). But as Blackman and Segal further argue:

> ...[L]ocal linkage opportunities may not always be sufficient or appropriate. Apart from the possibility that a suitable partnership may not be found locally, the stretching of horizons and perspectives provided by non-parochial partners is likely to provide greater opportunities for intellectual stimulus and wider opportunities for institutional growth (Ref. 12, p. 939).

In the modern context, some universities invest in startup entrepreneurial firms or accept equity in lieu of royalties on university-held patents, raising the concern that they might become indebted to a (local) company in which they have a financial stake. To protect universities from becoming indebted to any one entity, prudent administrators will develop a diverse portfolio of separate funding sources, including sources from outside the immediate geographic region. Likewise, they will continuously communicate with elected officials to ensure that local officials understand how university faculty select research targets and to limit inappropriate use of the university to promote regional economic growth.

Guiding Principles. Ultimately, it is important that university officials and researchers (and their corporate and governmental partners) study the multiplicity of conflict of interest issues. It is equally important for those involved to acknowledge several fundamental first principles:

- That the core values of academic freedom must be honored and protected.
- That industry funding cannot and should not be viewed as a substitute for adequate, long term public funding of basic scientific research.
- That universities and companies must act with transparency, clarity, and consistency in identifying actual and potential conflicts of interest.
- That all participants in the research process must strictly adhere to the scientific method to safeguard public and academic support for university research.

3.2. The Corporate Perspective. From the corporation's perspective, barriers include (a) engendering internal respect for the value of collaborative research; (b) integrating university research with product development; and (c) corporate policies and managerial practices. All three of these difficulties stem, at least in some part, from the oft-held position within industry known as N.I.H. (Not Invented Here). Although it might be generally perceived that corporations welcome technology transfer relationships with university partners, in reality the more common practice among business managers and industry researchers continues to be to perpetuate the N.I.H. syndrome.

According to the Industrial Research Institute (27), those corporations that do seek collaborative partnerships assess intellectual property collaborations on a "relative scale of expected benefit" (Ref. 27, p. 2) based on factors that include who (corporation or university) owns the intellectual property; who has rights to continued basic research; and whether, to whom, and with what field restrictions exclusive license is granted. Table 1, adapted from the Industrial Research Institute Position Paper (27) on intellectual property, presents an overview of five generic collaborative arrangements with respective comments on the potential viability of each arrangement to a business partner. Notice that as the costs, including risk management costs, to business increase (and control decreases), corporate partners become less interested in collaborative research arrangements.

4. Negotiating Agreements

To ensure successful negotiations, it is extremely imperative to establish mutual trust between or among partners. The negotiation process is enhanced when each partner is familiar with the other's needs and expectations and when neither partner has reason to worry about whether the playing field is level. Such familiarity is most often present when the partners have long-standing ties and a history of collegial and professional working relationships. Without high levels of trust and collegiality, negotiations are unlikely to succeed.

A second ingredient for expediting the negotiation process is to involve experienced people and to draw on their experience to orchestrate the process. For this leadership role, the ideal person is an individual who brings both university and corporate experience to the table. At the same time, effective negotiations require well prepared, skilled technology transfer professionals, the responsibility for whose training rests with each government, university, or corporate office of technology transfer.

Notwithstanding the skill and experience of the primary negotiators and the quality of past relationships among the partners, internal bureaucracies, inadequate procedures, and personnel turnover can retard and damage the negotiation process. Negotiation delays will frustrate all parties to the process. A discouraged faculty member might take his intellectual property "out the back door" by working directly with companies, thus skirting intellectual property rules (28). Alternatively, companies with cumbersome processes may exit the negotiations simply because the industrial cutting edge moved faster than the lawyers doing the negotiating (29).

4.1. Contracts

Master Contracts and Model Agreements. Technology transfer professionals generally employ two different types of negotiation agreements: *master contracts* and *model agreements*. To select the appropriate instrument, the negotiating parties need to fully understand the nature of the negotiation and the relationship between the parties involved.

A *master contract* is ideal for those partners who have collaborated in the past and have, therefore, already come to understand each other's cultural differences and organizational preferences. Having these contextual understandings avoids plowing the same ground when negotiating new agreements covering individual research projects. Master contracts are also used to formalize the relationship between strategic partnerships (arrangements under which a corporation sponsors a large number of projects at a particular institution). A master contract generally contains provisions to address intellectual property ownership, confidentiality, publication delays, and the process whereby researchers apply for and gain approval for funding of individual projects under the overall agreement. With this groundwork in place, negotiations can move ahead to focus on the scope of work, the timeline, and the project budget.

Master contracts generally work well when a large company sponsors a sizeable number of recurring projects at a single university and the research being performed adapts well to boiler-plate provisions (30). The major limitation of master contracts is that they do not always translate well among different divisions of a company. Nor do they always transfer successfully among research projects at the university (31).

Rather than providing a final contract for all arrangements, by comparison, a *model agreement* provides an initial point of departure for negotiating a specific agreement between two parties. To be effective, a model agreement should consist of basic, agreeable terms that are designed to induce quick consensus. While a model agreement should not be offered as a "take-it-or-leave-it" proposal, prospective partners need to be aware that requesting changes might lengthen the time it will take to negotiate a deal, thus potentially affecting the willingness of the university to participate in the sponsored-research effort. A model agreement can work well for a small company whose involvement with universities is limited to a single research project, often of modest value. Finally, a cautionary note: While model agreements can speed the negotiation process, they can also be difficult to develop and implement because varying business practices across different industry sectors (and sometimes even within a single company) require disparate agreements.

Compensation. Whatever form a contract takes, compensation to the university will be the result of the contract itself, the costs of bringing a product or technology to market, and the risks and rewards to business that obtain from the collaboration. The business partner will view the contract from the perspective of competitive advantage and profit generation. Therefore, when a business partner brings the idea and the financial support to the university, often the business partner will anticipate exclusive rights (or will negotiate non-exclusive rights) to use any intellectual property that results from the work.

Because research collaborations can take two general forms (i.e., contract research or sponsored research), compensation forms likewise generally parallel the contract form. Universities have participated in contracted research since the end of World War I (and extensively during and following World War II)—notably through government defense contracts. But in the 1980s and 1990s, universities expanded their contract research to include agreements with industry. The expanded interface with industry reflected new efforts by industry to investigate "pre-identified problems" and the recognition within industry that it could not itself necessarily "be excellent in every facet of technology relevant to [its] products and processes" (Ref. 12, p. 941). Moreover, competitive factors, brought into sharp focus by the developing global environment for business expansion, worked to encourage corporate reviews of in-house technology and how best to manage it. Having said that, it must also be noted that

...The main beneficiaries [of contract research] were the specialist R&D contractors and consultancies in the commercial sector, which were far better equipped than the higher education institutions to mobilize the required multidisciplinary resources, bring to bear technological rather than scientific skills, and to do so in the time-scales and within the flexibility which the commercial discipline invariably demanded (Ref. 12, p. 942).

Although a small number of universities continue to be "competitive suppliers of contract R&D" (and then, generally in niche areas within a limited number of fields), many universities have come to recognize that their comparative advantage resulted from expertise in "basic and strategic [development] research, not in contract R&D" (Ref. 12, p. 942). Universities involved in basic or development research execute cooperative or sponsored research agreements, negotiating fees based on actual costs, expected outcomes, and the nature of the research collaboration. U.S. universities can ensure adequate compensation by seeking sufficiently high fees, an approach that is common practice among European universities (27).

The Industrial Research Institute (27) has estimated that more than "3000 raw ideas are needed" to "yield one commercial success" (Ref. 27, p. 6). While this claim is probably somewhat exaggerated, nevertheless, it indicates the risk-adverse nature of many potential corporate partners. While university researchers more often participate in early stage (and often externally funded) research and rarely assume the business or legal risks of commercialization, for business partners a real-world analysis of project risks versus expected returns is required before management will commit resources to a technology development project. Such risks and costs will need to be included in compensation negotiations. Moreover, university negotiators will want to recall that while ample evidence of anecdotal success is readily available, one rarely learns of all the failed products that those successes financed (Ref. 27, p. 7).

But compensation is not always measured in dollars and cents alone. Interviews with senior industrial officials conducted by the National Academy of Sciences found that

. . .with occasional exceptions, the real benefits of such collaborative R&D are 'softer;' they arise from the process of collaboration itself, from the mutual influence on each side's perspectives and research agendas, and from the increased resources available to produce highly trained people capable of deploying their skills in new fields" (U.S. Government–University–Industry Research Roundtable, 32) reported in Blackman and Segal, (Ref. 12, p. 942).

Confidentiality. In the development of scientific knowledge, it is essential that faculty researchers be able to discuss their work with colleagues and that research results are published in a timely manner. Therefore, it is important that research collaborations in no way inhibit these freedoms. At the same time, however, companies have legitimate needs, among which are accountability to shareholders and the mandate to protect the value of corporate investments.

There are various ways to protect confidential information in a university setting. Because it is difficult for a university to be responsible for policing all faculty and students, some universities choose to have individual researchers sign confidentiality agreements. Other universities believe that it is important to obtain an institutional signature to protect the faculty's personal assets. In addition, when a university signs a confidentiality agreement, the corporate partner's access to legal remedies for breach of contract is greater than if an individual alone signs: When an institution signs an agreement, it is legally binding; but when a faculty member does so on behalf of the institution, often it is not binding. Sometimes, confidential information must be discussed before a project can be negotiated. In such situations, individual faculty members can sign exploratory confidentiality agreements, or provisions can be made in a master agreement between two strategic partners (33).

In the case of students, the challenges and consequences surrounding maintaining confidentiality are particularly acute. Universities differ in their ability and procedures for managing this process, with differences reflecting the specific needs of the university. Methods for monitoring student confidentiality range from requiring faculty disclosure about students' possession of confidential information, to reliance on standards for discretion in communication with academic and corporate researchers. Unfortunately, informal protocols are unlikely to be sufficient, and procedures are under development at many universities to improve vigilance.

Another means for protection of confidential information is through publication delays. The "standard" acceptable publication delay is 60–90 days. However, universities are beginning to come under increased pressure to extend this time. Such pressure should be resisted for a number of reasons. Timely publication is essential in meeting federal tax regulations regarding unrelated business income. In addition, it is important to respect the academic needs of faculty and graduate students (who perform the research). Publication embargos can delay release of a student's thesis, complicating a student's final examination schedule, and impacting a student's progress to program completion and credentialing. If necessary, a university can terminate a publication delay by filing for a patent. But, strict rules regarding patents for existing technological knowledge (also referred to as "prior art") can trump desires and promises about when and how to disclose research results. Thus patent regulations can impede seminar presentations, can leave the presenter with only edited content to present, and can be construed as an infringement on academic freedom.

The advent of the Internet and the widespread use of email may begin to significantly alter the terms and conditions for publication. Due to its speed and outreach potential, the Internet may well create a need for revisions in copyright law, and may provoke new schedules for publication and additional regulations for protection of confidential information.

Facilities and Administrative Costs. Facilities and administrative costs (F&A), also referred to as indirect costs, are the costs to the university that exceed those for researcher's salaries and new materials. F&A costs can include, but are not limited to: operation, maintenance, and use of university facilities (including allocation of space among projects); compliance with health and safety practices; disposal of hazardous wastes; provision for campus security; records-keeping and accounting for sponsored research funds; financing of debt incurred to construct new university research facilities (but not to contribute to reserve funds to build new facilities); and other mundane, but essential expenses, including expenses like heating and cooling, library access, and salaries for departmental and central office staff (34).

Periodically, the university and the federal government negotiate the F&A rate. The effective rate reflects costs that have been documented through audits by both independent and government accountants. The rate varies according to the needs of each individual university. However, it generally averages about 50% of direct costs.

4.2. Intellectual Property. Ascertaining the ownership, value, and use of new intellectual property is difficult and must undergo a rigorous process of purposeful negotiation to determine stipulations for each component of the agreement. Traditionally, the opening position for both sides during negotiations rests on the premise that each party will either own or have access to the property under negotiation. However, when a specific project includes both federal funding and industry ownership, the Bayh-Dole Act requires that the university (rather than the corporation) retain ownership of any resulting patents (35). Where the federal government is not in the mix, companies often seek ownership of resulting patents to enable manufacture, use, and sales of products that result from the research. The universities, for their part, will likewise seek ownership to allow continued access to the property by faculty and graduating students, to meet joint sponsorship obligations, to enable commercialization, to meet federal tax regulations, and to license the technology on a nonexclusive basis.

The treatment of intellectual property ownership and patents differs by industry sector. In the information technology sector, short product lifecycles make time-to-market issues more important than patent protection. By contrast, capital intensive, process-intensive industries like chemicals and pharmaceuticals, carry high risk of development failure, and therefore often require patent protection prior to investing in expensive research tools and practices.

Peregrim, Guschl, and Rappaport (13) warn that "One of the most overlooked aspects of intellectual property management is the aggressive enforcement of patents," and the authors suggest that patent enforcement "goes beyond the returns on any individual situation" (Ref. 13, p. 45). They recommend strong enforcement, especially during the early stages of a licensing effort to ensure that all parties understand that patents will be enforced "on principle" (Ref. 13, p. 45). The authors make a salient point. Given the time and expense incurred to establish ownership through the patent process, it is critically important that patent holders—whether university or corporate—enforce not only their particular rights, but also recognize that in so doing, they are safeguarding the legal principle that underlies those rights (a principle from which all researchers and economic participants benefit).

4.3. Background Rights and Copyrights. Background rights are the licensing rights provided by a university to an industry partner for intellectual property developed by the university while using funds from other partners, including government partners. Companies seek the background rights to such property to ensure complete licensing rights in the event that the results of the sponsored research are commercialized (Ref. 19, p. 14).

Providing background rights is a difficult task, because many faculty members believe that the intellectual property of one faculty member should not be mortgaged to benefit another member. Faculty likewise question whether university receipt of sponsored-research funding is sufficient reason to permit the provision of background intellectual property rights (Ref. 19, p. 14).

Agreements on background rights generally include the stipulation that the university put forth a reasonable effort to identify potential conflicts. But corporate partners also participate in this process by conducting a "freedom to practice assessment" (Ref. 19, p. 14). Because the language used in such agreements is frequently subject to alternative legal interpretations, it is rare to find a university that will sign a binding agreement on background rights. However, best practices suggest that universities "discuss any patent rights that such a search by the company uncovers—provided these rights are unlicensed at the time" (36).

When educational materials are involved in collaborations, the copyrights are the predominant intellectual property ownership mechanism. Problems often surface over the question of who owns the copyright to the property and who, in turn, can use it. In negotiations between universities and companies, an ongoing frustration occurs when an individual professor owns the copyright to a property, and the university cannot promise the company full use of the copyright. In response to this problem, some universities are beginning to re-evaluate and revise their copyright policies to allow industry sponsors to receive licensing terms on a basis similar to that provided by patents.

4.4. Licensing. A license is a legal agreement or contract between two or more parties to transmit intellectual property rights such as patents, copyrights, trademarks, or general know-how from the licensor (original property holder) to the licensee (property recipient). There are benefits to both licensing in and licensing out. To determine which action to take, it is essential to conduct several analyses: (a) an assessment of competing products; (b) an assessment of alternative approaches; (c) an assessment of the real and perceived features, advantages, and benefits of the property; (d) projections of market potential; and (e) determinations of the product life. In the course of this analysis (which is essentially a marketing plan), Peregrim, Guschl, and Rappaport (13) suggest that a number of related questions will need to be addressed:

- To whom or from whom should we license? Where? Under what terms and conditions?
- What are the exclusions? Will sublicensing be permitted? What is the duration?
- Who are the competitors? What are their markets, industries, applications, and geographies?
- What know-how, trade secrets, equity, or cross licensing should be included?
- Will innovations be shared?

The authors also recommend close attention to certain pragmatic issues prior to making licensing decisions:

- What is the licensing objective?
- What is the motivation (e.g., to increase cash flow, advance strategic position, or strengthen reputation or alliances)?
- What is the scope of the effort?
- Who will staff the effort? Who will sponsor and champion the effort?
- Who will resist the effort?

In addition, a potential licensee needs to consider the ultimate question of whether the property is evolutionary, revolutionary, or unique.

Licensing agreements can comprise a variety of components, depending on the needs of the parties involved. The key components to consider are diligence, financial terms, exclusivity and nonexclusivity, and provisions for termination. Diligence provisions specify the obligations of the licensee to conduct the research with dispatch and in accordance with accepted practice. In addition, due diligence provisions set forth the expectations and understanding of all parties as to the time frame for development and the milestones to be met by the licensee (e.g., to ascertain whether the license is being met or not; to provide a means for the licensor to monitor the progress of the licensee).

When determining the financial terms of the licensing agreement, if the terms do not involve solely the sale of the technology, then either a *royalty-free* or a *royalty-bearing license* can be used. To date, royalty-free licenses have been the more popular choice, and although they are the norm in the information technology field, they are less popular between universities and life sciences companies (unless the university also negotiates an up-front payment. In the case of the life sciences, the more common model, however, is industry sponsorship of the research at the full federal rate for research). Royalty-free licenses allow the licensor to retain ownership or other control over the intellectual property and allow the licensee to practice an invention or obtain rights under copyrights without having to compensate the intellectual property owner.

Royalty-bearing licenses presume a financial exchange between the parties. Some royalty-bearing licenses are fully paid, while others specify payments throughout the term of the agreement. In cases where payment is made throughout the agreement's life, payment arrangements can vary and may include a license issue fee or other up-front payment, annual payments, milestone payments, or earned royalties based on sales.

Intellectual property can be licensed either *exclusively* or *nonexclusively*, with variations in between those polar options. Typically, an exclusive license gives the licensee incentives to develop the intellectual property. Exclusive licenses are most beneficial for technologies that require significant expense and a long development period, as they encourage the licensee to invest the risk capital required to develop and market the intellectual property. Due to the higher risks that are involved, exclusive agreements are more expensive to obtain. In addition, while licensees prefer a worldwide life of the patent and exclusive license for all fields of use, exclusivity limits can be specified as to duration, geography, field of use, and application parameters, among others. Licensors can also grant the exclusive licensee the right to grant sublicenses to sublicensees; these subsidiary licensees may then contribute to or conduct the research and develop the technology.

Other terms and conditions of licenses that are of slightly less, but nonetheless salient import, are issues such as reporting, infringement, indemnity and warranties, governing law, assignment, and notices.

Whatever decisions the corporate practitioner makes about licensing from the university, an important first step is to catalogue and assess available technologies, including know-how, trade secrets, and trademarks. Cataloguing enables the categorization of the potential portfolio by kind of property and technology, application, proprietary position, originator and internal owner, and kind of asset—defensive, blocking, or breakthrough research patent (13).

5. Best Practices and Exemplars

5.1. How Universities Can Facilitate Research Partnerships. At universities, the success of collaborative research with industry sponsors depends primarily on the interest and enthusiasm that faculty scientists bring to the joint research effort. But, university administrators can promote collaboration by motivating their faculties to partner with industry and by creating a customer-friendly environment for potential corporate partners.

Role of the University Researcher. University researchers operate as independent contractors in the selection and organization of their research efforts. As a result, establishing university–industry research collaborations presupposes attracting the interest and involvement of individual faculty members. No collaboration can be sustained without faculty participation as its foundation.

Industry collaborations offer researchers new funding for their laboratories and their varied research agendas. Researchers who pursue such projects are usually interested both in the fundamental science of their disciplines and in how new knowledge can be applied. They tend to be skilled at networking and at nurturing the relationships necessary to uncover potential partners.

Many of those faculty members who are most effective at collaborating are already oversubscribed, so encouraging them to do more will probably not greatly increase the number of university–industry partnerships (37). Generating and sustaining the interest of those who have not yet collaborated extensively with industry is the challenge for university officials and corporate partners. To address sustainability, one East Coast public university instituted a series of roundtables between research faculty and corporate research officials. At these meetings, the participants discussed common research interests in an informal forum. However, while sponsoring colloquia adds value, it does not substitute for a targeted "business" plan with strategies for facilitating research partnerships.

Research collaborations are usually considered part of the faculty member's official duties and almost always result in research that can be published. Nevertheless, traditional university hiring, tenure, and promotion processes do not always make allowances for industry-sponsored projects, and faculty who collaborate with industrial partners may weaken their career prospects. Some researchers have suggested special incentives or other compensation for participating in university–industry research collaborations (38), and some universities have agreed.

Universities should not overhaul their faculty performance measures to require increased ties with industrial partners. Doing so would threaten the basic mission of the university and lead to faculty resentment. Tulane University, for example, believes that hiring and tenure decisions should be based on merit, institutional needs, and the anticipated productivity of the individual, and not on the pursuit of industry-sponsored research (39). Given that industry interests might change, it is prudent to be conservative when revising an institutional mission.

Role of the University Administration. The administrative offices serving university research programs have different names and perform different functions on different campuses, and their duties are sometimes consolidated under a single shingle at smaller universities. But however they appear, they have a common mission. The key offices are the Office of Sponsored Programs or the Office of Research Administration (charged with institutionalizing and managing collaborations); the Office of Technology Transfer or Office of Technology Licensing (charged with determining when to seek patents and when and with whom to negotiate patent-licensing agreements); the Office of Development (charged with university fund-raising); and the Office of Corporate Relations (charged with oversight of the university's interface with industry). In recent years, even some large universities have centralized many or all of these purposes under an umbrella organization, commonly an Office of Industry Relations. Such consolidated approaches ensure that each hand knows what the other is doing and serve to facilitate the big picture approach to corporate relations with university partners.

Most collaboration partners have worked together before. All of the major partnerships at a private, East Coast institution, and 80–90% of non-federally sponsored projects at a public university in the Midwest, are with existing partners. At a private university on the West Coast, only about one-third of new collaborations are with prior partners, but prior partners account for almost two-thirds of its sponsored research portfolio (Ref. 19, p. 74). Thus, finding new partners may be both a challenging task and a promising tactic for universities that want to increase their industry collaborations.

Although Technology Transfer offices and Sponsored Programs offices can promote new collaborations, a Corporate Relations Office can be particularly well suited for this task. The Corporate Relations Office is externally oriented, usually has high-level connections, and is experienced in marketing the strengths of the university. Local companies are sometimes the best initial targets, simply because they are nearby. But national corporations can be good prospects, too, when they share the same objectives.

Motivating and assisting researchers to locate potential collaboration partners requires a sophisticated understanding, not only of how university researchers operate but, also, of individual researchers' focus areas and the companies that share their research interests. When technology transfer, sponsored programs, or corporate-relations officials are knowledgeable about faculty research interests, they can play a key role in pre-screening companies with which faculty might wish to collaborate (40).

The University of Massachusetts Office of Strategic Technology Alliances views faculty as clients and goes to some length to assist them (41). Purdue University's John Schneider, Assistant Vice President for Industry Research, agreed, "We consider our office to be a service organization. We want to help our faculty through the university's bureaucracy and facilitate them in developing relationships with industry. We want them to succeed and to make it as easy as possible" (33).

Administrative officials add value when they reinforce the efforts of these offices. Those most frequently involved in promoting research issues are Vice Presidents for Research, Deans, Department Chairs, and their staffs. Collectively, these university officials are responsible for establishing university and departmental research policies, for allocating resources, and for coordinating with other entities on campus. Deans and Department Chairs often operate independently in smaller universities, and in larger universities, they wield considerable influence. Their positions and roles, and the attendant status in the university hierarchy, often give these administrators access to senior corporate research officials. Likewise, their knowledge of the university's research strengths and their ability to understand corporate research priorities allow them to identify fruitful areas for collaboration. They are well positioned to support the university's relationship with industry given their ability to coordinate the efforts of the faculty, the Sponsored Programs Office, the Technology Transfer Office, and the Corporate Relations Office.

Nevertheless, most universities could review the way their administrative offices work together to promote collaboration with industry. The Office of the Dean can effectively act as a central clearinghouse. Some universities suggest that the Corporate Relations Office can play a major role.

At the Pennsylvania State University, the Development Office compiles a short profile of the research, recruiting, and vending relationships it maintains with industrial partners. This profile includes information about campus visits, interviews, alumni, philanthropy, and key contacts (42).

However the university is organized, it is beneficial to implement systems that minimize bureaucracy (43). Fortunately, much of the bureaucratic rivalry within universities over industry collaborations has dissipated in recent years. Universities have learned that improved coordination results when the university devises system-wide performance measurements that encourage cooperation among the various offices. Likewise, many universities understand that it is wise to avoid measuring the success of the research efforts in dollar terms alone. At the University of Massachusetts, the performance of the Office of Strategic Technology Alliances is evaluated in several ways. One benchmark is revenue generated from industry, but other measures include the level of university–industry partnerships, the initiation of new faculty projects, and whether a company is visible on campus beyond its recruiting efforts (44). This sort of multifaceted approach to performance assessment—encompassing a review of other relevant university offices—holistically captures the collaborative effort across the university.

Some universities have encouraged teamwork by co-locating related university offices. About 10 years ago, the Pennsylvania State University decided to cluster its administrative support offices working with industrial partners in one facility. This has fostered cooperation, rather than competition, in establishing relationships with companies and has led to increased information sharing (39). North Carolina State combined its Office of Industry Research Relations and its Office of Technology Transfer, combining them into an Office of Technology Transfer and Industry Research.

Sometimes faculty and staff are reluctant to work with industry. In those cultures, the university president may need to promote collaboration by building consensus within the university in support of balanced research collaborations. The university president must understand the issues well enough to be able to speak the language of staff experts. The president can likewise play a constructive role by fostering increased numbers of collaborations. Again, he or she must be well informed. Industry leaders are usually aware of all the elements of the existing relationship between the organizations, and they usually expect university presidents to be similarly familiar with the totality of their interactions (45).

Role of Graduate Students. University–industry collaborations offer attractive opportunities for the graduate students who are working toward advanced degrees in university laboratories. An increasing proportion of these students now go on to careers in private industry, and sponsored research can provide them a working knowledge of the private sector, can help them make contacts that might lead to job offers, and can sometimes provide entrée to corporate laboratories to continue promising projects that they began during work toward their degrees.

But sponsored research may also pose risks. Graduate students' labor should not be diverted to work that is unlikely to advance their education or their thesis research. Graduate students should not be barred from presenting their work at scientific meetings, nor should they be unable to publish a doctoral thesis because the release of data or its analysis is truncated, or even embargoed, by corporate confidentiality requirements.

Proactive Facilitation. It is not necessary to secure full support for a research initiative from one corporate sponsor. Universities can leverage corporate support with public funding, alumni contributions, or foundation support. Internal resources can be used, where available, to seed initiatives. The goal is to offer the company a win–win scenario, not a risky investment. As the relationship grows, it can be leveraged to garner additional contributions, including non-financial support. Proposing a well thought-out plan, and providing specific ways for the company to work with the institution, can be an effective hook (46).

The $25 million, five-year collaborative agreement between the University of California, Berkeley and Novartis Seeds grew from just such a plan. Gordon Rausser, then Dean of the College of Natural Resources, analyzed the market needs of firms for which UC-Berkeley's research would be relevant. The university then sought out potential partners. "Typically, the university and its faculty wait passively until they receive a request for proposals (RFP) from governmental agencies or private companies and then generate a response to the other parties' terms," Rausser related. "By contrast the Berkeley–Novartis agreement resulted from the University staking out its strategic advantage, taking the central position in the bargaining process and inverting the typical protocol. The research agreement was structured by Berkeley, and the corporate candidates were asked to compete among each other to meet its conditions" (47).

Exchanges between corporate and university partners should be clear and direct. They should also be frequent, ideally every week to every month informally, with more formal presentations, including written artifacts every 6–12 months (39). Timing visits to company sponsors to coincide with the company's internal budget process can help secure ongoing support (37).

Meeting corporate schedules and timelines is a recurring challenge (37). Industry officials often complain that university researchers lack management expertise and fail to respect contractual deadlines (48). For their part, university researchers frequently report that meeting deadlines is most difficult when the project has commercial applicability; unsurprisingly, corporate pressure and commercial objectives appear to be positively correlated. University administrative offices provide some help in this situation, but the researcher retains primary responsibility for managing the collaboration from the university side. Moreover, some forms of research are not amenable to timelines, and university researchers and officials should make certain that their corporate partners recognize the difference. For example, clinical researchers can reasonably be asked to keep a large clinical trial on schedule (although even here, some factors, like recruiting subjects, are not entirely under the researcher's control). But at the other extreme, that of basic research (e.g., an effort to determine the function of a newly discovered protein), the nature of the project makes it impossible to predict the end date with any precision. Effective communication and documentation will help the participants work out disagreements without resorting to legal intervention. At the same time, researchers will benefit from knowing when to involve legal counsel. (See also the section below on Managing Collaborative Research Partnerships.)

More than any other technique, a proactive, customer service attitude is at the heart of successful university–industry collaborative research partnering. North Carolina State University has taken steps to coordinate, and where possible streamline, its relations with industry partners. Charles Moreland, Vice Chancellor for Research and Graduate Studies, employs a consistent rule: A company should have to make only one call to his office to get what it needs (35).

5.2. How Corporations Can Facilitate Research Partnerships

Role of Corporate Management. While the impetus for initiating specific new projects is typically driven by the research needs of company scientists, industry support for collaborations with universities generally has to begin at the top, if it is to begin at all. In every company, no matter what the product or sector, the Chief Executive Officer (CEO) and senior leadership team establish the priorities and operating tone. Typically the Chief Technology Officer (CTO) is the senior leader who encourages collaboration between the company's internal R&D organization and external partners.

By contrast, university presidents and administrations play a more limited role. While university administrators have no direct control over faculty researchers, corporate managers do control research directions through corporate strategic planning decisions. This dichotomy has important implications for university–industry research collaborations. Private sector companies are results driven and thus are quite focused when making research investments. Management will engage in collaborative research partnerships only if the projects align with business and financial objectives, and are likely to increase the bottom line and shareholder value.

For this reason, the company—and not the university researcher—will often define the research priorities. But the interest of the university scientist remains a critical factor, because in most cases university researchers choose their own research topics. In effect, this means that corporate management and university faculty must ultimately negotiate an agreement about not only the goals of the collaboration, but also its vision.

Thus, the support required from the CEO for any project varies with its complexity and its proximity to specific operating and strategic goals. Because the CEO's level of active interest resonates throughout the corporate culture, project managers, technology transfer managers, and company scientists who seek to develop university–industry partnerships are keenly attuned to signals of support from top management. Corporate research divisions will benefit from ongoing efforts to develop a supportive culture and from policies that recognize the time required to establish and maintain an effective collaboration. Company decision makers are well advised to recognize that effective collaborations require the substantive involvement of many key personnel across many departments and divisions of a company.

Role of Corporate Decision Making Models. Corporate decision makers generally employ a sequential model that is informed at every level by business considerations. The first decision a company must make is whether a prospective research effort is a good candidate for outside collaboration. Collaboration will not necessarily be the corporation's preferred road to research or commercialization, in part because the corporation must address competitive pressures by capturing market share with a first-to-market product (49).

Once the decision is made to pursue a collaborative research program, the next decision point for company managers is whether to work with a university, a government laboratory, a partner company, or a contract research organization. Analysis of the proposed collaboration's purpose and objectives can help guide the selection of partners.

Most university and industry research coordinators share a baseline sense of what constitutes a research collaboration that is mutually beneficial. Characteristically, the relationship should demonstrate appropriate ethical standards. It should anticipate basic (or slightly applied) research and a publishable outcome. And it should pair the expertise of the university with the interests of the company, including the commercial interests of the company (39).

Fortune 500 corporations are the most likely sponsors of basic research on campus, while mid-sized and small companies tend to view somewhat applied research as appropriate for university collaborations (39) (see Endnotes 7). Both large and small companies can utilize the university to explore new directions before developing a product or process in-house, although small companies may try to use the university to provide all their research needs (see Endnotes 8). Large, technology-driven companies often find it cost effective to work with universities through extended (e.g., three to five years), complementary research projects. The short-term research needs of large companies generally do not align well with university goals or timeframes. Alan Lesser, an associate professor at the University of Massachusetts and the editor of *Polymer Composites Journal*, concurs, adding that well matched projects are usually non-proprietary and often anticipate a longer time horizon than is typical in a corporate research laboratory (37).

Selecting research partners is a multilayered process. The strategic planning exercise may identify technological areas of interest or specific projects that might be appropriate for collaboration with academic researchers; but it is often those company researchers who closely follow external developments in their fields who will identify potential projects and suggest university partners. Other resources for identifying suitable faculty researchers and qualified institutions include the corporate researcher's professional networks, university alumni connections, databases of practitioners and experts (e.g., ScienceWise.com; Community of Science), and the experience gleaned from corporate recruiting and campus relations. Some companies have a central coordinating office that identifies preferred faculty members and institutions and maintains a list of universities with whom the company has successfully collaborated in the past (39). Professional organizations, including the External Research Directors' Network of the Industrial Research Institute, are an additional source of information about university quality and researcher expertise (39).

As noted earlier in describing the University of California's collaboration with Novartis, occasionally university administrators and their researchers propose collaborative research projects to companies. Companies who welcome such exploratory initiatives from universities employ an open door Request for Proposal (RFP) policy, enabling these companies to harvest proposals that align with their areas of strategic interest (39). Some companies have established internal matching-fund programs to encourage external research. A chemical company used this approach in the early stages of its research collaboration program (39).

Examples of the Corporate Decision Making Process. As part of its annual strategic planning process, Boeing Rocketdyne selects its potential external partners by identifying projects that might lead to a competitive advantage or might usefully provide opportunities to mentor potential employees. The company's strategic plan also defines technological areas that the company is considering for development, and its planning exercises sometimes extend to the design of programs to promote university exploration in these areas (38). Company researchers' expertise complements this process: Researchers define areas for exploration and draw on personal contacts or professional networks to identify experts.

Sun Microsystems (Sun) provides logistical support for its matchmakers (39). It identifies potential collaborators through recommendations by company engineers, and through seminar contacts, visits of the 'collaboration coordinator' to universities, and university-initiated contacts. Its technology sponsors use a template to describe proposed projects to potential collaborators, thus alerting outside researchers to the company's interests (39). If the company's first choice for a faculty partner is unavailable, Sun may approach the university's most recent departmental graduate who remained in academe. Or, it might consider funding a start-up grant to attract new faculty members to its areas of interest (50).

Unlike others in the information technology industry, Sun Microsystems does not use RFPs to solicit proposals from universities. The Office of the Collaboration Coordinator screens institutions and unsolicited proposals, applying criteria similar to those used to manage internal research projects (29):

- Is the appropriate engineering group willing to be the technical sponsor?
- Does the university have the appropriate expertise?
- Does the university have a reputation for negotiating deals expeditiously?
- What are the outcomes from using the template?

While Sun Microsystems does not use RFPs, it does invite university researchers to email a one-screen project proposal abstract, after which a Sun engineering group evaluates the concept and responds to the researcher about the company's interest. If there is mutual interest and benefit, the corporation negotiates with the researcher and the sponsoring university to determine project terms and funding (51).

From the corporate perspective, the number of potential university opportunities can be daunting. Although universities' efforts to identify compatible corporate partners can facilitate corporate efforts, companies that want to capitalize on university outreach will need to likewise provide universities with outside access and with a clearly articulated means for entry to their research activities (52). Sun Microsystems' approach satisfies those access and articulation parameters.

DuPont, which receives more than 1000 project proposals a year, filters unsolicited proposals using several criteria. First, DuPont assesses whether a proposal fits its existing research agenda or signals an opportunity to branch into a new area. If this preliminary review generates interest, an electronic abstract is sent to a corporate Expert Panel for review. Should a project proposal clear that hurdle, it then moves to the scientist-to-scientist level for more detailed study (52) (see Endnote 9).

Although DuPont employs this venue to entertain unsolicited proposals, its research activities are conducted primarily through close work with a few key partners in ongoing relationships. Employing this approach, DuPont continues to work with several different universities worldwide that are conducting research in areas of interest to the corporation, while in the United States, the Company most frequently works with a narrowed list of about two dozen "preferred technology partners." Its preferred list approach reflects the need to manage scarce resources and priorities, while at the same time enabling DuPont to nurture deep relationships with its partners.

Role of the End-User Champion To ensure success, university–industry collaborations require an "end-user champion"—someone inside the sponsoring company who is committed to making the partnership work (49). The end-user champion's goals are to bridge the language gap between academia and industry; to find rapprochements that skillfully mesh university and industry cultures; to consistently work to reconcile the conflicting interests inherent in any collaboration; and to ensure that the research underway is successfully integrated with internal company processes to safeguard its relevance. If the end-user champion is to have the requisite time, resources, and political capital to manage all these tasks, senior company research officials, including the CEO, will need to message the value of external research through both words and deeds company-wide (see Endnotes 10).

Managing Collaborative Research Partnerships How the corporate partner oversees a collaborative effort will depend on the type of research performed and its goal. Applied research, such as regulatory and problem-solving research (which characteristically features well-defined goals and milestones), can often be managed like internal research or like external research under contract. However, applied research is usually a relatively small piece of the industry research performed in universities. Basic, exploratory research, on the other hand, requires a partnership management approach.

In general, companies have not yet honed the necessary collaborative skills to partner effectively with scientists conducting basic research. To begin, the distinction between basic and applied research should be clearly understood (through conversations between the company and the faculty member to establish the company's research agenda in relation to the university researcher's interests)—and even more clearly defined in the contract. Ideally, the project will explore a research pathway that (a) the company perceives to be an important new direction for its R&D, and (b) the university researcher believes to be a promising route for advancing a given science or technology.

Managing a partnership relies heavily on the strength of personal relationships. It requires that both university and corporate scientists draw on their collegial and team-building skills, and it places a premium on clear communication, openness, and forthrightness (39). In addition, in a collaboration no one person or organization controls all the resources necessary to accomplish the program's objectives (49). When the partners are making roughly equal financial and intellectual contributions, decisions are almost always made by consensus.

Corporations operate on fiscal year calendars and strategic plan timelines, making integration of research results into a company's strategic processes a significant management hurdle. Nevertheless, aligning university research with company schedules is essential for successful collaboration. The best defense here is a good offense: The company, the university, and the researcher are well advised to carefully attend to all timelines before any project agreements are signed.

Experienced corporate and university officials agree that frequent turnover of company project managers is the most disruptive personnel change that affects collaborative teams (39). Because the corporate collaboration manager is such a key attribute of the collaboration team, his or her departure can seriously disrupt a project. University researchers sometimes read personnel changes as evidence of lack of commitment by the company (39). Even experienced faculty can become frustrated when personnel changes bring less skilled replacements and inhibit project progress.

Managing the role of student researchers in the work of a collaborative research partnership is a somewhat special case and requires particular attention. While a university–industry collaboration gives the company a natural opportunity to preview graduate students' work and potential as employees, knowledgeable corporate sponsors will not be surprised to learn on occasion that a particular student cannot work on a project or that the university will not accept a project due to confidentiality constraints. A prevalent nightmare for university professors is the thought that a student may complete the thesis research and then find that it is not publishable because it contains confidential corporate information. Some faculty advisors and researchers mentor their students before allowing exposure to company representatives (53). Mindful of these concerns, companies can still build relationships directly with student researchers, while respecting university policies. Ultimately, however, collaborative research relationships are not recruiting forums, and what separates these relationships from alternative opportunities to meet promising students is the expectation that the project will generate meaningful research results for the company. Yet, student participation remains a desirable tradition that is well worth the management investment, because student participation provides novices with cutting edge opportunities and adds manpower, fresh insights, and occasionally, new solutions to research problems under investigation.

Accountability Mechanisms Because corporations view their R&D projects as capital investments (and measure outcomes using metrics that include return on capital), research partnerships are subject to the same rigorous oversight and reporting requirements as are other corporate activities.

Corporate management can apply measures for assessing the progress and achievement of a collaborative project at the project, personnel, or organizational level. However, adequate measures for assessing the integration of collaborative research results into product and service development are yet to be developed (39).

Corporate management can improve evaluation of collaborative research projects by designing a matrix of measurements that can be used to evaluate a range of project types. The matrix should differentiate among problem-solving, exploratory, and regulatory research, and should recognize that different or additional factors will be become important through the various stages of the project. Communicating these protocols to prospective university researchers improves transparency and solidifies the partnership's understanding of the mission and objectives of the collaborative.

With appropriate metrics, project evaluations can also be used to assess the company project manager and to determine incentives and rewards for meeting project goals. To be effective, these metrics and incentive systems need to be determined during the project definition phase (50). The same approach and protocol can also apply to company researchers.

Collaborations with strategic partner universities also require periodic evaluation. Rather than simply reviewing the results of specific projects, however, these assessments should rate the efficiency and effectiveness of the entire relationship, including the university legal team, faculty cooperation, and any change in the relationship over time. If selection and continuation of a university as a "preferred provider" is to be a meaningful tool for management decision making, it must be based on carefully designed metrics and thoughtful, fair evaluations. (Fairness includes some protocol for sharing a university's evaluation with appropriate university personnel.) In short, relationship status should be based on a track record of success (50).

Evaluation of master agreements and strategic alliances is generally a formal process. It includes regular review of both the research results and the collaborative process itself. It makes inquiries about whether new projects and individuals are involved in the relationship and whether academic freedom is impaired. Such a review process is specified in the master agreements at the University of Massachusetts and the Pennsylvania State University, and it is built into the partnership agreements between Washington University in St. Louis and Pharmacia (39), and between the University of California, Berkeley and Novartis.

Formal reports are additional tools for promoting project accountability and for assessing a multiyear university collaborative over time. Reports from university researchers provide the industry sponsor with an essential, detailed, written account of the status of the collaborative effort. The Industrial Research Institute (54) observed that a formal annual report "allows for a reasonable level of oversight, considering both the flux of new people entering the university and the rapidly changing array of consulting, publishing, and research activities of a faculty member." Importantly, formal annual reports showcase the project, increasing exposure beyond the immediate project circle to include additional corporate officials (55). Managers can also augment formal systems for documentation with information from peer reviews of publications or from presentations at scientific meetings.

Managing well requires managing ahead. Informal monthly reports and a campus visit about six months into the project are useful activities that serve to keep a project on track (55). In addition, project oversight within the company often includes internal profiles at the beginning of the effort, at the point when a patent should be considered, and at the one-year anniversary (55). These reports are included in corporate research summaries and are used for project planning and personnel evaluation (see Endnotes 11).

5.3. Exemplars. While there are many different models for how to implement technology transfer partnerships, at least three models are frequently used in describing industry–university–government research relationships. A model often used by the electronics and computer industries involves the development of multiple consortia of companies to fund research and increase technology applications. A second model, the biotechnology model, is often employed to link small, entrepreneurial companies with the capabilities of a sophisticated university laboratory. Finally, a third model moves a portion of corporate R&D to university laboratories under long-term, cooperative arrangements that, through licensing agreements, improve options for capitalizing on any opportunities resulting from extended research partnerships (13). Generally, the model employed is a direct function of profit margins in the specific industry sector (27).

The best demonstration of technology transfer's success is the results generated by the working partnerships—results that would have been impossible without the creation of collaborative links between two or more research organizations sharing a common goal. Three snapshots of successful research collaborations are included in the Appendix of this article: the Power Electric Building Block program, a government initiative that included university and industrial partners; the relationship linking start-up company, Ribozyme Pharmaceuticals with the University of Colorado; and the Monsanto-Washington University collaboration, one of the longest standing university–industry partnerships. These exemplary cameos demonstrate the capacity of technology transfer to add value and deliver results for government, university, and industry technology transfer practitioners. They teach us that sometimes the project outcome is the same, but is developed quicker or at a lower cost through partnering. Or, sometimes the outcome is different, or improved, and those differences are an effect of the partners' interactions. Above all, they alert us to the necessity to couple the right problem with the right partner.

When the technology transfer process is executed properly and professionally, it often appears to be a synthesis of two rather than simply a partnership of two. Such was the case when DuPont and the University of North Carolina's Maurice Brookhart collaborated to develop a new family of polyolefin catalysts, Versipol™. Alternatively, it can be a complex collaboration involving many partners. For example, early in the last decade DuPont worked with 10 universities and 13 government laboratories to develop a new family of hydrochlorofluorocarbon refrigerants to substitute for the chlorofluorocarbons then in use (and which were implicated in atmospheric ozone depletion).

One cautionary note: While the snapshots in the Appendix are included as exemplary studies, success is neither easy, nor assured. In the words of Theodore Tabor of Dow Chemical Co., "We made our External Technology Program a core competency just in the fall of 1998. What is interesting is that we've had this program in place for nearly 20 years now. It took a lot of work" (56).

6. The Technology Transfer Professional: The Key to Successful Collaboration

The key to success with technology transfer lies in the professionalism of the individual practitioners. Typically the technology transfer process requires people with expertise in science and technological fields; in business, including finance and marketing; and in law; and often includes people with expertise in fields outside those that directly intersect to effect technology transfer. Whether the practitioner is engaged in technology transfer activities from the government, university, or corporate position, an understanding of all aspects of the specific industry is essential, including extensive knowledge of the product, product cycle, and marketplace; familiarity with the relevant legal issues involved in licensing and patent protection; and an appreciation (that is both pragmatically and creatively informed) of the alternatives for utilizing the product to its full advantage.

Historically, many technology transfer professionals have come to their work with broad-based experience in R&D and in technology intensive businesses. Other professionals have been drawn from careers in patent law. As technology transfer has rapidly evolved in its importance to industry, government, and academic laboratories, a growing number of practitioners have entered technology transfer careers under a broad range of job titles, including licensing, collaborative or sponsored research, corporate and foundation relations, and technology transfer, among others. One organization useful for getting a handle on the university–industry R&D interface is the Association of University Technology Managers (AUTM). Although AUTM has existed for more than 20 years, it saw its membership explode from 1700 to 2700 in the year 2000—a clear sign of the interest that technology transfer currently generates!

The real question for the future is: From where will all the new technology transfer practitioners come? Many will be retired industry researchers and managers launching second careers, but some will be entering the field directly out of college, armed with technical or business degrees and the desire to build a business from basic science or engineering. Finally, a growing number are already appearing with little background in business, technology or law, but rather with a liberal arts background.

To date, there are very few colleges or universities that have developed or implemented a coherent curriculum to address practitioner preparation for this specialized, albeit multidisciplinary field. Technology transfer courses *are* beginning to appear in some college catalogues, along with debates centered on where the courses should reside: in the law school, the business school, or the engineering school. Indeed, three universities—Georgia Institute of Technology, Purdue University, and North Carolina State University—have each recently graduated doctoral students in traditional science or engineering programs, who then immediately entered positions as technology transfer practitioners. Moreover, a few university professors have begun to focus their research efforts on technology transfer as a discrete field. And a few innovative programs for training technology transfer professionals have also appeared, including the National Technology Transfer Center's Entrepreneurial Technology Apprenticeship Program (ETAP) and several programs created by the national laboratories for their employees. Until these efforts increase, most new technology transfer players will learn from on-the-job training and courses they take at the Licensing Executive Society, the Association of University Technology Managers, and related meetings.

The successful technology transfer professional requires four major skill sets. These are (a) *organizational skills* to develop partnerships, to provide a consistent external presence, to increase internal coordination, and to nurture implementation skills; (b) *communication skills* to develop and articulate the benefits of outsourcing and technology transfer; (c) *resource gathering skills* to identify and tap potential sources of assistance and expertise; and (d) *social skills* to effectively facilitate colleague-to-colleague relationships. In addition, it is likewise important that the technology transfer professional be sufficiently flexible and imaginative to encourage the best possible partnerships. Administrative skills (including an ability to employ a focused approach to ensure expeditious and useful results and an ability to assist university and government laboratories in documenting and promoting their competencies) are invaluable for establishing credibility with internal participants.

7. The Future of Technology Transfer

Government, academia, industry, and the consumer all benefit from technology transfer. As society has shifted from an emphasis on manufacturing to an emphasis on intellectual property, technology transfer has grown in prominence within the domains of science and engineering and has served to increase both the urgency for and feasibility of intellectual property development. At this writing, it can be stated without reservation that technology transfer has generated more success than ever thought possible. The result is a new, worldwide intellectual "boom" whose potential is, surprisingly, not yet fully realized (see Endnotes 12).

Still barriers remain to be overcome if the emergent field of technology transfer is to attain the status of a professional discipline and thus achieve its fullest potential to benefit all those who are involved either directly or indirectly. To this end, as discussed earlier in this report, the education and training of technology transfer professionals is essential. Without skilled and knowledgeable practitioners, and their desire to make technology transfer possible, it will not happen. Part of technology transfer's future will almost certainly be its development as a profession (which will necessitate the creation of effective organizations to promote research partnerships in universities, government laboratories, and industry). Companies likewise need to commit to investment in the training of employees.

Alternatively, technology transfer could simply become part of a changed R&D process (and corporate structure) as Chief Technology Officers are increasingly pressured to deliver the technologies their businesses need at lower costs and in shorter time frames. The ever-present requirement to leverage corporate investments might reframe how collaborative projects are viewed and might drive technology transfer into the day-to-day job descriptions of researchers and managers. In such a configuration, the technology transfer function would be subsumed into a support function under either the R&D or legal banner. Relationship building and maintenance are key components of successful collaborations, and thus alternative conceptualizations will require new processes through which to link partners, negotiate common terms for multiple interactions, and create mutually beneficial outcomes.

It is incumbent on corporate managers to recognize the benefits of technology transfer and to understand what are, to now, the un-codified practices of an emergent field. While technology transfer practitioners may be accused of employing what appear to be vague parameters and practices for initiating and nurturing research partnerships, nevertheless these approaches work well for practitioners, allowing them to form alliances while avoiding the misunderstandings and disagreements that can plague and delay more formal approaches. For corporate and university partners, technology transfer and related research collaborations contribute to the development of professors and researchers, provide opportunities to share expertise and equipment, and increase opportunities to leverage federal funding (27).

It is likewise incumbent on university researchers and administrators to recognize that

> The primary driver from industry's perspective is the ability to obtain some *competitive advantage* from its research initiatives, which will lead to increased profitability in the marketplace. In fact, when companies do not obtain competitive advantage, then they are no longer industrial partners, but philanthropists. The goal is to get the best research results for the lowest possible investment (Ref. 27, p. 1).

For the future, the federal government is expected to remain an active participant in technology transfer. There are several reasons for this expectation. First, as the Cold War receded, the government laboratories altered their missions to reflect their new quasi-commercial status. That alteration culminated in a reconceptualization of the various government laboratories, yielding a variety of specialized missions and aligning particular laboratories and agencies with clearly articulated zones of expertise. Second, only the government can finance the many specialized facilities, including high-energy and x-ray light sources, super computers, and specialized radiation sources that are essential to the development of particular technologies. Third, it is anticipated that government laboratories hold unique and useful knowledge as a result of previous defense contract research.

However, despite such attributes, there are several obstacles to overcome before the federal government can become the significant partner its assets suggest. These obstacles include issues surrounding intellectual property rights and the specificity of right-to-know regulations; ongoing suspicion of industry; political sensitivities; limited access to seed money; and unintended consequences related to the restructuring of government programs (18). Adding to these obstacles, passage of the Technology Transfer Acts of 1986, 1987, and 1989 produced a noticeable shift toward university–industry partnerships, in part because universities sought new relationships with industry to replace their historical relationships in defense contract research, and in part because in re-defining themselves, many of the government laboratories proved to hold unique expertise in specialized niches that are, as yet, unrelated to the directions of corporate research and commercialization efforts. However, the important point here is not the source of the technology, but that all three traditional producers of intellectual property—universities, government, and industry—are now able to actively participate in the benefits of the technology transfer process (see Endnote 13).

Another point must be that all technologies are not alike. The dynamics of technology transfer that work well for biotechnology may work not at all for information technologies like computer hardware and electronics. And the traditional R&D models employed by chemicals and materials sciences are again different from those embraced by the life sciences and the information technology industries. The size of R&D budgets (as a percent of sales) varies widely among technology sectors, and there are significant differences across sectors for new product life, next-generation development time, and the capital required to bring an invention from its basic science to commercialization. Having made those observations, nevertheless, it remains that all three sectors can learn from each other (see Endnotes 14).

A final point relates to the protean nature of technology transfer and the emerging opportunities among university, industry, and government participants for increased interaction noted in the opening paragraph of this section. As observed by Blackman and Segal (12):

> It is almost a cliché that international competitiveness, whether at the level of the individual business or of a regional or national economy, is increasingly dependent on the intelligent and swift use of information—information about markets, competitors, production and product technologies, government laws and regulations, and the like, all worldwide. Similarly, the ability strategically to manage technology—in the sense of identifying, acquiring, and effectively using technology—is seen *a fortiori* as critical to competitiveness; and although the relationship between science and technology is complex, there prevails a conviction that science constitutes an essential underpinning of technology (Ref. 12, p. 935).

To manage this complexity, universities, companies, and government must learn to more effectively leverage each other. The federal government, and especially the National Science Foundation, has established several programs that foster or require collaboration. Examples include the Engineering Research Centers (ERC); Industry University Collaborative Research Centers (IUCRC); the Grant Opportunities for Academic Liaison with Industry program (GOALI); and the Small Business Technology Transfer (STTR) and the Small Business Innovation Research (SBIR) programs mentioned earlier in this document. State governments are also implementing collaborative programs—among them New York, Maine, Ohio, Indiana, and California— and other states will discover the benefits of leveraging their academic and industrial institutions. Some universities are engaged in short-term, applied research investigations in partnership with small and medium sized companies through the various Technology Application Programs, while other universities are active partners in the federal government's Manufacturing Extension Program. Although the first science park in the United States traces its roots to the Stanford Industrial Park opened in 1951 on land owned by Stanford University, today University–Industry Research Centers and science parks are increasingly common features of the regional landscape, and these intellectual mini-cities are contributing to economic development by leveraging the flow of ideas among university and industrial participants. Evidence of their success resides in the development of Silicon Valley in California, the Route 128 corridors around Boston, Massachusetts, and the Research Triangle Park in North Carolina. These three examples, all conceived or launched in the 1950s, bode well as catalysts for future growth: Notably, some 80% of the approximately 115 science parks in the United States today were established after 1979 (Ref. 26, p. 943).

Perhaps the real future of technology transfer lies in its ability to shape its future in ways that will unite the three pillars of research and development—government, university, and industry—in new and synergistic partnerships that work collaboratively in fresh ways to leverage intellectual assets and to streamline the process for bringing inventions to market.

Authors' Note: The authors wish to gratefully acknowledge the American Council on Education and the Business-Higher Education Forum for permission to draw on text from their publication, *Working Together, Creating Knowledge*: *The University-Industry Research Collaboration Initiative* (for which Michael Champness served as Project Director).

8. Endnotes

1. Many organizations and authors discuss technology transfer wherever it is found; others address research and technology transfer from the perspective of one source: the university, the government, or industry. Only a handful of organizations recognize the synergies that result from interaction among the three primary sources of technology transfer, among them the Council of Chemical Research Leaders and Bio for the Life Sciences. In this article, we follow the latter approach, recognizing the leverage that obtains from interactions among the what we have characterized as the three pillars of technology transfer.
2. Among the reasons for this focus is the fact that of the approximately 700 government laboratories now in existence, fewer than 50 boast the scale required to conduct the basic science research that interests at least some large global corporations. And as noted above, for the most part, corporations do not allocate substantial portions of their research budgets to basic research "because the probability of success is too low" (Ref. 10, p. 856). Notwithstanding the fact that the large government laboratories provide access to certain unique equipment and facilities (18), the vast majority of the government laboratories are small regional or local facilities. Moreover, in the general sense of how practitioners use the term *technology transfer* and understand its evolution, the national laboratories have been understood to be charged first with attending to national needs. Thus, while the laboratories have reconfigured their missions in recent years to become more attuned to private sector research, they remain a primary instrument for government research, especially as that research relates to the defense of the United States.

3. In the early 1990s, industry responded to the new organizations, missions, and attitudes that resulted from Bayh-Dole and the Technology Transfer Acts by designating Technology Transfer leadership teams and divisions to develop appropriate organizations and structures. For example, DuPont created a Corporate Technology Transfer Group (CTTG) in 1993 for this purpose.
4. In 2000, DuPont CTTG's success and its network's growth and development led to a reorganization that included formation of two new groups engaged in technology transfer within DuPont: (1) an Intellectual Assets Business (IAB) to focus on the licensing of technologies with commercial potential, and (2) a Center for Collaborative Research and Education (CCRE) to encourage increased collaboration in research and to explore additional new business opportunities between universities and DuPont.
5. In 1918, DuPont launched its unrestricted grants program to encourage the development of chemistry, science, and engineering at research universities in the United States. These partnerships continue, and in today's complex world, they now include technology transfer as well as other activities (e.g., initiatives to improve K-12 science and mathematics education, and programs to increase access by underrepresented minorities to careers in mathematics, science, and engineering).
6. In licensing agreements that include royalties, a general rule of thumb is that an earned royalty stream will reflect approximately 25% of profits earned in the particular technology. Minimum royalties are often based on one-fourth to one-third of a conservative projection of sales.
7. The industrial commodities sector is, however, an exception. Generally companies in these industries rely on internal laboratories for research, and thus, they are not significant consumers of university research (37).
8. Historically smaller companies have relied on geographic proximity to a university and the general reputation of the university to make decisions about research collaborations. Unfortunately, for many smaller companies, these decisions have been informed more often by convenience and by past relationships than by recognized expertise in a particular field.
9. The Sun Microsystems and DuPont models stand in marked contrast to the federal grant process, which generally requires researchers to submit comprehensive, detailed grant applications with little indication about the potential for funding approval.
10. Management support also can be vital for keeping a collaborative alive through changes in funding priorities. Nothing is more deadly to a collaborative program than financial cutbacks. When company research expenses must be pared, research contracts with universities can be among the first fatalities.
11. Reporting requirements in a strategic university–industry relationship can become quite complex, but the system at smaller companies is usually more informal (39). Funding by third parties (e.g., SBIR, the Small Business Innovative Research program; STTR, the Small Business Technology Transfer program; or the Department of Defense research funding pro-

grams) offers additional external assessments. The president of one start-up company consciously uses the SBIR sponsoring agencies as a source of external review (39).

12. For example, the Association of University Technology Managers (AUTM) Licensing Survey (57) reported results for its FY1999 survey, indicating 417 new products introduced from collaborations with 98 universities (including healthcare, software, agricultural, and research and reagent products). Moreover AUTM determined that licensing generated $40.9 billion in economic activity and supported nearly 271,000 jobs, with 62% of the total new licenses granted to companies with fewer than 500 employees in FY1999. Growth from collaborative university–industry partnerships, as reflected by a variety of indicators during the five-year period, 1994–1999, is also impressive: Total U.S. patent applications filed increased 93.9%; total new U.S. patent applications filed increased 107.6%; total U.S. patents issued increased 89.9%; total U.S. licenses and options executed increased 49.8%; and adjusted gross income to universities rose 132.3% during the 5-year period.
13. It should be observed, as well, that many of these obstacles also obtain with regard to state governments, although for the most part, state participation generally occurs indirectly through funding to state universities.
14. Some industry sectors are more open to collaboration than others. Life sciences companies spend a high percentage of their research budgets on campus—but in many cases, their investment is limited until a significant or promising discovery occurs. Electronics and computer firms are also heavy users of university research—particularly the smaller tech companies—often for the purpose of gaining access to particular students or professors with cutting edge knowledge, rather than for basic research *per se*. But chemicals and materials companies tend to spend less than 5% of their research budgets in universities. They try to develop the project in-house after culling good ideas from universities (58).

9. Appendix: Case Study Exemplars

9.1. The PEBB Program: Creating Synergistic Collaborative Research Interfaces. Launched in 1994, the Power Electronic Building Block (PEBB) program is one of the most extensive collaborative research efforts ever undertaken by government, academia, and industry. Under the leadership of the Office of Naval Research (ONR), the revolutionary impact of PEBB technology on naval systems sparked new interest in the power electronics field.

Power electronic building blocks—electrical connectors that use software to sense other devices that are plugged into them—are essential parts of all naval ships, aircraft, ground vehicles, and most weapons and sensors. They act as super-efficient switches, converters, inverters, circuit breakers, power supplies, generators, and motor controllers.

"Research in high-power electrical systems had dribbled off in the 1960s and ≈70s," said Dave Rossi, head of Industrial and Corporate Programs at

ONR. With research efforts and budgets focused on solid-state electronics for computers, communication systems, and sensors, research for generating and transmitting electrical power became almost nonexistent. The military demands of the 1990s, however, created new requirements for electrical power sources with increased efficiency and reduced size, weight, and cost. “The military needs shifted,” added Rossi, “and solid state electronics for power was in demand.”

Today, the PEBB program’s mission is to harness the potential richness of government–industry–university partnerships by involving all entities at every stage of the technological innovation process. The Office of Naval Research currently devotes more than $10 million a year to PEBB research through more than 100 contracts and grants involving more than 200 researchers. Industry partners commit more than $40 million to PEBB research each year, an amount that continues to grow. Participation in the PEBB program is “a once in a lifetime opportunity” for researchers, reports Terry Ericsen, program officer for PEBB.

But building the program was not simple, and there were challenges to overcome along the way.

In the 1990s, the Department of Defense, and in particular the Navy, needed to quickly and efficiently design and produce new electronic power platforms for applications in ship building. The Navy’s interest focused on a range of concepts, including high-energy weapons, hybrid electric engines, communications, and stealth technologies. However, the Navy’s “all-electric” ship goal required the rebirth of the very same electronics research that had been in decline since the 1970s.

At the same time, industry had started to tackle power electronics issues for civilian products. ONR, working with the Department of Energy’s Partnership for a New Generation Vehicle program, identified demands for PEBB technology within the automotive industry. “There was a lot of cross-talk,” recalled Rossi. Commercial automakers, already in partnership with government, teamed up with Virginia Tech (Virginia Polytechnic Institute and State University) to begin work on the Science and Technology Power Electronics program, a government-sponsored program that includes such partners as ONR, the National Science Foundation, and the state of Virginia.

As technological discoveries emerged from university laboratories, government laboratories developed standards for the new processes, thus providing the universal access necessary to satisfy the engineering requirements of both military and industrial partners. Enabled by these standards, automobile companies entered commercial product development. And, because military requirements were embedded in the systems, the technologies could be spun back to the Navy, and the systems could be purchased off the shelf at commercial prices.

The success of the dual-product development process is due in large part to the Navy’s aggressive outreach and oversight effort. Knowing that the technology would have commercial applications, the Navy pursued the innovation process in partnership with academia. As the technologies advanced, the Navy communicated updated information to all industry partners and potential suppliers. These standardization and open communications processes reduced business risk, enabling industry to enter the project as an active partner that could bring new discoveries to commercial development quickly.

Today, the PEBB program has grown to include the companies that participate in the Small Business Innovation Research (SBIR) program. SBIR sets aside a portion of federal research funding for research grants to smaller companies. Sharing lessons learned about how government, industry, and universities can join in collaborative enterprises, the Office of Naval Research continues to seek out additional government agencies that might benefit.

9.2. Ribozyme Pharmaceuticals: The Small Company Advantage. In its start-up stage, Ribozyme Pharmaceuticals, Inc. was a small biotechnology venture seeking to develop new therapies from the discoveries of the University of Colorado's Nobel Prize winning researcher Tom Cech (pronounced "check"). Then Ribozyme's President and Chief Executive Officer, Ralph Christoffersen, made a serious move. He presented the university with an offer it could not refuse: a $500,000, five-year research grant, to be used for anything the university wanted to do.

> "I used to be the president of a university, Colorado State, and I was an academic for 20 years," Christoffersen recalled. "So I had a pretty good idea of what kinds of things would be of interest to the university. And one of the things that's most difficult to get, for a university president, is unrestricted dollars." Christoffersen knew that state and federal funding is generally restricted: "So I thought this [unrestricted grant] would be a powerful thing for the university president's office to have."

In return, Ribozyme got an option to license, exclusively, any ribozyme-related discovery made in university laboratories—whether or not the company's funding had been involved. (The Company already had an exclusive license to the University's broad patents on ribozyme manufacture or use.) It also forged friendly ties with Colorado University scientists through collaborative projects, and through seminars convened at Ribozyme's laboratories and at the University's nearby Boulder campus. Finally, Ribozyme recruited Professor Cech and other Colorado researchers to its Scientific Advisory Board.

Christoffersen's half-million dollar grant to the University of Colorado represented a gutsy bet for the young start-up company, amounting to between 5 and 10% of its total research budget. The significance of the stake dramatizes what Christoffersen called "the biggest conceptual difference" between small start-ups and large pharmaceutical companies when it comes to university–industry research collaborations: Big pharma can take more chances by spreading its investments over a number of promising ventures.

"Large companies can and do create a collection of interactions with universities, multiple ones, because they can afford it," said Christoffersen, formerly Senior Vice President and Director of U.S. Research for SmithKline Beecham Pharmaceuticals. "Therefore, the importance of any one collaboration is less than is typically the case for a small company." In a small company, he added, "Because resources are limited, you only have so many pieces you can play, and you have to pick them far more carefully."

A smaller company does have some advantages over an industry giant when it comes to university collaboration, however. Small companies are nimble, and they can move more quickly than can larger companies. For example, although Ribozyme's agreement with the University of Colorado included the usual provisions for publication delays to allow the company time to evaluate a discovery, the company never had to delay the process for long, and never had to ask for an extension. According to Christoffersen, "We can look at something in a week, and have a patent written in a month. So in practice, it's not a real problem."

9.3. Monsanto–Washington University: Respecting the University Culture. One of the oldest and most successful university–industry collaborations is the 20-year pact between Monsanto Co. (now a part of Pharmacia Corporation) and Washington University in St. Louis. Since 1981, the agreement has granted more than $100 million in research funding to the Washington University Medical School, resulting in 180–190 patents. Moreover, the relationship fostered some personnel exchanges, most prominently the move by Philip Needleman, now Pharmacia's Chief Science Officer, from the University's faculty to Monsanto in 1989.

At its inception, certain components of the agreement were very important. One critical issue was to ensure the integrity of the University's research agenda. University officials did not want to create the fact or the appearance of having yielded the University's research programs to the purposes of corporate science. Monsanto concurred and readily agreed to this stipulation.

While the agreement was under negotiation, the group working on it did so privately, but once an agreement had been reached, the participants went public in a big way. They conducted multiple informational presentations, providing transparency and earning support. Rather than maintaining secrecy throughout (which is often the case in university–corporate relationships), the participants determined that beyond the negotiations period, secretive approaches would have created more problems than they would have solved.

Initially, Monsanto committed $2 million a year, a figure that grew to $9 million by 1988. Simultaneously, and partly due to the success of the arrangement, Monsanto expanded its pharmaceutical business by acquiring G.D. Searle & Co. in 1985. At that point, Washington University's medical school determined that no single corporation should provide more than 5% of its research budget. Thus, Monsanto gradually scaled back its annual contribution to $5 million, a more manageable representation in the medical school's research budget totaling some $230 million today.

What makes this collaboration so effective? Certainly, a critical factor is the ability of the people involved to understand and respect each other's goals and objectives. Likewise, each partner must be able to successfully articulate the benefits of the relationship within their institutions. Candid, open lines of communication are very important. As is remembering that a partnership is about more than financial incentives.

Note: These synopses of exemplary collaborations are taken from *Working Together, Creating Knowledge*, authored by the Business-Higher Education Forum and published in 2001 by the American Council on Education, Washington, D.C. For complete reports of these collaborations, see the Spotlights sections of the full document. The authors gratefully acknowledge the Business-Higher Education Forum's cooperation in using its examples in this report.

BIBLIOGRAPHY

CITED PUBLICATIONS

1. C. Jencks and D. Reisman, *The Academic Revolution*, Doubleday, Garden City, N.Y., 1968.
2. C. Gellert, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 1624–1641.
3. J. Ben-David, *Centers of Learning: Britain, France, Germany, United States*, McGraw Hill, New York, 1977.
4. R. A. McCaughey, *Perspectives Am. Hist.* **8**, 239 (1974).
5. S. L. Goldman, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 1106–1117.
6. J. L. Wagoner and S. E. Kellams, in B. R. Clark, and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992 pp. 1674–1686.
7. R. J. Bawden, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 1061–1066.
8. R. S. Friedman and R. C. Friedman, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 1453–1464.
9. P. H. Crosson, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, 1992, Pergamon Press, Oxford, U.K., pp. 1596–1605.
10. B. R. Williams, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 853–863.
11. G. Williams, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 863–871.
12. C. B. Blackman and N. Segal, in B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education*, Pergamon Press, Oxford, U.K., 1992, pp. 934–946.
13. J. T. Peregrim, R. J. Guschl, and J. B. Rappaport, *Chemtech* **29**(4), 41 (1999).
14. Bayh-Dole Act of 1980. (Public Law 96- 517), § 35 U.S.C. §§ 200-212 (1984, 1998).
15. R. Jensen and M. Thursby, *Am. Econ. Rev.* **91**(1), 240 (2001).
16. Federal Technology Transfer Act of 1986. (Public Law 99-502), § 15 U.S.C. §§ 3701–3705; 35 U.S.C. § 210 (1998).
17. National Competitiveness Technology Transfer Act of 1989. (Public Law 101-189),§ 15 U.S.C. §§ 3710, 3710a, 3710c (1998).
18. A. L. MacLachlan, *Res. Technol. Management* **38**(6), 48 (1995).
19. Business-Higher Education Forum. *Working Together, Creating Knowledge*. (Item. No. 309142), American Council on Education, Washington, D.C., 2001.
20. P. A. Roussel, K. N. Saad, and T. J. Erickson, *Third Generation R&D: Managing the Link to Corporate Strategy*, Harvard University Press, Boston, 1991.
21. R. R. Gruetzmacher, S. Khoury, and T. F. Willey, *Les Nouvelles* **35**(3), 116 (2000).
22. A. Smith, *An Inquiry into the Nature and Courses of the Wealth of Nations*, J. M. Dent, & Sons, London (original work published in 1776).
23. T. Arnold, *Les Nouvelles* **22**(1), 9 (1987).
24. P. F. Drucker, *Management: Tasks, Responsibilities, Practices*, Harper & Row Publishers, New York, 1974.
25. Association of University Technology Managers, Inc., *AUTM Licensing Survey: FY2000 (Survey summary)*, Northbrook, Ill., 2001.
26. B. R. Clark and G. Neave, eds., *The Encyclopedia of Higher Education: Vol. 2. Analytical Perspectives*, Pergamon Press, Oxford, U.K., 1992.

27. Industrial Research Institute, Inc. *Industry–University Intellectual Property* (Position Paper). Washington, D.C., External Research Directors Network, Issue 2001.
28. E. Starbuck, Interview with James C. MacBain, unpublished Case Study Final Report, 6, 2000.
29. E. Starbuck, Interview with Emil Sarpa, Sun Microsystems, unpublished Case Study Final Report, 27, 2000.
30. L. G. Tornatzky and P. G. Waugaman, *R&D Enterprise Asia Pacific* **2**(2/3), 29 (1999).
31. I. J. Petrick and M. M. Reischman, *SRA J.* **27**(3/4), 13 (1995).
32. United States Government–University–Industry Research Roundtable, *Industrial Perspectives on Innovation and Interactions with Universities: Summary of Interviews with Senior Industrial Officers*, National Academy of Sciences, Washington, D.C., 1991.
33. M. D. Champness, e-mail from John A. Schneider, unpublished raw data, July 17, 2000.
34. C. A. Goldman, T. Williams, D. Adamson, and K. Rosenblatt, *Paying for University Research Facilities and Administration*. RAND Corporation, Santa Monica, Calif., 2000.
35. M. D. Champness, Personal conversation with Charles Moreland, Vice Chancellor for Research and Graduate Studies, unpublished raw data, April 1999.
36. S. Cowen, Memo to Judy Irwin, Managing Director, Business-Higher Education Forum, unpublished raw data, Aug. 8, 2000.
37. E. Starbuck, Interview with Alan J. Lesser, ed., *Poly. Comp. J.*, unpublished Case Study Final Report, 34–35, 2000.
38. E. Starbuck, Interview with Robert Carman, unpublished Case Study Final Report, 18, 2000.
39. E. Starbuck, Final Report, unpublished case study data, 2000.
40. E. Starbuck, Interview with Pramod Khargonekar, University of Michigan, unpublished Case Study Final Report, 36, 2000.
41. C. Sanzone, Building an Effective University Technology Transfer Team: Teleconference remarks, unpublished raw data, Dec. 17, 1999.
42. G. Moellenbrock, Building an Effective University Technology Transfer Team: Teleconference remarks, unpublished raw data, Dec. 17, 1999.
43. M. D. Champness, Interview with Gene Allen, Director of Collaborative Development, MSC Software, Inc., unpublished raw data, July 18, 2000.
44. E. Starbuck, Interview with Carolyn Sanzone, unpublished Case Study Final Report, 33, 2000.
45. R. Levy, *Untitled*, remarks presented at the Collaborations and Partnerships Conference, Duke University, N.C. Durham, Nov. 15, 1999.
46. C. Sanzone, in P. M. Buchanan, ed., *Handbook for Institutional Advancement*, Council for Advancement and Support of Education, Washington, D.C., 1999, pp. 321–324.
47. G. Rausser, Unpublished letter to the editor, *The Atlantic Monthly*, May 19, 2000.
48. D. MacArthur, (Response to Business-Higher Education Forum Questionnaire), unpublished raw data, (April 1999).
49. G. Allen and R. Jarman, *Collaborative R&D: Manufacturing's New Tool*, John Wiley & Sons Inc., New York, 1999.
50. E. Starbuck, *Res. Technol. Management* **44**(1), 40 (2001).
51. R. Bramley, *IEEE Comput. Sci. Eng.* **5**(3), 8 (1998).
52. R. J. Guschl, *Chem Tech.* **27**(7), 7 (1997).
53. E. Starbuck, Interview with Ron Iacocca, unpublished Case Study Final Report, 31, 2000.

54. Industrial Research Institute, Government–University–Industry Research Roundtable, and Council on Competitiveness. *Industry–University Research Collaborations; Report of a workshop*. National Academy Press, Washington, D.C., 1995.
55. E. Starbuck, Interview with Steve Hahn, unpublished Case Study Final Report, 22, 2000.
56. T. E. Tabor, Making collaborations a corporate core competency: Teleconference remarks, unpublished raw data, Oct. 15, 1999.
57. Association of University Technology Managers, Inc., *AUTM Licensing Survey: FY1999 (Survey summary),* Northbrook, Ill., 2000.
58. M. D. Champness, (e-mail from Randolph J. Guschl, Director, DuPont Center for Collaborative Research & Education), unpublished raw data, Sept. 29, 2000.

Randolph J. Guschl
DuPont Center for Collaborative Research & Education

Table 1
Corporate Propensity to Engage in Collaborative Research with a University*

Intellectual Property Arrangement	Business Propensity to Favor Collaboration
1 Business Partner Owns the Intellectual Property Generated through Collaborative Research	1 Very High Probability Maximum Potential for Agreement Maximum Freedom of Action Business Prepares Information to Secure Intellectual Property Rights
2 Business Partner Owns the Intellectual Property; University Retains Rights to Pursue Additional Basic Research	2 Very High Probability Fosters Long-Term Relationship Allows Continued Research by Faculty & Graduate Students Business Prepares Information to Secure Intellectual Property Rights
3 University Owns the Intellectual Property; Business Retains Exclusive Rights	3 Reasonable Probability Business Maintains Competitive Advantage Increases Administrative and Legal Fees University Prepares Information to Secure U.S. Property Rights Business Prepares Information to Secure Foreign Property Rights
4 University Owns the Intellectual Property; Business Retains Narrow Field Exclusive Rights	4 Limited Probability Inhibits Multiple Use of Developed Technology Limits Additional Applications
5 Non-Exclusive Royalty Free	5 Very Low Probability Favors Consortia Partnerships Favors Basic Research Used for Unique Product Development

*Adapted from Table 1 and related text in *Industry-University Intellectual Property (Position Paper)*, Industrial Research Institute, Inc., April, 2001, pp. 3-4.

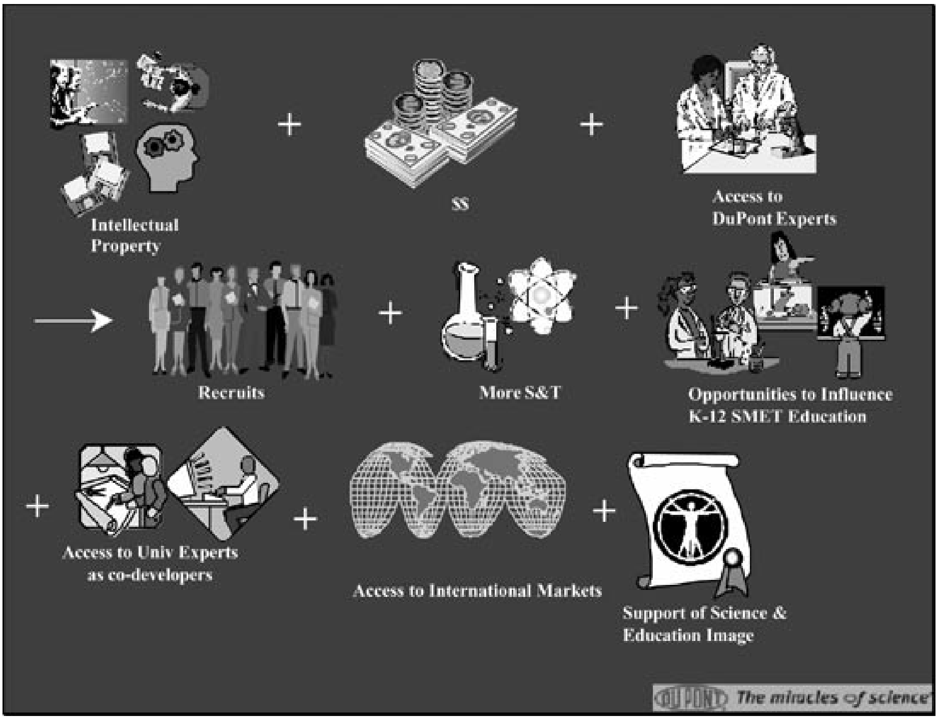

Fig. 1. The DuPont–University Interface Model © (2000).

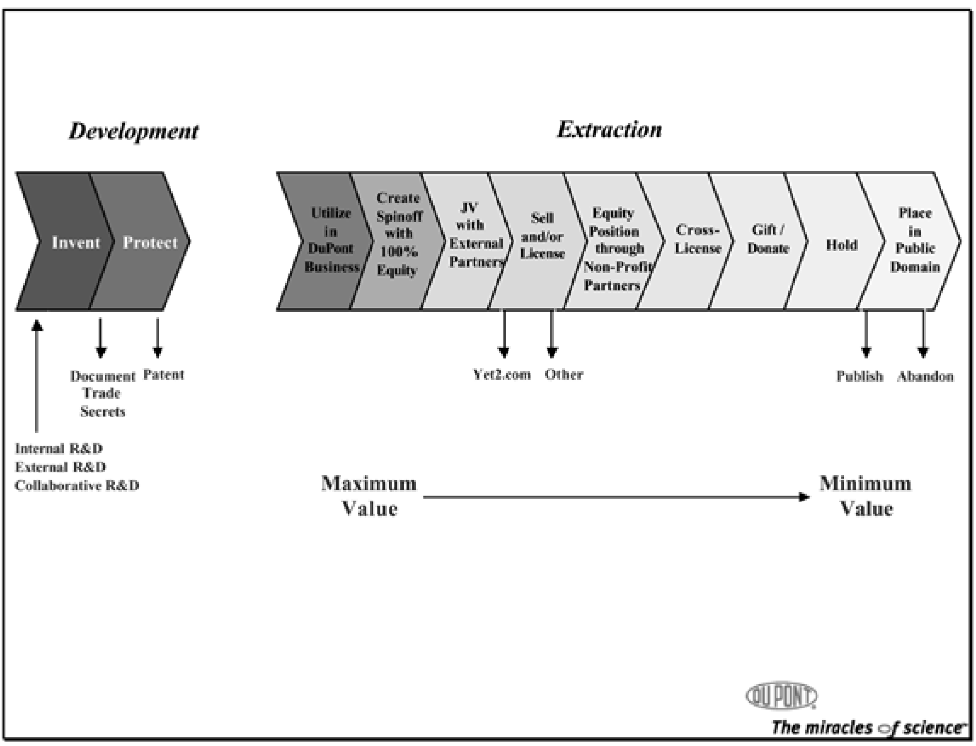

Fig. 2. Development and Extraction Model for Valuation of Intellectual Assets © (2000).