Industrial Perspectives on Innovation and Interactions with Universities

Summary of Interviews with Senior Industrial Officials

The purpose of this document is to add the perspectives of seventeen industrial officials to the ongoing discussion on industry-university alliances. The paper is not an official policy statement of the Roundtable Council; its sponsoring organizations, the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine; or the Industrial Research Institute.

GOVERNMENT-UNIVERSITY-INDUSTRY RESEARCH ROUNDTABLE

INDUSTRIAL RESEARCH INSTITUTE

MICHAEL SCHRAGE

Research Universities, Corporate Sponsors Need a Different Relationship

When America's top research universities glance down at their well-heeled corporate sponsors from their ivory towers, alluring visions of dollar bills just aching to be seduced keep dancing in their heads.

But what do America's top research companies see when they peer into the groves of academe?

Their view is equally unflattering. They see "many university officials [who] tend to have an inflated view of the importance of university research efforts in innovation," according to the just-published "Industrial Perspectives on Innovation and Interactions With Universities."

What's more, asserts this government-university-industry research round-table survey, "many university officials erroneously believe that the discovery of new ideas represents the most significant step in the process of innovation, and that universities are the key source."

Not so, the report concludes. "Industry is the primary source for innovation. Universities play only a limited role in this realm."

So much for getting that endowment for the new chair in molecular biology.

Actually, the report—which summarizes the opinions of 17 top research officials from companies ranging from Procter & Gamble Co. to General Motors Corp. to Bechtel Group Inc. to Martin Marietta Corp.—offers more than the casual snipes at academic pretension. This is what you read if you want quick insight into the conventional research and development wisdoms. It's a terrific snapshot of attitudes. Sure, most of the comments seem obvious—incremental innovation in industry is more common than breakthrough innovation; the primary role of the university is as educator and provider of talent, etc.—but then, if they weren't obvious, they wouldn't be conventional wisdoms.

The overarching message is that these senior officials are less than thrilled with their relationships with and investments in America's research universities. They're not getting the bang for the buck that they want. They complain that, while research universities may be loaded with talent and data, they just are not in sync with either the needs or the aspirations of American business. Essentially, universities neither understand nor effectively contribute to the technology transfer process.

This may or may not be true—but that's what they say, and it should be taken seriously. What also has to be taken seriously, however, is the dangerously narrow perspective that most industries have of the innovation process. To wit, the report notes that "most industry officials interviewed believed that, whereas universities are at the forefront of scientific discovery, product- and process-oriented technical change occurs within industrial firms for most fields."

This is one of those statements that sounds perfectly reasonable but is actually meaningless. As any sophisticated industrial researcher will tell you, the lines between "scientific discovery" and technical innovation have blurred into shades of gray. Where do you draw the line between the science of molecular biology and the technology of genetic engineering when the same researchers are doing both?

The science of computational chemistry is transforming the technology of new materials design. Mathematical research in digital signal processing is quickly translated into custom-designed computer chips. In virtually every major industry—automotive, aerospace, agriculture, medicine—science and technology are converging.

So here are industry and academe struggling to draw clean research distinctions between themselves at the very time that's becoming virtually impossible. The reality is that universities can no longer be seen as traditional "suppliers" of students and "subcontractors" generating new knowledge. A different relationship is necessary, one that's far more intimate and collaborative than giving a university a million bucks and expensive equipment in exchange for the exclusive rights to some anticipated "breakthrough."

Proof of this can be found in the single most interesting finding in the survey. These corporate giants are now turned off by research consortia and expensive alliances. Instead, they've discovered that the most fruitful industrial-academic collaborations emerge from the "bottom up"—small groups of researchers from industry and academe who share common interests and build on them.

These are the people honing the cutting edge of research and innovation—not their bosses. In fact, it is precisely because the research bosses are constantly trying to draw a corporate dotted line between basic science and applied technology that they can't quite see the convergences their researchers are creating.

Ironically, while the research executives complain about their relationships with American universities, Japanese companies have platoons of their top young scientists and engineers studying at the top universities. They prefer to send people, not money. The Americans do just the opposite.

Indeed, the most damning aspect of this survey is that none of the research executives talks about how many people they have on campus or, for that matter, how many top-notch professors and grad students come into their facilities to consult. I'm sure it's going on—but why wasn't it discussed?

Institutions don't collaborate; people do. That's not a profound statement. However, until both industry and academe recognize that the key to effective university-industry productivity is to enable individuals to collaborate instead of having institutions sign intellectual property deals, the relationships will continue to disappoint. More important, American companies will not be effectively drawing upon a vital resource that can dramatically boost their ability to innovate and compete in world markets.

Michael Schrage is a columnist for the Los Angeles Times.

Danaher Profit Down 63 Percent in Quarter

...ine Company UNC Inc. of Annapolis Posts a 2...

...based man- $6.7 million a year ear...

...tem—a rocket carried aloft by a B-52 bomber and then launched—twice so far this year.

Revenue in the quarter rose 20 percent, to $26.8 million from $22.4 million.

■ **Ameribanc Investors Group**, parent of Ameri... Sav... Bank, said it lost $1.9 mil...

...its fee income and reduced the amount of interest paid on accounts. It also plans to consolidate three branches.

■ **MBNA Corp.**, the parent of the credit card bank company that was spun off from MNC Financial Inc. last year, said it earned $30.9 ... (62 cents) in the first quarter, com... profit of $26.8 million (54...

GOVERNMENT-UNIVERSITY-INDUSTRY
RESEARCH ROUNDTABLE

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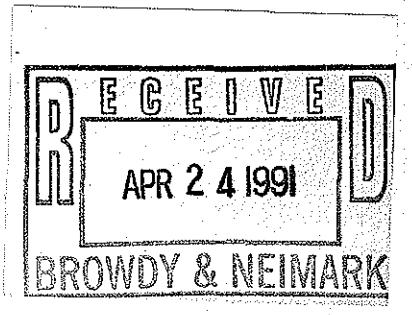
April 1991

MEMORANDUM



TO: Interested Parties

FROM: James D. Ebert, Roundtable Chairman

SUBJECT: Document on "Industrial Perspectives on Innovation and Interactions with Universities"

The enclosed document, "Industrial Perspectives on Innovation and Interactions with Universities," is the product of a joint effort of the Government-University-Industry Research Roundtable and the Industrial Research Institute (IRI).

The document is a summary of interviews with seventeen senior industrial officials who were asked how innovation occurs within their companies and how they expect alliances with universities to contribute to innovation. The opinions of these seventeen industrial officials are not meant to be construed as a general policy statement by the IRI or the Roundtable and its sponsoring organizations. We present these impressions to complement the large body of knowledge and perspectives that have been articulated over the years through ongoing discussions on university-industry alliances. Indeed, earlier Roundtable efforts have explored alliances from different points of view, particularly in the 1986 report, "New Alliances and Partnerships."

We recognize that the views of these seventeen leaders do not necessarily present a balanced view of university-industry alliances, where a wide range of opinions and experiences exist, and that others may not agree with the statements put forth here. The Roundtable will continue its tradition of addressing issues by laying out views of all involved. To assist us in future Roundtable discussions on alliances and innovation, I invite your comments on the perspectives presented in this document.

Enclosure

Industrial Perspectives on Innovation and Interactions with Universities

Summary of Interviews with Senior Industrial Officials

GOVERNMENT-UNIVERSITY-
INDUSTRY RESEARCH
ROUNDTABLE

INDUSTRIAL
RESEARCH
INSTITUTE

National Academy Press Washington, D.C. February 1991

PREFACE

As a natural extension of earlier Roundtable efforts that mapped the diversity of university-industry research alliances and culminated in the 1986 report, **New Alliances and Partnerships in American Science and Engineering**, the Roundtable, in conjunction with the Industrial Research Institute, has examined industrial perspectives on how innovation occurs and on how alliances with universities are expected to contribute to technical change and competitiveness within individual companies. This examination was carried out initially through individual discussions with seventeen senior research managers (see Appendix A) representing a range of fields of research as well as a variety of sizes and types of companies. The questions used to guide the sessions are listed in Appendix B. The results of the individual interviews were summarized and reviewed by the industry interviewees, a few members of the Roundtable Council, and senior federal R&D officials at a meeting in October 1990. Comments from that meeting have been incorporated into the summary of the interviews presented here.

The objective of the Roundtable in undertaking this project was to add a stronger component of industrial views to the ongoing discussions of university-industry alliances—discussions that, in the view of many Roundtable Council members, have been dominated by the perspectives of the university community. The results achieve this objective fully and effectively. We have here, concisely stated, the collective views of seventeen knowledgeable and experienced industry officials who have participated in many components of the innovation process across a broad spectrum of industry and in a variety of types of interactions with universities. Readers may not agree with all that is said in these pages, but given the caliber of the interviewees, these points of view deserve the attention of those considering the nature of university-industry alliances, their expected results, and their operating procedures.

This being said, it is also important to recognize the limitations of the interview results. Not all industry sectors are represented, nor are all the types of industry officials responsible for promoting innovation. These gaps certainly result in missing perspectives given the variation we found as a function of the experience of the individual interviewees, their industrial sector, their specific company and particular job, and the size of their company. The perspectives summarized here, therefore, should not be interpreted as general statements about the issues but rather as a collection of opinions of seventeen officials, albeit seventeen very knowledgeable and experienced individuals. Likewise, publication of these views does not represent endorsement by either the Industrial Research Institute or the Research Roundtable.

In my opinion, however, most of the conclusions presented in this document are totally consistent with the perspectives of most industry officials involved in the development of technological products and processes. The fact that these views may not be consistent with the perspectives of university officials illustrates that a serious gap in understanding persists between universities and industry. I hope that the views presented here help to break down some of the current misconceptions.

The industry officials interviewed provided sometimes varying views and sometimes a consensus on issues concerning innovation—its process and its primary sources; roles for universities, including training and serving as "centers of thought"; and collaboration of companies with universities, in-house, with other firms, and with federal laboratories. Each topic is introduced in the paper with a general statement that portrays the views of the majority of interviewees. The full complexity and diversity of views and the nuances among them are captured in the remarks attributed to individual interviewees that follow each general statement.

The central themes that emerged from these interviews are: most innovation occurs through incremental improvements to existing products or processes; industry is the primary source for innovation; the primary role for universities is in training and education; and industry needs to collaborate with universities, other companies, in-house research divisions, vendors, and federal laboratories to maximize knowledge transfer and to identify emerging new technologies. These themes are more fully described in the summary to this paper. I heartily endorse these conclusions. In addition, the commentary on generic, precompetitive research, intellectual property, and federal laboratories has profound implications for public policies and university-industry relationships. A difference of opinion continues to exist between university and industry officials in these areas because, I believe, university officials tend to have a somewhat myopic opinion of the university role in innovation. It is my hope that the commentary presented here will pave the way for beginning to address the implications for public policy, initially by means of creating an understanding of how many from industry view these issues.

By design, most of the views of industry officials presented here concern universities and industrial collaborations with them. I also want to point out, however, that the industry officials did not shy away from acknowledging their large competitiveness problems. On the contrary, some officials were critical of the ability of U.S. industry to advance an idea to market, as compared to Japan and other competitor nations. The issues involved in competitiveness go beyond relationships that U.S. firms have with universities and thus are outside the scope of this paper. Suffice it to say that although these relationships and collaborations are valuable to both parties, they are not going to solve the competitiveness problems for U.S. industry.

In closing, on behalf of the Roundtable Council, I want to thank the people responsible for the preparation of this valuable document. Foremost are the industrial officials who were interviewed, as listed in Appendix A; Nathan Rosenberg, professor, Department of Economics, Stanford University, and Richard Nelson, professor, School of International and Public Affairs, Columbia University; provided overall guidance for the project and conducted most of the interviews; Charles Larson, executive director, Industrial Research Institute, helped us in identifying the interviewees; and Casey Kiernan, senior program officer, Research Roundtable, made it all happen—she did an outstanding job of organizing and summarizing the individual interviews and preparing this summary document. I commend it to your attention.

John D. Macomber
Chairman and President, Export/Import Bank of the United States
Former Chairman and CEO, Celanese Corporation
Member, Roundtable Council, 1987-1990

February 1991

CONTENTS

Innovation and Technical Change 1
- Breakthrough Discovery versus Incremental Advance
- Sources of Innovation and Technical Change

Key Role for Universities in Training and Education 5

Industrial Collaboration for Innovation 8
- Collaboration with Universities
  - University Misconceptions about Commercialization and the Process of Innovation
  - Universities as Network Nodes
  - One-Scientist-to-One-Scientist Relationships: a "Bottom-up Approach" to Collaboration
  - Geographic Proximity
  - Consortia, Centers, and Affiliates Programs
  - Large Multimillion-Dollar Alliances
  - Intellectual Property Rights
- In-house Collaboration
- Collaboration with Other Companies
- Collaboration with Federal Laboratories

Summary 20

Appendix A—Industrial Officials Interviewed 21

Appendix B—Questions for Discussions with Industrial Officials 22

INNOVATION AND TECHNICAL CHANGE

How innovation is viewed is important in thinking about how it occurs and what roles universities can play in the innovative process. For the purposes of these interviews with seventeen senior research managers (see Appendix A), innovation was considered as the conception of an idea and its movement toward and embodiment in a commercially successful product or process. Technical change and technical advance are steps in and contributors to the process of innovation.

Breakthrough Discovery versus Incremental Advance

In many industries, technical advance occurs most often through small incremental improvements to existing products and processes rather than as large technical breakthroughs. It is the incremental technological advance that is the dominant step in the process of innovation that is related to competitiveness and international trade. This view—stressed by most interviewees as the most important perspective on the process of innovation—is one that affects industrial approaches to technical change and collaboration. Incremental advance most often occurs in industry; universities play a small role, according to interviewees, because university scientists often tend not to operate on or understand industry's short-term schedules or the tools involved in developing an incremental improvement.

The interviewed industrial officials stated that during the early stages of a large, breakthrough discovery, however, industries often need to interact closely with universities to gain a more thorough understanding of the science underlying the discovery. Thus universities sometimes play a major role following a major breakthrough, when it is necessary to establish a base of understanding on which the breakthrough can be bolstered and continue to grow. Industry looks to universities to fill this role but does not want universities to become oriented toward product development, according to interviewees.

> The reputation of a research lab is often based on feats of invention rather than incremental improvement...in spite of the fact that most of its staff are involved in incremental development and, typically less than 10 percent are doing truly creative breakthrough research, according to Albert Westwood. Procter & Gamble also continuously works to change or improve products through a combination of evolutionary and revolutionary product improvements. Geoffrey Place feels this is fundamental to P&G's success.
>
> Hubert Schoemaker noted that the basic research in biotechnology conducted at universities and the initial hybridoma products speak to the

significant role for universities in this emerging field. As biotechnology matures and the focus turns more to product development and incremental improvements, Centocor and other biotechnology firms may rely less on universities than they currently do.

Sources of Innovation and Technical Change

Most industry officials interviewed believed that, whereas universities are at the forefront of scientific discovery, product- and process-oriented technical change occurs within industrial firms for most fields. Industry is the primary source of innovation because industry culture fosters entrepreneurial awareness of profitable emerging fields and ideas. In addition, industry scientists and engineers know more about a technology—its detail and its system—than do academic scientists and engineers. The limited role of universities in innovation has not been recognized because of the misconception that technological change generally occurs through a remarkable breakthrough that will revolutionize an industry, because of the excitement that accompanies such radical new ideas regardless of how infrequently they occur, and because university scientists tend to have a simplistic understanding of how product development and commercialization occur, according to interviewees.

Peter Boer believes that the forefront of innovation often comes from industry. Industrial scientists have a good nose for profitable emerging fields. They tend to be better at setting goals and at interdisciplinary research, and can assess what needs to be done to develop a field; they are better than academics at seeing the broader scope and the long-range outcome.

For new advance, Rodney Hanneman stated that Reynolds Metals adopts alternative materials where strategically appropriate and synergistic with existing materials and products using the existing infrastructure (e.g. Reynolds Plastic Wrap and vinyl siding). In-house experts conduct complex and expensive process-oriented R&D using full scale systems involving many disciplines to achieve such advance. Technical advance also tends to come from in-house research at Inland Steel. There, according to Howard Pielet, innovation develops out of specific needs for a better system or widget.

Centocor is oriented to look outward for its sources of technology and to rely heavily on academic collaboration. These collaborations provide access to a tremendous pool of government-funded basic research that is critical for small businesses. For small biotechnology companies like Genentech and Centocor, according to David Botstein and Hubert Schoemaker, advance requires close connection with universities. In this

field, as in superconductivity, innovations come from universities. Allied-Signal also looks to universities for advances, but only those 20 years or so into the future; advances that are not even conceived of in the present. Lance Davis noted though that "next generation products" at Allied-Signal, like many other firms, are developed in-house.

Place noted that the foods business at Procter & Gamble, on the other hand, is an industry that is not driven by technology change; it is low technology and has a limited science base. There is a fair amount of research into food products at universities, but it is not at the cutting edge.

At the same time, an enormous amount of basic research is being conducted in universities to add to the knowledge base that supports both the processes of incremental technological advance and breakthrough discoveries. How much companies rely on universities, however, varies as a function of the technical field, the maturity of the industry, the stage of research, and the size of company.

For many reasons that will be discussed below, there are limits to the role that research divisions—from universities or industry—can play in the innovation process, according to industry officials. However, interviewees also noted that without university research there would be a considerable lack of depth in the level of scientific understanding about products and processes. The industry interviewees recognized the role of universities in providing understanding and techniques that enable companies to solve problems, invent, and design effectively.

Not much new product technology comes from universities unless Procter & Gamble leads a project on an innovation, according to Place. University contribution is through access to knowledge, not access to technology. Universities do not have a sophisticated understanding of the commercial needs, so when they apply knowledge to a need, they are frequently off base.

Westwood considers that Martin Marietta has had few if any products come directly from university research. However, coupled university and company programs have often been very productive. Udo Axen agreed stating that Upjohn sees little that academics are doing directly that the company may want to buy into; universities generally have not been a source of new pharmaceuticals beyond biotechnology. Universities are not equipped to develop products through a multidisciplinary approach.

Much of International Paper's work is in process optimization and product design that involves such technological development, according to Keith Hall. Most work is done internally; universities do not have

appropriate equipment. However, some R&D in the pulp and paper industry emphasizes "better" trees. This R&D is carried out in cooperatives run by universities.

Joel Birnbaum noted that in computing, new research is generally carried out by entrepreneurs and industrialists; universities can then take the time to search for fundamental understanding which leads to refinement and the second wave of innovation. A prototype then often comes out of university research with new experimental tools often calling for new measurement capacity. Universities do not need to carry out the initial breakthrough, but a relationship should be sought to take advantage of creating complete and correct systems.

KEY ROLE FOR UNIVERSITIES IN TRAINING AND EDUCATION

A key role for universities is the training and education of scientists and engineers. This message was highlighted and repeated throughout the interviews as the most important and significant role for universities. Most interviewees stated that U.S. colleges and universities are doing a good job of teaching science and engineering students the fundamentals, although educating students is not always a priority for faculty members. Many commented that there is room for improvement in certain areas, however, including management skills, communication skills, quality assurance, and a team approach to problem solving. Some interviewees noted that training students for academic careers does not fully prepare students for industrial careers—teaching focuses on the single investigator rather than on a team approach.

> Multidisciplinary training is essential to achieve the team approach required in industry. Birnbaum noted that many of the most creative employees in computing tend not to come from computer science or computer engineering departments. Rather, a high percentage were trained in other fields and were turned on to computers to solve problems. These people may have worked as a member of a research team in a way computer science students at many schools do not (many computer science students are trained individually with a solo thesis). The university's competitive culture may serve the academic system well, but it does not serve the industrial system, according to Boer. Most university education is in defined disciplines. For many industries including the construction industry, according to Tim Killen, research is problem-oriented, and requires interdisciplinary approaches.
>
> Axen believes, however, that the fact that universities do not train in a project-oriented approach is not necessarily bad because Upjohn wants the best students in each discipline. Upjohn can then combine disciplines into a project team of experts in important areas. Upjohn does not want to create hybrid scientists, but wants team players who are not tied to their own disciplines.

The consensus among industry interviewees was that companies need both trained specialists and generalists to ensure a strong R&D effort. University graduates do not enter industry as "finished products"; many have yet to learn anything about industrial practice and the realities of the marketplace, according to a number of interviewees.

> Centocor, like other firms, seeks out researchers who are not only scientifically talented, but also who understand that: time is money, product focus is essential, and communication and management skills are critical to success in industry research. These skills are often not

emphasized at the university, and Centocor must invest heavily to develop them in its employees. Westwood concurred. He believes that the real inadequacies in U.S. college and graduate education are the unmet need to teach people to think and become problem-solvers rather than technicians. How to determine what are good problems to pursue, what can be done, and what ought to be done (including value judgments, ethics, and humanity issues) are lessons yet to be taught in universities. Place believes that university students are trained to be deductive as opposed to inductive and have great trouble creating hypotheses in highly uncertain areas. He believes that the problem is getting worse, particularly in the life sciences where students receive an increasingly narrow training and where fewer and fewer students can develop a broad hypothesis for research. The education function needs to be changed to provide adequate preparation for the breadth of interaction needed in industry.

On the other hand, Robert Frosch stated that universities should not transform the education process from one of depth to one of breadth. GM Research Laboratories needs Ph.D. specialists rather than generalists. Scientists frequently get a general education at the bachelors' degree level, and then go on for specialization and depth. Engineers, however, are on track too soon, are too narrowly educated at the bachelors' degree level, and thus, become technicians. Engineering students need a broader education beyond engineering disciplines and business.

Frosch believes that although universities are responsible for training researchers, they should not be concerned with the specifics of the industry. After a student is hired, the firm can teach the specifics of its business and further leadership skills, according to Hanneman.

There was concern among many of the interviewees about the questionable quality of precollege education, and the potential for shortages in science and engineering talent.

Ora Smith thinks U.S. graduate schools are fundamentally in good shape, but he is very concerned about undergraduate institutions and high schools. In Allen Heininger's view, math and science education in K-12 grades are especially needy and critically important if the U.S. is to remain competitive. Hanneman is also concerned about the quality and quantity of technically prepared students in the education pipeline. He sees the emerging shortage of U.S.-born engineers as coming from inadequacies in motivation, role models, and the U.S. educational system prior to and during high school. Hanneman noted that European

education is far superior through high school and that the U.S. provides a less positive climate for science and technological advance.

All interviewees recognized the important role of universities in cooperative training and education, and in continuing education in order to maintain a knowledgeable workforce. Industry officials expressed the belief that continuing education and cooperative training are essential in supplying them with the capacity to keep their employees educated in the state-of-the-art technical expertise and equipment.

INDUSTRIAL COLLABORATION FOR INNOVATION

Although most firms look to themselves as a source of incremental technological advance, all industry interviewees acknowledged their reliance on other organizations and institutions for scientific and technological breadth and for in-depth understanding. Collaborative efforts are forged—with universities, other companies, federal laboratories, and in-house departments—to allow a firm access to new and emerging ideas, bright minds with varying perspectives, and financial leveraging for precompetitive R&D.

In general, industry interviewees stated that they find the most fruitful form of collaboration to be a "bottom-up" scientist-to-scientist approach with one-on-one relationships rather than "top-down" management decisions for collaborative arrangements. Although a number of interviewees indicated that they participate in collaboration that did not arise from a "bottom up" approach, primarily with university centers, consortia, or affiliates programs, all see these as mechanisms for accessing expertise—of consultants or recruits—or for promoting good will. Interviewees emphasized the importance of informal as well as formal interactions for collaboration; often long-term interactions begin as informal discussions among potential collaborators.

Most industry participants expressed skepticism about the results of generic research contributing to competitive advantage, and thus they are not willing to support it to a large extent. Many stated the belief that it is the role of the federal government to pay for the major share of this type of research. In the interest of the national welfare, many firms are willing to spend a small amount—less than 2 percent of their R&D budget—on precompetitive, generic research, although there is some variation by industry. In addition, precompetitive research is not generally pursued through company-financed consortial arrangements with universities either, according to industry interviewees. Companies would want to retain proprietary status for any discoveries that might emerge and would prefer not to lose competitive advantage through the sharing required in a collaborative program.

> Procter & Gamble is less internally focused with respect to science and technology than it was a decade ago, Place noted. This change has been driven by two factors; the need for external expertise as the business moved into diverse areas of technology, and the movement of environment and safety issues and concerns into all areas.
> Environmental concerns are key to the paper industry, now and in the future according to Hall. Research on environmental concerns at International Paper is conducted through cooperatives with vendors, competitors and with other industries.

> Bell Laboratories research scientists, on the other hand, do not often need to collaborate because they usually have the capacity to do the work in-house. They consider the Laboratories to be a peer of universities, and as a "captive university" to AT&T, according to Robert Lucky.

According to the industry interviewees, the amount and type of collaboration that a company will undertake is based on the stage of the research, the scientific field, and the size of the company and R&D effort. For small companies, in particular, external collaboration is critical, because these firms often have limited R&D budgets and therefore need to maximize research capacity by leveraging work through collaboration.

Collaboration with Universities

Although industry does not rely on universities for commercially viable innovative technologies, all interviewees acknowledged the importance of collaboration with universities. Industry needs new knowledge from universities in order to build new technologies and to improve old ones. In fact, a company will occasionally support university research in an area that is new to the company and that also extends the university's research program into new topics. In addition, industry officials increasingly participate on advisory committees at universities to provide their perspectives on promising long-term research frontiers. Collaborations also occur with consultants from academia who provide perspective, analysis, and special expertise for many industry projects.

> Smith pointed out that there are only a finite number of relationships with universities that a company can sustain. For every dollar spent on research, $10 needs to be spent on development, and $100 on design and building. Currently, Conductus is focusing on development and design and, therefore, can only participate in selected opportunities to leverage those developments in the best way possible. Collaboration with universities is also self-limiting by the number of in-house lab scientists who care about the research project and are willing to put in the time for collaboration as well as by financial constraints, according to Boer and others. A few interviewees noted that university contracts are a financial cost at the margin of the company's portfolio, and can be put on hold if need be during times of financial stress.
>
> Martin Marietta prefers to fund university research that will stretch it into an area where the firm has only limited expertise, according to Westwood. Otherwise, the flow of information tends to be from the company to the university. This work at the margin of Martin Marietta's

current capabilities will permit the firm to expand its know-how and understanding. Similarly, GM Research Laboratories funds only basic research or specific technology that is not close to the firm's proprietary research, Frosch noted. W.R. Grace also does not establish contracts with universities in technologies where the firm has a vested interest. Rather, it seeks to create relationships around emerging technologies in key scientific areas for the company. Boer believes that the company has no choice but to stay abreast with university research applicable to key areas for the company. A high percent of Procter & Gamble's drug discoveries or therapies will come from understanding underlying mechanisms, not primarily from a new drug structure, Place said. Therefore, it is important to work with universities whose scientists are highly competent in relevant research. Cost, talent, speed, and degree of protection dictates the amount of collaboration that P&G will seek from universities on any given project. In-house research can be done much faster at high cost if need be.

University Misconceptions about Commercialization and the Process of Innovation

According to a number of industry interviewees, many university officials erroneously believe that discovery of new ideas represents the most significant step in the process of innovation, and that universities are the key source. While the creative aspect of invention should not be minimized, even in the rare breakthrough event the development of an idea into a commercial product is a long, costly, and often unsuccessful process. Interviewees stated that many university officials tend to have an inflated view of the importance of university research efforts in innovation. Most often ideas from university scientists are too embryonic to be quickly or easily commercialized.

Some industry interviewees expressed the concern that universities in the wake of increasing financial constraints and limitations on the support of basic research will take on product discovery as part of their mission and research. They stated that this would be a mistake. Universities should not attempt to orient their research more closely to product discovery; this is not an appropriate role for universities, nor is it a task for which they are generally well suited, said the interviewees. Rather, they must continue to teach, to foster creativity, and to advance the frontiers of knowledge through long-term basic research. Most, if not all, interviewees commented that this role does not conflict with the need for university-industry collaboration. On the contrary, they explained that this role creates the underlying structure for the nature of collaborations and the expectations that universities should have when entering into cooperative programs with industry; universities can provide the trained manpower to address long-term basic research questions related to industrial goals. In addition, it

was noted that for a few particular industries—not represented in the IRI-Roundtable study—applied research at universities is germane to industrial development.

> Boer finds that 50 to 60 percent of the industry-university relationships have poor convergence of goals, i.e., typically where W. R. Grace is seen mainly as a source of money. In the other 40 to 50 percent, however, the relationship is successful, persists for a long time, and funding tends to increase. W.R. Grace is generally loyal to those who establish ideas and move them forward. Money spent at universities should be focused on long-term basic research, but universities also must understand the goals of industry: to link discovery and commercial reality. Boer views successful projects as those where convergence on a meaningful societal goal has occurred and both intellectual and commercial achievements are attained. Boer agreed that W.R. Grace contracts may cause a shift in direction of university research, but he pointed out that this is a voluntary process beginning with a proposal from a faculty member.
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> Heininger believes that since World War II, university research has tended to focus on the source of funds and has de-emphasized interaction with the users of the output of research. Government funding by peer-review decisions means that university scientists have played a key role in deciding what research to fund and this has emphasized the pursuit of scientific knowledge, while not necessarily providing a balancing input as to what society's needs are likely to be from other points of view. Heininger acknowledges that the needs of industry cannot be the only important criteria for the conduct of basic research, but he believes the selection process for investing in R&D may be part of the reason for our current competitiveness problem. Place believes that universities should continue to conduct basic research; that if industry and technical growth were the "customers" for the results of academic research, the use of discoveries and the education system would be drastically altered.

Universities as Network Nodes

The process of innovation requires a complicated network of interactions and exchange of ideas among companies, universities, federal laboratories, vendors, and customers, and universities are part of the glue that holds the network together, according to interviewees. The network facilitates communication of new knowledge and ideas, and contributes to in-depth understanding of existing ones, often via interaction at meetings arranged by professional societies.

Lucky sees universities as important "centers of thought." Bell Laboratories gets information from universities by hiring students who know what is happening in these "centers of thought." An open line of communication exists between the Bell Lab's research division and universities so that if a breakthrough occurs at universities, AT&T is in a good position to take advantage of the discovery. Lucky likened closing down universities to closing down coffee shops in Paris at the turn of the century and asking whether there would have been an effect on art. Universities are enormous producers of ideas. For the purpose of general knowledge development and access to new ideas from academia, Procter & Gamble has an exploratory-research program. Through this program, P&G hears about ideas that the firm would not have been aware of if it had not funded the program.

Since R&D activities in the pulp and paper industry are interdisciplinary, it is difficult to put together an effective group with all relevant expertise, according to Hall. Using the existing university network can help International Paper establish focused interdisciplinary teams, in spite of the fact that universities try to enter industrially innovative fields primarily because they see this as a source of money.

One-Scientist-to-One-Scientist Relationships: a "Bottom-up Approach" to Collaboration

Many interviewees prefer to set up collaborations between universities and firms on a one-to-one basis. The working relationship between the industry scientist and the university scientist is crucial to recognizing a potential product or a goal, assessing the appropriate time frame, identifying the risk and "marketability" of an idea, and assessing the credibility of the researchers involved, according to interviewees. Almost all interviewees agreed that one-to-one research collaboration is the most likely type of university-industry interaction to foster communication of innovative ideas. University consultants to industry also provide an important mechanism for one-to-one interactions.

One key ingredient for successful collaborations with universities, according to Axen, is who initiates the collaboration. He believes it must come from a scientist from each sector working together, include in-house technology capacity as part of the project team, and have truly complementary research. If the systems overlap too much, scientists in-house and in the university become competitors rather than collaborators. In general, when the collaboration comes from Upjohn and university administrators in a top-down approach, it does not work.

Boer noted that in the past too much emphasis had been given to top-down ideas for partnership. These may be good at the "slogan level", but are not good at the motivational level. W.R. Grace now prefers using a bottom-up approach originating between a professor and an internal scientist.

Geographic Proximity

In establishing relationships with universities, geographic proximity is very important to most firms, according to a number of industry interviewees, in order to maximize the potential for communication and interaction.

Conductus was formed with a conscious effort to nucleate the company around universities where fundamental work on superconducting materials (as well as some device work) is being done. Allied-Signal and Reynolds Metals also tend to have closer association with geographically proximate universities to maximize the ability for one-to-one exchange.

However, for Upjohn, having access to research is the number one priority; geography is secondary. In fact, the company created a European Discovery Centers program because it did not have a significant image or presence in Europe.

Consortia, Centers, and Affiliates Programs

Consortia and centers that include the participation of several companies may be good at promoting basic science but are not effective at commercialization: they are too remote from the marketplace; they provide uncertain commercialization benefits given the generic nature of the work; and there is a strong motivation for individual industrial members to develop products in-house rather than share results, according to a number of industry officials interviewed. Consortia and centers may be effective in addressing generic issues in the development of new technologies and providing a networking source, interviewees noted, but they are unlikely to play a significant role in the process of innovation.

Generally, industrial affiliates programs are not profitable, according to industry interviewees, and generally, companies are less and less interested in participating. Those that continue to support such programs tend to do so either as good will gestures or to have access to students and faculty for recruitment.

W.R. Grace has joined a number of consortia, and subsequently has dropped out of most of them because they were not meeting W.R. Grace's needs for competitive advantage. In their primary form,

university-based consortia are strong interdisciplinary faculty groups working on industrial issues of common interest to leverage financial investments. Boer believes that: the value for a company to join a consortium is inversely proportional to the amount of knowledge it has about the subject—creating the possibility of proprietary technology leaking to competition if one

participates actively; often faculty do not collaborate actively with member companies; and it is time-consuming to find out what is going on in a consortium.

International Paper participates in consortia in forest research, according to Hall. The company does not expect proprietary information from consortia arrangements and sees no advantage other than that the firm is the largest landowner in the U.S. and, therefore, has the most potential for advance. For a modest investment, consortia provide the company with access to cutting edge research.

Place believes that sometimes creating a structure for interaction gets in the way of the potential when two individuals—one in-house researcher and one university researcher—want to work together to address a particular problem or system. The one-on-one approach is the vehicle of choice for collaborating with universities from the perspective of Procter & Gamble and other industries.

Large Multimillion-Dollar Alliances

In general, most firms do not opt for large multimillion-dollar partnerships with universities or university departments, according to industry interviewees. Indeed, only a few of the interviewees work in companies that are involved in large alliances.

From Heininger's point of view, both of the large university alliances in which Monsanto has participated—with Harvard and with Washington University—have not yet demonstrated success. He noted, however, that others within Monsanto view the alliances quite differently and believe them to be very successful. The bottom line is that products need to be eventually developed if a major collaboration is to be judged successful for both parties, Heininger believes. Otherwise, Monsanto's participation becomes a charitable donation to the university. No product leads emerged from the 12-year project with Harvard. The current interaction with Washington University cannot be judged yet, but to date no products have been developed. Primarily, those ideas touted thus far have been failures because the assumption that a product was

ready for development was premature. Heininger says that at this point in a well-run in-house project, Monsanto would have expected products by now.

Many of the interviewees noted that they had some skepticism as to the ultimate commercial success of these partnerships. Some commented that while the projects are viewed as great successes from the university perspective because they provide a large source of funds in support of worthwhile basic research efforts, the industry perspective is that their success in promoting innovation and commercialization remains to be seen.

Intellectual Property Rights

Industry interviewees complained about difficulties in negotiating intellectual property rights and patenting and licensing agreements in university-industry partnerships. The probability of any commercially viable product or process evolving from an alliance with a university is remote, according to a number of interviewees, because of the type of research that companies support at universities. Interviewees noted that, ironically, industry in general is becoming more flexible in the conditions of its support for university research while universities are becoming more stringent in negotiating intellectual property rights for potential discoveries based on the slim chance that a significant, commercially viable breakthrough will occur and hence will result in an opportunity for the university to reap great financial rewards. Industry interviewees stated that these expectations are, in general, unrealistic and arise from the views held by many university officials regarding the innovation process and the role of breakthrough discoveries in that process. Furthermore, these expectations on the part of university officials can cause divisiveness on the campus between university administrators adamant about claiming intellectual property rights and university scientists who wish to conduct the research without burdensome policies, and between the university and industry participants, according to interviewees.

Martin Marietta is not overly sensitive to how the intellectual property issue is handled in contracts with universities because, in Westwood's view, the probability of any moneymaking product being developed is very low. However, he resents any university lawyer or financial spokesman declaring that the company has no rights to outcomes of research that the firm has funded at a university. Westwood's opinion is that these people do not understand the R&D process, and are sometimes so rigid that further useful dialogue is not possible.

Hanneman observed that at Reynolds Metals, most patents from academia are usually not crucial from a business viewpoint. Internally generated technology is often sufficiently complex that it is unlikely that

a competitor will stumble onto an exact replica. Because this industry is more mature than some, it is less likely that a competitor will develop a broad dominating patent.

Because Conductus and Centocor are small companies, they are more dependent on patents that come from outside the firm. Exclusivity is important in many technologies in order to limit others from doing the same work. Universities must find a way to grant exclusivity to firms in which faculty are involved, according to Smith. This is often viewed as a conflict of interest. Rather, it should be viewed as a mutuality of interests to maximize the chances of marketing the discovery.

In-house Collaboration

Many of the industry interviewees noted that the problem of bridging between basic research ideas and product development that occurs in university-industry collaborative research is also present within a company; the same breakdowns in communication and understanding can occur between research divisions and development divisions. Some interviewees stated that the research divisions of their firms view themselves as part of the academic system, and they conduct similar long-term basic research. These research divisions feel pressures comparable to that felt by universities to move into more applied areas of research because of financial constraints.

According to Smith, senior technology managers tend to think somewhat nostalgically that if corporate laboratories could conduct R&D that might or might not be relevant to the company's interests—the way they did 15 years ago—then everything would be alright. This method of searching for breakthroughs worked in the past because the U.S. had no competition and money was cheap. The system has changed, however, and many R&D facilities have not evolved. Better relations with management will stabilize corporate laboratories more. The focus must be on closer cooperation with corporate laboratories reaching out to meet the needs of business units.

AT&T has a difficult time fostering communication and interaction between Bell Laboratories scientists and scientists in product development divisions. When scientists in development sections have research problems, they do not always share them with scientists in the research division. Even if research scientists work on a development problem, often they are not familiar with the "real world" problems that affect the system once scale-up and other considerations are taken into account. AT&T tries to create formal and informal networks for

communication between the development and research sectors of Bell Labs. In fact, Bell Labs has even established a "thief of the month" award to the scientist who takes someone else's idea to market. Lucky anticipates that Bell Labs research will become more relevant to AT&T in the future.

There is currently some pressure on the technical and research staff of GM's Research Laboratories to be more applications-oriented like the manufacturing and development divisions. The oscillating shift through the years from operations to research and back again is real and may be healthy: if a division is too research-oriented, it is viewed as an ivory tower; if it is too operations-oriented, it can become too dependent and, therefore, too short-term oriented. The relevance of science is important, according to Frosch, but when a company allows irrelevance in its research, the firm also creates the opportunity for an unexpected advance.

A major function of the corporate research lab at Martin Marietta is, according to Westwood, to acquire needed knowledge from the outside (as a systems integrator firm) and to transmit it in a timely and understandable fashion to an in-house "receptor." The lab carries out research only when the needed knowledge is not obtainable elsewhere. More often than not, a problem or a need in marketing is identified, and the industrial scientists reach back into science to pull up a new idea, i.e., technology needs drive the science.

Schoemaker stated that Centocor's in-house research effort is designed to improve and accelerate the lengthy and expensive process from discovery to commercially approved product. Centocor's scientists do not carry out true exploratory research; they are product-focused. To achieve effective technology transfer, research scientists at Centocor must maintain a tight technical focus, promoting product development and resisting the tendency to stray into the basic end of research. They must also stand on equal ground with their counterparts in academia because successful collaborations require mutual professional respect between the scientists involved. Centocor scientists are trained to spot important technical breakthroughs and product opportunities early on, and to effectively bring them into the company at the optimal time.

Collaboration with Other Companies

For conducting precompetitive research, sometimes companies will collaborate with each other to leverage expenditures and to reach a new level of understanding about

a technological advance, according to interviewees. Some development work can also be undertaken with company-company collaboration, primarily with foreign firms. Partnerships of this sort can be successful because they do not violate U.S. antitrust laws, nor do they usually involve competition between the two firms, given that often the markets for two firms willing to collaborate in such ventures tend not to overlap.

> Occasionally, Reynolds Metals deals with a competitor in a joint development, to a point. Hanneman stated that this works when neither firm alone would have been able to independently justify carrying out the research at that time. The aerospace industry sometimes operates by joint ventures to create an industry-wide team. Davis pointed out that Allied-Signal eventually competes with other industrial team members, but cooperation is worthwhile in the early stages to leverage the expense of development. Joint ventures are particularly useful with foreign companies where access to foreign markets would otherwise be difficult. Pielet noted that Inland Steel also collaborates with other companies (e.g. Nippon Steel).
>
> The use of strategic partners will be increasingly important for aerospace companies as the defense industry tends to have reduced capability to drive the development system. International markets and cost reduction will become increasingly important factors along with speed to market and ecologically clean products, according to Westwood.

Collaboration also occurs between firms when the cost of conducting the R&D is prohibitive for one firm alone, when the general topic and issues of concern cross individual company and industry sector boundaries (e.g. meeting environmental regulatory requirements), and when the collaboration will contribute to the credibility of the research.

> Heininger predicts that companies will have to consolidate because of federal regulations. Large companies will get larger and the small ones, less able to meet regulatory requirements, will gradually disappear.

Research collaborations with small firms can be advantageous to larger firms: these large firms can explore a new field with minimum risk or investment by providing financing for the research to be conducted in an atmosphere relatively free of bureaucratic constraints.

Partnerships with vendors can also be important in addressing how to convert old equipment and machinery for use with newer products or processes, and to conduct trial work, according to some industry interviewees.

Collaboration with Federal Laboratories

Some interviewees have R&D interactions with federal laboratories, but few strong collaborative arrangements exist between these laboratories and the firms represented in the interviews. Industrial officials noted that the primary issue that gets in the way of industry-federal laboratory collaboration is that the laboratories do not have a clear mission related to the development of civilian technology or an understanding of industry as a customer.

> Monsanto does not interact much with federal laboratories even though it started and operated one for over 40 years. Similarly, Martin Marietta has not used Oak Ridge as a resource as much as company officials hoped it would, in part to avoid any criticism regarding some perceived privileged position.
>
> Westwood believes that the federal laboratories need to review their focus, and to recognize U.S. industry as their most important customer. They will have to learn more about this customer in order to be of assistance and this will require extended visits, sabbaticals, joint programs, etc.

Industrial interviewees observed that since the enactment of the Federal Technology Transfer Act of 1986, federal laboratories have been in a state of change, and some laboratories have adapted more rapidly than others. Although traditionally the laboratories have not collaborated effectively with industry, their collaborative capacity has not yet been proved or disproved in their current but changing form, according to industry interviewees. Some of the interviewees stated that the federal laboratories can be a greater asset than they now are and that the time may be ripe for enhancing their collaborative interactions with industry. The interviewees were quick to add, however, that change on a small scale by federal laboratories was likely to have a negligible effect on interactions with industry. Interactions between federal laboratories and industry will increase substantially only if the missions of the laboratories can be changed dramatically to focus on the needs of industry.

SUMMARY

The purpose of this document is to add the perspectives of seventeen senior industrial officials to the ongoing discussions of how innovation occurs and how alliances with universities contribute to technical change and competitiveness within individual companies. It is important to note that the term innovation was considered by these industrial officials as the conception of an idea and its movement toward and embodiment in a commercially successful product or process.

The perspectives presented in this document are not intended to represent generalized conclusions for all of industry, but rather should be interpreted as a collection of opinions of the seventeen industrial officials interviewed. As is reflected in the text, diverse perspectives exist among these industry officials.

Four central themes emerged from the interviews:

- In many industries, innovation usually occurs through in-house incremental improvement to existing products or processes rather than the rarer breakthrough event that revolutionizes a product or process.

- Industry is the primary source for innovation. Universities play only a limited role in this realm. Interviewees noted that the role of universities varies depending on the maturity of the field, the type of innovation—incremental or breakthrough—and the "culture" of the company.

- The primary role for universities is as educator and provider of talent. This function is universities' greatest contribution to the process of innovation, according to interviewees. Providing in-depth, fundamental understanding of scientifically and technologically new or emerging ideas is another significant role for universities. According to interviewees product development should not be an academic role.

- The challenge for industry is to determine the adequacy of the knowledge base; to identify emerging technologies and barriers to knowledge transfer; and to define approaches to collaboration for maximum input of new knowledge. No company is large enough or smart enough to meet all of its knowledge needs within the firm. Interviewees stressed that industry must maintain relationships with universities, companies, and federal laboratories on topics relevant to their company's technological focus.

APPENDIX A

Industrial Officials Interviewed

Udo Axen, Vice President, Planning and Administration, The Upjohn Company

Joel S. Birnbaum, Vice President and General Manager, Information Architecture Group, Hewlett-Packard Company

F. Peter Boer, Executive Vice President for W.R. Grace and Group Executive for Corporate Technical Group, W.R. Grace and Company

David Botstein, Professor and Chairman, Department of Genetics, Stanford University School of Medicine

Lance A. Davis, Vice President, Research & Development, Allied-Signal, Inc.

Robert A. Frosch, Vice President, Research Laboratories, General Motors

Ralph E. Gomory, President, Alfred Sloan Foundation

F. Keith Hall, Chief Scientist and Director, Science & Exploratory Development, International Paper Company

Rodney E. Hannemen, Vice President of Corporate Quality Assurance and Technology Operations, Reynolds Metals Company

S. Allen Heininger, President Elect, American Chemical Society

Timothy S. Killen, Manager, Engineering & Construction Technologies, Bechtel National, Inc.

Robert Lucky, Executive Director, Research Communications Science Division, AT&T Bell Laboratories

Howard Pielet, Scientist, Inland Steel Company

Geoffrey Place, Vice President, Research and Development, The Procter & Gamble Company

Hubert J.P. Schoemaker, Chairman and CEO, Centocor, Inc.

Ora Smith, President and CEO, Illinois Superconductor Corporation

Albert R.C. Westwood, Vice President for Research and Technology, Martin Marietta Corporation

APPENDIX B

Questions for Discussions with Industrial Officials

Character of Technological Advance

- How would you characterize technological advance in your industry?
  - Is it principally new products or processes or both?
  - Do technical advances come about incrementally, in discrete steps, or both?
  - To what extent are the important advances patentable?
  - Has technical advance accelerated or slowed over the last decade in your industry?

Sources of Technological Advance

- In your industry, what is the role and importance of the following sources of technological advance?
  - R&D done by your company and other firms in the industry
  - Work of equipment and material suppliers
  - Work done by and ideas from customers
  - Research in government labs
  - University research
  - Other

University Training and In-Company Training

- How important are universities in providing the right kind of training if one is to be an effective R&D engineer or scientist in your industry?

- What must a new university trained scientist or engineer learn at your firm before he or she can be effective in R&D?

- Does your industry look to industrial training institutes (e.g. the Wang Institute) as an important source of trained people?

University Roles

- What is the role and the importance of the following possible university contributions to technological advance in your industry?
  - As a source of inventions or prototype new products or processes
  - As a source of new knowledge that enables your firm to better identify and conduct its inventive efforts

- As a window to a world-wide knowledge base
- As a source of research techniques and new equipment
- As a source of educated young engineers and scientists
- As a source of consultants
- Other

- What type of formal structures—in your company and in your industry (e.g. technical societies)—facilitate one-on-one interactions between industry scientists and engineers and university scientists and engineers?

- Are universities providing functions that others could perform (e.g. private consulting or research organizations, or industry consortia), or that you could do yourself? What criteria do you use in deciding to interact with universities rather than to conduct similar efforts in-house?

- If not to universities, to what other organizations and arrangements does your company look to provide the kinds of inputs listed above?
  - private research and consulting organizations
  - trade or technical associations
  - industry-wide laboratories or consortia
  - government labs

New Alliances

- What kind of alliances between your company and universities have come into place in recent years (e.g. industrial collaborations funding university research, industry participation in university-based or affiliated research, technology centers, etc.)?

- What other kinds of alliances are forming in your industry?

- What does your company expect from these alliances?

- Does your company's participation in new alliances reflect activities and attitudes that are typical of your industry?

- What are barriers to new alliances? What are new approaches to alliances?