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ABSTRACT

The results of a study of university/industry research interactions are presented, along with four reports on collaboration, and an annotated bibliography. The study, "Current U.S University/Industry Research Connections" (Lois S. Peters, Herbert I. Fusfeld, and others), involved on-site interviews with 66 companies and 61 public and private universities that were top-ranking research and development institutions. The focus was fields of study in the physical and life sciences, plus some social science, business, and medical education programs. Types of interactions formed four major groupings: general research support, cooperative research support, support for knowledge transfer, and technology transfer. Appendices include a geographical listing of each of 475 research interactions, including the names of the institutions, the discipline, the mechanism of interaction, and the duration. Report titles and authors are as follows: "State College Science and Engineering Faculty: Collaborative Links with Private Business and Industry in California and Other States" (Frank and Edith Darknell); "University-Industry Connections and Chemical Research: An Historical Perspective" (Arnold Thackray); "University-Industry Cooperation in Microelectronics and Computers" (Erich Bloch, James D. Meindl, and William Cromie); and "Report on a National Science Foundation Workshop on Intellectual Property Rights in Industry-University Cooperative Research" (National Science Foundation). (SW)

University–Industry Research Relationships

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University–Industry Research Relationships

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CONTENTS

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In early 1980 the National Science Board chose as the topic of its 1982 Annual Report to the President and the Congress, "University-Industry Research Relationships." This was a propitious selection as 1980 and 1981 turned out to be boom years for relationships between campuses and corporations. It is perhaps even more significant that these enhanced activities have persisted despite economic difficulties in 1981 and 1982.

A scan of the literature on the subject in early 1980 revealed that there was no comprehensive information available on the extent and nature of research relationships between universities and companies. Discussions among NSB members revealed great variation in types and character of relationships by science and engineering discipline, by type of industry and by character and history of individual corporation or campus.

Given this state of affairs it was decided that the Board would undertake to contribute to the factual information base about university-industry exchange through commissioning several studies and assessing the available statistical data.

The National Science Board's interpretation of the materials gathered in these studies has been published as, *University-Industry Research Relationships: Myths, Realities and Potentials*, the Fourteenth Annual Report of the National Science Board to the President and the Congress.

In this volume, we make available the commissioned studies and reports themselves in the belief that the detailed materials will be of use to both practitioners and policy makers.

The National Science Board is responsible for the selection of the study topics and the authors. While affirming the high quality of the studies and the reporting methods employed, the specific findings and conclusions of these papers remain the responsibility of the authors and are not necessarily endorsed by the NSB. All of the studies were subjected to critiques by outside reviewers, and modified in the light of their comments.

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CURRENT U. S. UNIVERSITY/INDUSTRY RESEARCH CONNECTIONS

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This study could not have been accomplished without the willing participation of university and company representatives. The authors gratefully acknowledge the considerable amount of time spent by those who helped us arrange our site visits and the many professors, administrators and industrial researchers who spent their valuable time patiently answering our inquiries.

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CONTENTS

INTRODUCTION

A. Objectives of the Study

The intent of this study is to present a broad view of the extent and variety of current university/industry research interactions; to characterize the principal forms of these interactions, and the factors involved in their initiation and evolution; to develop a basis for understanding the relationship of each type of interaction to the objectives of university and industry; and by such systematic analysis offer a perspective on the current state of university/industry research interactions.

B. Scope of the Study

This study was commissioned by the National Science Board to provide background information for the Board's 1982 report on University/Industry Research Relationships. The intent was to focus on research programs. We reviewed training and education programs only insofar as they were related to research.

Within the constraints of time and funding, we assembled a rich data base of research interactions, and reviewed as many distinctive types of research interactions as possible.

The emphasis throughout this study was to develop case studies of interactions through detailed on-site interviews of university, industry and government research partners. Supplemental information was gathered through material provided to us during our site visits and through literature surveyed during the course of gathering facts and perceptions about a large number of categories of interaction. We were able to assemble some numerical data that lend themselves to quantitative analysis. These detailed qualitative and quantitative data provided us with insight into many issues, barriers and opportunities for university/industry research interactions.

This study avoided duplication of information in the following areas:

* Historical university/industry linkages in the development of chemistry and chemical engineering in the U.S.
* Industry relationships of science and engineering faculty in non-doctoral state colleges and universities.
* Analysis of the existing data base on the flow of resources from industry to universities.

CHAPTER II

UNIVERSITY/INDUSTRY RESEARCH INTERACTIONS IN CONTEXT

A. Concerns About the Health of Our Overall Technical Enterprise System

A number of national concerns arose just prior to the establishment of this study relating to the health of our overall technical enterprise that give the subject of effective utilization of our technical resources a certain level of urgency.

Among these national concerns are the following:

(1) There has been a growing belief that basic research conducted by universities is being weakened by a decline in Federal support (Smith and Karlesky, 1977) obsolescence of research equipment (Berlowitz *et al.*, 1981) and shortages of new faculty in specific areas such as computer science, electrical and chemical engineering (David, 1981).

(2) There has been a genuine concern with the innovative capability of U.S. industry, leading to a major Presidential study of the subject (Mogee, 1979), and which included among its premises:

a. The belief that U.S. industry was devoting a decreasing share of its R&D resources to long-range research (Mansfield, 1980), and

b. The fear that the international competitive status of the U.S. would decline by placing too great an emphasis on short-term product development. (Five Year outlook on Science and Technology - 1981, National Science Foundation).

c. There has been increasing emphasis on the financial difficulties of universities, the decline in academic openings for Ph.D. researchers outside the fields of critical shortages and their potential consequential effects on the innovative process (Vetter, 1977).

There are many questions that can be raised with regard to the data behind these concerns, and with their interpretation. The issue of importance to this study is that university/industry research interactions bear upon all of these concerns, and thus is a subject for examination in its own right. The general line of thought is that, if we understand more about the nature of these interactions, and how their functioning could be of benefit to both university and industry, then some of these national concerns might be addressed by encouraging particular mechanisms.

For example, closer relations might lead to expanded research by universities in areas of basic science and engineering that could be built upon by industry for future growth. Greater rapport between industrial researchers and faculty could strengthen support for graduate students and, presumably, increase industry funding for university research. Cooperative programs might provide leverage for further grants, and thus expand the level of basic research generally. Programs encouraging equipment donations might reduce critical instrument shortages.

B. The Need for a Strategic Approach to Research

Current perceptions of modern science suggest that there are other important reasons for reviewing university/industry research interactions.

In the Twentieth Century, scientific and technological activity has been increasingly recognized as a productive force. Technical research has led to the formation of new industrial sectors—microelectronics, computer and information processing, biotechnology. Science-based industries—electronics, chemicals, synthetic fibers, scientific instruments—have grown at a considerably faster pace than traditional industries—mining, shipbuilding, iron and steel, and textiles (Johnson, 1973).

A recent study by Edwin Mansfield (1980) even suggests that the composition (basic vs. applied research), as well as the magnitude of an industry's or firm's R&D expenditures, affects its rate of productivity increase. Because of this increased awareness of the interrelationships among science, technical change, and economic growth, we have come to expect scientific research to produce concrete benefits.

Another aspect of modern science is that it continually increases in size, cost, and complexity. Not only have the internal dynamics of scientific disciplines become increasingly complex, but it is evident that their subject matter does not evolve through linear or unidirectional stages into innovative inventions or into providing the basis for technical change (Mogee, 1979).

The growth of science and technology is reflected in the expansion of the research university, national laboratories and industrial research laboratory. Each of these sectors covers a wide range of activities from basic research through development and engineering. While each has evolved independently, there are overlapping interests in technical activities, and research interactions have an ongoing history (Thackray, 1982; Rabkin, Y.M. and LafitteHoussat, 1979). The concern for effective utilization of research activities has raised the question: to what extent would more conscious attention to these interactions result in greater benefits?

The expansion of science at all levels has been accompanied by the expansion and significance of externally funded research at universities. But in recent years, our sensitivity to finite resources and limited funds has also grown. Increasingly, a criterion for externally funded research has been social relevance (OECD, 1981).

These three factors, science as a productive force, its complexity and cost, and our increased awareness of limited resources have been used in the past as well as the present as justifications for orienting research to the demands of society and for increased efforts to rationalize our present mix of research institutions and facilities. This interest in effective coordination of research efforts leads to pressures to consider avenues of optimizing the use of our technical resources. It is within this context that we approach the subject of university/industry research interactions. Many of the issues brought up specifically with respect to university/industry research interactions, in fact, bear directly on these more general topics.

C. University/Industry Research Interactions: A Perspective

Thus there are many pressures to review and understand university/industry research interactions. Interestingly, the attention to this subject has grown almost simultaneously over the past several years throughout most of the OECD countries. In industry, a joint Working Group was established between the European Industrial Research Management Association (EIRMA), and the Industrial Research Institute (IRI). The OECD itself has started a study covering its member countries within its Directorate on Science, Technology and Industry, to be completed by the end of 1982. A review is currently in progress within the European Communities on the exploitation of public sector R&D, which includes concern with the response of university research to industrial needs. The Scientific Affairs Division of NATO has taken initiatives to encourage exchanges of technical personnel between university and industry across national boundaries of NATO member countries.

It is our opinion that there is an underlying assumption in all industrialized countries that each must derive the maximum output from its total technical resources. This assumption is not always articulated, but it flows from some of the ideas presented above: Despite the very considerable progress resulting from the independent growth of each sector and the evolution of many forms of research interaction between university and industry, there seems to be a widespread belief that university/industry interactions in particular are an under-utilized mechanism for optimizing our technical resources and that greater attention to these interactions can result in greater benefits.

We believe that the potential benefits of this attention rest upon our ability to determine what is going on today and to understand the impact, so that each sector can create suitable mechanisms for achieving its own objectives, and so that public policy can serve to expedite the process. This perspective underlies this study.

METHODOLOGY

A. Approach

In order to select a significant sample of joint research interactions within the time frame of our study (approximately 9 months to gather data), we chose to concentrate our efforts on collecting information from major research universities and research based firms. This choice reflected four observations:

(1) University based research is conducted in a relatively small number of "research" and doctorate-granting universities. Although there are 200 such institutions, the top R&D ranked 100 universities typically account for about 85% of the total federal R&D funds, with the top 20 accounting for 40% and the top 10 about 25% *(Science Indicators*, 1979).

(2) Basic research within industry is carried out by a small number of very large firms (two firms account for over 25% of the man years and almost 20% of the funds allocated within industry in support of basic research according to an NSF study (Nason and Steger, 1978).

(3) Seven major industries—nonelectrical machinery, electrical equipment and communications, chemicals, petroleum products, aircraft and missiles, motor vehicle and motor vehicle equipment, and instruments—account for over 80% of total company-funded R&D *(Research Management*, 1981).

(4) The ten largest corporate R&D spenders account for about one-third of total industrial R&D (*Business Week*, 1978-1981).

Despite these concentrated efforts in a relatively small number of major universities and very large firms, the authors recognized the potential for innovative interactions at other universities and among universities and smaller firms. Information was requested about such additional interactions at each university site visit. Representatives of several small firms were interviewed. Several universities not ranked in the top 100 R&D spenders were visited. Furthermore, in order to place our sample in perspective, visits were made to a small number of companies and universities known to have less extensive university/industry research connections than the majority of our sample.

Because accurate quantitative data adequately representing the broad spectrum of interactions was unavailable or difficult to obtain, the authors emphasized gathering systematic information on specific individual experiences. After several attempts to collect broad based quantitative information, we recognized the following:

(1) The National Science Foundation already collects information on industrial monetary support of university research;

(2) It is difficult to evaluate time and effort contributions to cooperative programs in discrete monetary units;

(3) Industrial monetary support of university research has been approximately 3% of total university expenditures for a decade. Because it has been a small part of total expenditures, it has not warranted detailed accounting.

(4) The distribution of external funds is pursued in a complex pattern throughout a major corporation, therefore industry does not usually keep central records addressing this function (see Chapter VI, B. 1.).

The study emphasized on-site visits and personal interviews that would provide case studies for the categories of interest. Much background material was available in the literature, and questionnaires were used to develop information specific to the institution or program of interest. Nevertheless, the personal interviews formed the core of the study.

Our interviews were directed toward understanding how different mechanisms operate, what motivations formed the base for a given type of interaction, and how well objectives of all parties were served. They were not primarily concerned with total numbers of people involved or total funding on a national scale. We therefore devoted attention to diverse types of interactions and focused initially on fourteen mechanisms of interaction identified in a preliminary study conducted by the Center for Science and Technology Policy at New York University (Brodsky, *et al.*, 1979).

B. Site Visits

Institutions were selected for visits after a search of the relevant science policy literature, discussions with government officials from the National Science Foundation, Office of Naval Research, and National Institutes of Health, selected contacts with industry and academic personnel knowledgeable about university/industry relationships and trends, and a formal meeting of the project's Advisory Committee with the research team. The members of the Advisory Committee were: Rustum Roy, Pennsylvania State University; Joseph Libsch, Lehigh University; Edward David, Exxon Research & Engineering Corp.; Kenneth Brondyke, Alcoa.

A complex set of criteria evolved in the selection of institutions for site visits. The first concern was to design visits to include the maximum number of distinctive types of interactions within time and funding constraints. We thus selected a minimum set of major institutions that would provide information on the fourteen mechanisms of interactions identified in our preliminary study (Brodsky *et al.*, 1979). This set of institutions was then expanded to include several companies reported to be very active in support of academic research and a selection of companies representative of a broad spectrum of industrial sectors. In constructing the final study sample, we also considered a selection of institutions that would provide a broad range of R&D ranked universities and a broad range of levels of industrial support of academic research. We then adjusted our final sample so that it would provide us with information on major economic regions of the U.S.

Site visits were arranged with the help of the American Association of Universities and members of the Industrial Research Institute. Research administrators at each institution were asked to help the research team set up interviews with directors or participants in university/industry programs. The research team identified these programs by surveying the literature, and by soliciting suggestions from the project's Advisory Committee, and top level governmental and industrial administrators. Administrators at the institutions visited were also asked to identify programs at other institutions that might be regarded as a unique, significant, or a potentially important emerging university/industry research interaction.

Members of the research team interviewed over a hundred top level administrators and about 400 scientists. Visits lasted for a half-day (42), one day (45), or two—three days (8). A few interviews (10) were by telephone conference. In a few instances, the research team visited with university scientists who had no past research support or interactions with industry, and a few discussions were held with humanities professors.

Companies and universities were visited in all regions of the United States. Lists of companies and universities surveyed are appended (Appendix I). Interviews were conducted at a total of 95 institutions. The universities visited included 22 public and 17 private institutions. The university sample concentrated on the top 50 R&D ranking institutions based on NSF 1978 figures of total research expenditures of the major U.S. research universities. The team also visited six universities each in the 50-to-100 and 100-to-200 ranking levels (Table 1). For each of the R&D groupings, 1-25, 25-50, 50-100, and 100-200, the team covered four levels of industrial support representing, respectively, 3%, 3-4.5%, 5-.0%, and ,10% of the total university R&D funding that came from industry (Table 1). The universities visited accounted for about $1.5 billion of university research and development, or from 25% to 30% of all university R&D activities.

The 66 companies visited covered all of the *Business Week* Industrial Groupings. They were responsible for about $12 billion of private sector research and development in 1980. All but 9 of the companies visited were members of the Fortune 500, and had R&D budgets (1979) of over $100 million. Although we realize that our company sample does not permit in-depth treatment of the particular relationships that can exist between smaller companies and nearby universities, we did encounter particular anecdotal data in a number of cases relating to university and community involvement with new technically-based ventures (see Chapter VIII, p. 48 and Chapter X, p. 110).

In summary, the universities we visited were responsible for one-half of the total university research expenditures in the United States, and the companies we visited were responsible for about one-quarter of the private sector R&D expenditures in the United States. (NSF, *Academic Science, R&D Funds, FY 1979* and Company 10-K Annual Reports.)

C. Technical Fields Studied

The study focused on fields of study in the physical and life sciences and included the academic disciplines of engineering, agriculture, physics, chemistry, and biological sciences.

Two programs in the social sciences and one business school program were reviewed. Within the life sciences, activities in medical schools were covered at eleven of the universities visited.

D. Interview Procedures

Site visits to institutions included interviews with central administrators, department heads, faculty, and industrial scientists. A protocol of the types of questions asked during interviews is appended (Appendix II).

Table 1

Universities Surveyed in Study Grouped by R&D Ranking and Percent Industrial Support of Academic R&D by Total Campus R&D Expenditures—Top 200 R&D Ranked Institutions, FY '79

% Total R&D Derived from Industry, FY 79	Rank and Range of Total R&D Support			
Overall Average 4.4%*	1-25 $58.9M-141.6M 3.9%*	26-50 $35.1M-58.1M 4.0%*	51-100 $22.0M-21.6M 4.1%*	101-200 $2.6M-14.2M 7.5%*
<3.0%	U. Wisconsin Yale University U. Texas (Austin) U. Chicago	Washington U. Louisiana State U. U. Utah	Princeton University	
3-4.5%	Harvard Stanford U. Minnesota U. Washington U. Illinois	Colorado State U. Duke U. Cal Tech Case Western U.	U. Maryland U. North Carolina	Rice U.
4.6-10%	MIT U. Michigan Penn State U. USC	North Carolina St. Purdue U. U. Arizona	U. Delaware Clemson U.	Lehigh U.
>10%	U. Rochester	Georgia Tech.	Carnegie Mellon	U. Houston Rensselaer Poly. Tech. Colo. School of Mines
No data on Industry Support	U.C. San Diego Johns Hopkins UCLA			

*Excluding institutions for which there is no industrial support

The questions asked fell into three categories:

(1) General questions asked of both scientists and administrators,

(2) Questions directed toward administrators, and

(3)Those directed toward directors and participants in university/industry research programs.

Requests were made at each institution visited for numerical data on the amount, types, and form of industrial support of university research. If this information was not forthcoming, an attempt was made to document some of the difficulties in accounting for industrially supported research at universities.

E. Response

All institutions requested to participate in this study responded positively. Those interviewed usually responded enthusiastically to the majority of questions asked in the time allotted, most often one hour. One question, "What do you believe to be the ideal mix of government/industry/university support of university research?" was only answered by a few and then reluctantly.

While the response to the questions on the nature, origins, level of support, and structure of university/industry research interactions was generally easy to obtain, information on the outcomes for individual programs of these programs was usually less explicit.

Comprehensive data on the total amount of industrial support was unavailable at most institutions even for the current fiscal year. Not one institution could provide comprehensive data on the trends in industrial support of university research within the last three decades, or even over the last few years.

THE STATUS OF UNIVERSITY AND INDUSTRY R&D

This study was conceived just prior to the present shift (Bromley, 1982; Fusfeld *et al.*, 1981) in national focus and climate for research and development. Our field trips were carried out amidst an outpouring of articles that drew attention to university/industry research interactions in the '80s. These articles generally fell into three categories:

(1) Those which addressed the need for improving research cooperation between academic and industrial sectors to help lagging U.S. innovation,

(2) Those which raised concerns about university/industry research connections, and

(3) Those which document a variety of new arrangements.

This active discussion of, and speculation about, university and industry research and development in the '80s provided the investigators with a sense that there is a genuine interest in stimulating university/industry research interactions. Our interviews and in-depth investigation of the material at hand suggested that the character and level of these interactions were still in the process of change. Thus, while an evaluation of the current status of university/industry research relationships is valuable as a base line, any analyses of long-term implications is premature.

A. Current R&D Efforts Within the University and Industry Sectors

A brief statement of the current level and direction of R&D efforts within the university and industry sectors should place this current debate in some perspective. The data used is derived from "Science Indicators—1980" unless otherwise indicated.

The total amount of R&D conducted within universities in those disciplines covered by the NSF survey is given below, with the funding for this activity shown.

	R&D at Universities & Colleges[1] (in billions)	
Source of Funds	*1978*	*1981 (est)*
Federal government	$3.06	$4.10
Industry	0.17	0.24
Universities & colleges[2]	1.03	1.49
Other non-profit	0.36	0.48
	$4.62	$6.31

[1] "National Patterns of R&D Resources"—NSF.
[2] Includes state and local government funds of approximately $800,000 in 1978 and $1 million in 1981.

The total R&D activity within academia and industry, divided into basic and applied research and development activities, is given below.

	University R&D in billions)		Industrial R&D (in billions)	
	1978	*1981 (est.)*	*1978*	*1981 (est.)*
Basic research	$3.17	$4.30	$ 1.03	$ 1.55
Applied research	1.21	1.68	6.27	9.35
Development	0.24	.33	25.87	38.25
	$4.62	$6.31	$33.17	$49.15

The July 6, 1981 issue of *Business Week* magazine reports that 1980 R&D spending by industry increased by 16.4% above the 1979 level, a real gain of 4%. An accompanying article suggests that industrially funded R&D is on an established upward trend, and the breadth and scope of research currently underway in U.S. laboratories suggest that there will be a renaissance in technological vigor during the 1980's. It should be remembered that about one third of industrial R&D is funded by the federal government, the remainder by industry itself.

The above data on university and industry R&D deserve additional comments. We have given only the macroscopic data for these two sectors. The division into basic research, applied research and development, at best a very loose and difficult separation, is very different for different industries. Even more variation lies in the extent of government funding, which falls largely in the aircraft and missiles industry and electrical equipment industries. These breakdowns are shown in "Science Indicators" (NSB 1980).

There are comparable differences in the breakdowns of industrial support within disciplines at universities, but these are not collected nationally. Thus, an important feature of the present study has been to identify the division of industrial support at universities, for example, between chemistry and chemical engineering.

Since the greatest emphasis in university/industry interactions is on basic research, this should be placed in particular perspective. The data of "Science Indicators 1980" show that the total national basic research activity is given by:

	Basic Research (In billions)			
	1978	% of Total	1981 (est)	% of Total
Universities	$3.17	50.08	$4.30	49.03
Industry	1.03	16.27	1.55	17.67
Government	0.97	15.32	1.17	13.34
Other non-profit	0.59	9.32	0.85	9.69
Federally Funded R&D Centers	0.57	9.00	0.90	10.26
Total	$6.33		$8.77	

Several points are of interest from these data and the preceding tables:

1. The emphasis within university R&D is on basic research, about 70% in 1978 and 68% in 1981. This still leaves substantial activity in applied research and development to the extent of $2 billion in 1981.

2. The emphasis within industrial R&D is on development, about 78% in both 1978 and 1981. Basic research in industry has increased by $520 million or 50% in current dollars, about 13.8% in constant dollars. It has remained essentially constant as a percentage of total industry R&D. 3.10% in 1978 and 3.15% in 1981. This is, at first glance, contrary to the perception that less industry emphasis is going to long-range programs today then, say, five years ago. However, "long vs. short range" includes consideration of development programs as well as research.

3. Basic research at universities and colleges accounts for about 50% of all basic research in the U.S. Industry conducts about one-third as much as the universities, and government laboratories about 25% less than industry.

4. Of the total basic research conducted nationally, the percentage performed by industry has increased (16.3% to 17.7%), while the university share has decreased approximately one percent (50.1 to 49.0).

Thus, while the distribution of R&D activities is quite different percentage-wise between university and industry, there is a substantial overlap in absolute terms. We refer to the $1.55 billion of basic research in industry and the $2.0 billion of applied R&D in universities for 1981 (est.). This overlap is hardly the sole basis for interaction, but it serves as a minimum start for initiating dialogues. Whether this is the principal basis, whether basic research interests of the university are tied to applied research interests of industry, and how these interactions differ among disciplines are among the points explored in this study.

B. Current Circumstances Favoring University/Industry Research Interactions

These broad trends in university and industry research and development suggest that there is a sufficient basis for increased interactions. This can be seen as follows: On the one hand, federal funding of university research, while still increasing, is doing so at a slower rate (Five Year Outlook on Science and Technology, 1981). Nevertheless, overall industrial R&D expenditures are increasing steadily. Furthermore, there is sufficient overlap of types of funded programs in the two sectors to consider coordination of resources. Studies on support of basic research by industry (Nason and Steger, 1978) and the interdependence of academic and industrial basic research (Proceedings of a Conference on Academic and Industrial Basic Research, NSF, 1961) suggest that an increase in internally funded basic research in industry is usually concurrent with an increase in industrial support of university research. Besides these considerations of levels of funding, there are several other observations which suggest a favorable climate for increased university/industry research interactions. They include:

(1) A disenchantment with the restrictions of federal funding mechanisms is causing universities and scientists to look toward broadening their funding base.

(2) Several scientific fields have reached maturity, and industry is in a position to recognize their potential for new business (biological synthesis, microprocessors) and for increasing industrial productivity.

(3) Industry is expressing with some degree of urgency an interest in, and need for, specific types of technical personnel.

(4) University scientists are beginning to look to some industrial laboratories as a way to gain access to frontier research equipment and technical advances.

Most of the above mentioned forces driving increased interest in university/industry research interactions were alluded to during our field visits. A more complete description of factors motivating researchers to cooperate is given in Chapter VII. The point we wish to illustrate here is that there is at present a favorable climate for university/industry research cooperation.

OVERVIEW AND TRENDS IN CURRENT INTERACTIONS

In this chapter we summarize the extent and variety of university/industry research interactions and present a broad view of current trends in university/industry coupling. The spectrum of university/industry research interactions is described in detail in Chapter IX.

A. The Vehicles of Support and Interaction

Our field investigation of university/industry research interactions documents their variety and multifacted character. Examples of university industry research interactions are given in Table 2. Appendix III lists the interactions identified at 95 institutions, both companies and universities, which we visited. These interactions can be formal or informal. They involve not only monetary support of research, but also include donations, transfers, exchanges and sharing of people, equipment, and information. The duration of successful interactions can be for less than an hour or for more than thirty years. An important interaction can be as simple as a telephone call, or as intricate as a ten-year contract. Some require collaborative efforts either among scientists of different disciplines or between university and industry scientists, others the work of only one scientist. Examples of selected mechanisms of interaction are given in Table 2.

On occasion, special administrative structures or research units are formed to carry out the objectives of those interactions (Chapter IX, p. 106). There is some indication that such arrangements are being used increasingly. In one case, a venture company was formed to distribute research funds, collected from industry, to university scientists.

On our site visits we identified 464 examples of university/industry research ties (Table 3). We wish to stress at this point that we were not comprehensive in identifying all university/industry research interactions occurring at the institutions we visited. This study was not an attempt to establish a complete inventory. Furthermore, it should be noted that the more formal programs were much easier to identify.

In order to grasp more easily the nature of the rather large variety of interactions, we separated the mechanisms identified into four major groupings according to principal objective:

*General research support,
*Cooperative research support,
*Support for knowledge transfer, and
*Technology transfer.

Of the 464 research ties identified, approximately 60% can be characterized as cooperative interactions. It must be stressed here that this is a disproportionate number of the total number of university/industry interactions that occur at the schools we visited. Cooperative programs were generally easier to identify than other program types. Of the remaining total interactions identified, we classified 13% as knowledge transfer, 14% as technology transfer, and 11% as general research support (Table 3). This marks an expansion of the two broad types of university/industry relationships identified by Baer in his examination of the effects of university/industry interactions on industrial innovation (Baer, 1977). His categories include: collaborative research and knowledge transfer.

B. Types of Interaction: The Broad View

1. *General Research Support*

General research support continues to be an integral part of industrial philanthropy. There are several methods by which industry gives general funds to the university. One is through gifts. There can be short term gifts (funds or equipment) which are expended in a finite period of time, or gifts which enter into the general university endowment and provide ongoing research funds. Both types of gifts can be designated for research.

Table 2

Examples of Selected Mechanisms of Interaction

Mechanism of Interaction	Examples
University-Based Institutes Serving Industrial Needs	• Textile Research Institute • University of Michigan Highway Safety Research Institute • University of Minnesota Mineral Resources Research Center • Food Research Institute, University of Wisconsin
Jointly-Owned or Operated Laboratory Facilities	• Laboratory for Laser Energetics, University of Rochester • Peoples Exchange Program, Purdue University • Synchrotron Light Source, Brookhaven National Laboratory
Research Consortia (U/I or U/I/Gov't.)	• Michigan Energy and Resource Research Association • Council for Chemical Research (CCR)
Cooperative Research Centers	• Case Western Reserve Polymer Program • University of Delaware Catalysis Center
Industry-Funded Cooperative Research Programs (Partnership Contracts)	• Harvard-Monsanto Contracted Research Effort • Exxon-MIT • Celanese-Yale
Government-Funded Cooperative Research Programs	• MIT Polymer Processing Program • NSF Industry-University Cooperative Research Program
Industrial Liaison Programs	• Stanford University • MIT • CalTech • Systems Control, Case Western Reserve University • Physical Electronics Industrial Affiliates, U. of Illinois • Wisconsin Electric Machines & Power Electronics Consortium, U. of Wisconsin
Innovation Centers	• Center for Entrepreneurial Development, Carnegie-Mellon U. • Utah Innovation Center
Personnel Exchange	• NSF Industrial Research Participation Program • IBM Faculty Loan Program • Summer Employment of Professors
Institutional Consulting	• School of Chemical Practice, MIT • Yale-Texaco Program • Mechanical & Manufacturing Systems Design, Clemson U.
Industrial Parks	• Research Triangle Park • Stanford Industrial Park • MIT Technology Square (Route 128, Boston, MA) • University of Utah Research Park
Unrestricted Grants to Universities and/or University Departments	• Gifts from industry to departments of chemistry (e.g., Columbia University; U. of North Carolina (Chapel Hill); U. Illinois, etc.,)
Participation on Advisory Boards	• Visiting committees at most schools of engineering
Collective Industrial Action (Including Trade Associations Support)	• Electric Power Research Institute (EPRI) • American Petroleum Institute (API) • Gas Research Institute (GRI) • Motor Vehicle Manufacturers Association • Soybean Association • Council for Chemical Research (CCR)

Table 3

The Spectrum of Interactions Documented in NYU Field Study

Types of Interactions	% of Interactions Documented Falling Into Each Category	(N)*
All Categories of Interactions	100	(464)
• General Research Support	11	(54)
• U/I Cooperative Research	61	(284)
• Knowledge Transfer	13	(58)
• Technology Transfer	14	(68)
U/I Cooperative Research (Selected Categories)	100	(284)
• Special Interest Liaison Programs	23	(65)
• U/I Cooperative Research Centers & Institutes	25	(71)
• Research Consortia	5	(15)
• Grants & Contracts	45	(128)
• Collaborative Interactions	2	(5)

*Total Number of Interactions Falling Into Each Category

We heard of a few recent (4) substantial corporate donations for research facilities. Our talks with university administrators and department chairmen indicated that corporate donations of equipment, while very valuable in certain fields (*e.g.*, computer science), were not at a level to significantly upgrade equipment available for frontier research. Yet we did observe that many technical departments were receiving new gifts from corporations.

The recent Council for Financial Aid to Education (CFAE, 1981) *Survey of Voluntary Support for Education* verified our observations. This survey indicates that in relation to all sources of voluntary support for higher education, corporate philanthropy has steadily increased in share over the past decade, accounting for about 18% of the total by 1980. The CFAE survey also showed that corporate contributions for capital purposes (*e.g.*, "bricks and mortar" and endowment) have been declining in recent years. However, the percentage of total corporate contributions earmarked for research support increased to 27% of the corporate total in 1980.

2. *Cooperative Research Support*

Cooperative research interactions are defined as those requiring some degree of cooperative technical planning. These mechanisms include a spectrum of interactions from joint research endeavors, to cooperative participation of university and industry scientists in contract research, to the establishment of research consortia. Many times they lead to the development of special administrative structures and/or research facilities (see Chapter VI, p. 26). It is an activity where the two parties to some extent jointly plan their research, the program goals, and the disposition of the outcomes.

The general nature of cooperative research is to develop a basis for orderly flow of scientific and technical information on several levels in order to acquire new ideas or accomplish a specific objective through broader inputs, and to provide the foundation for future technical programs.

Money may or may not change hands. Thus, in such a program a company has a direct interest in, and relationship to, the research at a university. It is probable that work going on within the company will relate directly to research carried on within the university.

We attempted to focus on the development of these types of interactions because here there is the most intimate interplay between university and industry, and the barriers between university and industry research systems can become most pronounced (Chapter VII, p. 37). Cooperative research appears to be an area where there is much current creative movement, and is an area where we believe one might seek better and more efficient uses of our resources.

All the mechanisms identified as cooperative research interactions require an element of collaboration, even if only at the initial negotiation phase. However, the collaboration is usually only in general terms. One scientist suggested that the only true collaborative research projects occurred when the principal investigator at the university was also on the board, or was an executive of the company, as in the German model of interaction. He said that only in this way could the scientist ensure that the development and design work be truly integrated with the evolution of the feasibility of a concept, developed within the university. This appears to be an extreme statement, but does characterize a difficulty in designing truly cooperative research interactions between university and industry.

Thus, despite the current interest and activity in cooperative research, there are very few programs with extensive collaboration between university and industry scientists in research design and management. Out of 284 interactions we classified as cooperative, we believe only about 2% fall in this category of truly collaborative interaction (Table 3).

However, there are some recent models of extensive collaboration, particularly in the fields of biotechnology and microelectronics. In Chapters VII, VIII and IX (pp. 43-46, 55-56, and 70-84), we provide descriptions of several of these interactions. In general, it is too soon to determine if these new collaborative ventures are significantly better than other mechanisms in terms of value or significance of outcomes.

The other extreme is when a company negotiates a research contract and does not provide any substantial information pertinent to the internal company research or how this contract fits into the company's research strategy. This occurred in about 2-3 cases we reviewed.

Between these extremes there is a spectrum of cooperation. While all mechanisms can foster cooperation, it was repeatedly stated that only those which revolve around individual investigators develop into true collaboration. Several interviewees suggested that intimate collaboration is not always good, because each must then compromise his objectives, and the goals of the two differing research systems become submerged and/or diffuse. There is a fear that with extensive collaboration, a university professor will be "bought," and directed away from pursuing new avenues of research. One physicist warned that industry is only interested in supporting a knowledge base which is already formally conceptualized. University scientists, he said, must be allowed to explore so that they can provide the technical base of the future. In fact, most industrial scientists do not believe that a university scientist should focus his research too narrowly or become involved in developmental research. On the other hand, it is generally believed that by becoming too involved in the environment of university interests in basic research, the industrial scientist may lose sight of practical solutions and research design.

3. *Knowledge Transfer Mechanisms*

Programs facilitating research connections through knowledge transfer (our third category) become of increasing interest as the U. S. becomes more and more concerned about research coordination, innovation, and the technological base of its industry.

Knowledge transfer mechanisms essentially fall into two categories, those which are structured with this as a primary objective and those which are not. For example, a seminar is held for the purpose of exchanging information and ideas (knowledge transfer), while a university research institute is established to do contract research. However, industry contracted research at the institute will in effect provide a network for university/industry knowledge transfer and is a research connection.

Industrial support of knowledge transfer mechanisms is less formal and may not involve monetary research support. There is generally no institutionalized research structure in programs set up specifically to provide for knowledge transfer. In this study a broad brush treatment of knowledge transfer mechanisms (Chapter IX, pp. 85-98) is made to illustrate alternative possibilities for interactions and their relationship to other university/industry research mechanisms.

Knowledge transfer mechanisms, such as consulting, the exchange of people, seminars, speaker programs, and publication exchange, are key to forging stronger research ties between universities and industries (see Chapter IX, pp. 85-92). Program structure providing for personal interaction between scientists appears to be the most efficient means of transferring knowledge between the two sectors. Most company and university representatives interviewed stated that one-on-one communication is essential for effective linking of academia and industry research. Furthermore personal contacts and consulting relationships were mentioned frequently as critical factors in the initiation of university/industry research coupling (Tables 4 and 5).

Formal dual purpose program structures lead also to informal research ties. Continuing education programs and centralized liaison programs are knowledge transfer research interactions because the contacts developed in these programs provide the groundwork for the exchange and transfer of ideas for research and/or for adaptation of research techniques.

Informally structured programs of knowledge transfer were extensive and varied. Such programs, it was sensed, were the basis of all ties between companies and universities. Although there is no data base on which to detect to what extent these informal ties have increased, we sensed that as the climate for cooperation and coordination becomes more positive, these informal interactions will increase greatly.

4. *Technology Transfer—Programs to Expedite the Commercialization Process*

University extension programs in agriculture and engineering testify to the long and enduring role of universities in technology transfer (Rogers *et al.*, 1976). In difficult financial times, formally structured programs to capitalize on university research are likely to increase because there is a sense within the university as well as industry that opportunities are being missed.

Starting in the early '70's, the United States government established several special programs which were directed at innovation and university/industry technology transfer (Zerkel, 1972; Prager and Omenn, 1980). They were structured to transfer outcomes of cooperative ventures to a third party, or to play a role to see that the outcomes were brought to fruition as commercial ventures in and of themselves, or were integrated into the technology and science base of U.S. industry. Examples include: The DOE Industrial Energy Program, the New England Energy Development System (NEEDS, one of NSF's cooperative research centers), the University of Utah Innovation Center, the MIT Innovation Center, and the Carnegie Mellon Processing Research Institute, (Chapter IX, pp. 98-99).

Many of these formal government technology transfer programs have experienced difficulties, such as not attracting significant company participation or finding financial support from sources outside the government. Technology transfer from campus to industry has always been a difficult issue (Declercq, 1979).

The recent extensive literature developed on establishing government sponsored technology transfer through establishing generic technology centers (U.S. Senate Committee on Commerce, Science and Transportation, 1980; Industrial Research Institute, 1979; Cooperative Automotive Research Program, 1980; Mogee, 1979; Pavitt and Walker, 1976; U.S. Department of Commerce, 1980 a&b; U.S. Department of Energy, undated), and the subsequent failure of such programs to materialize, highlights some of the problems in setting up successful formalized technology transfer programs (Large, 1981; Fusfeld, H. I., R. N. Langlois and R. R. Nelson, 1981). They include company fears of antitrust difficulties and a lack of consensus on how to effectively structure such programs and allocate resources.

But with continuing concern about lagging U.S. innovation there is still much interest in developing successful technology transfer programs. Universities (*e.g.* Georgia Tech and Penn State) are beginning to take their own initiatives.

A few have structured programs to assist professors and/or entrepreneurs in developing new businesses. New products have not as yet been produced but these programs are still very young (one year or less).

Universities are also beginning to take the lead in capitalization of their own research through more

Table 4

Initiation of University/Industry Research Interactions

Number of Cases in Each Category

(as derived from interview data)

	(1) Total Number of Interactions	Initiator: University	Industry	Mutually Initiated	Other*	Prior** Relationships Contributing Factors	Consulting as an important element in Initiation
General Research Support	34	14	16	3	1	2	2
Cooperative Research Support	214	142	33	19	20	46	43
Knowledge Transfer Mechanism	42	29	12	1	0	2	4
Technology Transfer Mechanism	47	40	2	1	4	3	6
Total	337	225	63	24	25	53	55

(1) Total number of interactions = university + industry + mutually initiated and other.

*Other includes: government, alumni, or any other third party.
**Prior relationships include: professor having previously worked in industry; personal or industrial contacts; etc.

Table 5

Origins of University/Industry Cooperative Research Programs

(as described in interviews)

	(1) Total Number of Interactions	Initiator: University	Industry	Mutually Initiated	Other*	Prior** Relationships Contributing Factors	Consulting as an important element in Initiation
Cooperative Research							
Centers and Institutes	46	32	7	2	5	6	5
Grants and Contracts	78	43	17	12	6	31	28
ILP and Research Consortia	73	62	4	2	5	6	5
Other	17	8	6	1	2	3	2

Initiations of Cooperative Research Programs: Response to Direct Questioning Concerning Each of Factors Involved in Initiating a Project

	(1) Total Number of Interactions	Initiator: University	Industry	Mutually Initiated	Other*	Prior** Relationships Contributing Factors	Consulting as an important element in Initiation
Government Funded U/I Cooperative (Grants and Contracts)	29	16	2	9	2	22	10

(1) Total number of interactions = university + industry + mutually initiated and other.

*Other includes: government, alumni, or any other third party.
**Prior relationships include: professor having previously worked in industry; personal or industrial contacts; etc.

aggressive attention to patents and through the establishment of university based licensing and brokerage programs (see Chapter IX p. 101-106).

C. Technical Fields and Differences in Industrial Support

Industry generally supports research in scientific and technical fields most closely allied to their interests. The nature and tradition of the field also determine the level and type of industrial funding. Professionally oriented schools and departments tend to attract greater industrial support than traditional departments. This is most certainly tied to the companies' overwhelming motivation in supporting university research—access to qualified professionals with skills the company can use within one to two years (Chapter VII, p. 34).

Opportunities for cooperative university/industry research interaction frequently lie in subject areas at the interface of traditional academic disciplines, *e.g.*, polymer science, biomedical engineering, materials science, robotics, very large systems integration (VLSI). Of the 464 university/industry research ties we identified in our field study, 179 (approximately 40%) were programs covering two or more academic disciplines (Table 6).

A disproportionate amount of industrial support goes to engineering, medical and agricultural departments and schools. The breakdown for total industrial support of university research at ten universities was approximately 60% to engineering, 10% to agriculture, and 30% to all other technical programs. Several administrators stated that departments or schools of agriculture were "nickel and dimed to death." Although the total number of projects supported within the agricultural school was usually much greater than in an engineering school, the monetary support of engineering schools and the size of the projects supported were much larger.

Medical school support from industry is complicated because of the large influx of NIH money and the complexity of the schools themselves. Medical schools and their pharmacology departments do receive large grants or contracts from industry for specific purposes. Pharmaceutical firms contract large amounts of money to university medical schools to perform clinical trials of their new drugs (see Chapter VIII, pp. 62-63).

Of the academic sciences (biology, physics, chemistry, math, and the social sciences), chemistry generally receives the greatest amount of industrial support, not only contract support but also support in the form of unrestricted money. In a questionnaire to 100 chemistry departments asking for information about unrestricted gifts, Professor A. L. Kwiram of the University of Washington, found that the unrestricted grant total to a department averaged about $27,000 annually. Excluding the five largest departments, the unrestricted fund average is about $18,000 per department. In keeping with greater industrial support of engineering, chemical engineering departments receive three times the amount of money given to chemistry departments. Fifty chemical engineering departments responded to the questionnaire. The average total for unrestricted gifts to chemical engineering departments was about $67,000.

At one university, where chemistry, chemical engineering, and biochemistry were combined into one school, both the chemistry and chemical engineering departments received $150,000 each in unrestricted gifts; and the biochemistry department, zero dollars in unrestricted gifts.

At most universities, there is little industrial monetary support of research (for contract research or in gifts) in departments in biology, physics and mathematics (Table 6).

Biology is usually supported through a basic medical science department in a medical school rather than an academic biology department. The Harvard-Monsanto, the Dupont-Harvard, the Harvard-Hoechst agreements are contracts with medical schools. Despite the recent flurry of activity over genetic engineering, there has been little support of frontier genetic research, cell biology, or molecular biology by industry. Several scientists and administrators stated that they were in the initial stages of negotiating industrial contracts in support of the "new biology." Most expect that there will be growing support in this area, as the number of interested companies grows larger and more stable. There are at least two new biochemistry affiliates' programs attracting industrial support, and at least three of the new biotechnology companies are sponsoring grants at several universities. Genetic engineering research in the plant sciences is also receiving increasing funds from industry (*e.g.*, from the oil and chemical companies). Traditionally, this type of support for plant science research is from agribusinesses and through the agricultural schools.

Much of the ongoing research in high energy (experimental physics), astronomy, and oceanography has not in the past been considered to be relevant to industry's immediate interests. Therefore these subjects have not received much monetary support from industry. These fields usually require large expensive specialized research facilities which, because of the general nature of the research results coming out of these facilities, are supported by government funds. Yet there are opportunities at these facilities for joint university/industry research interactions and some companies have taken advantage of them. Bell Laboratory scientists in cooperation with university scientists have made major advances in astronomy. Synchrotron Light Sources at the University of Wisconsin, Stanford University, and Brookhaven National Labora-

Table 6

Technical Disciplines Represented in Cases Documented (N=464) in NYU Field Survey

Discipline	Sub-Disciplines Included	Single* Discipline Program	Joint** Areas
Engineering			
General		54	36
Materials	Materials engineering, materials science	18	9
Chemical		28	15
Electrical		26	17
Mechanical	Mechanical engineering, fluid mechanics, ceramic engineering	6	18
Other		9	11
Science		1	5
Computer Science		28	26
Chemistry		29	16
Physics	Space physics	5	6
Biology	Microbiology, environmental sciences	13	14
Biochemistry		4	4
Agriculture	Agriculture, plant science, forestry	15	9
Medicine	Medical sciences, toxicology, immunology, pharmacology, oncology, radiology	19	8
Oceanography		1	7
Mathematics		2	7
Metallurgy		2	5
Social Science		5	1
Business	Economics-industrial & mineral	2	2
Geology	Geophysics, geochemistry, geoscience	2	5
Non-Profit Organization		3	0
Multidisciplinary			67
Other		14	9

*Total Number Single Discipline Programs = 286
**Joint Area Programs May Encompass Two or More Disciplines; Total Number = 179

tories (administered by an association of universities) have all been supported and used by a number of private companies including IBM, Exxon, Bell Labs and Xerox. A particularly unique university/industry/govemment research interaction has occurred in the development of the Brookhaven Synchrotron Light Source. Here the private companies have borne the cost ($15 million) of the design and instrumentation of a number of beam lines which are available to the general user at least for one fourth of the beam time (see Chapter IX, p. 85).

Oil companies are increasingly giving their support to departments of oceanography. This is tied to their interest in seabed exploration for oil and minerals. It appears that much of this support to date has been in the form of gifts and participation in liaison programs. There may be a great potential here for increased cooperative research interaction and several scientists expressed the view that such interactions are beginning to occur.

In mathematics, which presently gets the least amount of industrial support (excluding computer science), academic scientists suggest that there are opportunities being missed. In developing robotics, certain basic geometry problems will have to be solved. Mathematicians also have a role in the new software explosion. They can be essential in providing new algorithms and in the development of new languages.

D. Current Trends of University/Industry Research Interactions

Our study indicates that there is a surge in the volume and variety of these interactions (Table 7). Although a majority of these interactions are initiated by university scientists with an applied background or an association with industry (*e.g.*, either a previous history of working in industry or continued participation in consulting arrangements), there is a wide variety in the structures and functions of these joint ventures. The volume and array of present interactions provide researchers not only with new opportunities to diversify funding sources, but also with alternative approaches to the conduct and design of research programs.

Specifically, with respect to mechanisms of university/industry research interactions, there are several emerging trends:

(1) Increased magnitude of industry funding of specific projects or programs. (However, in less than ten instances was this of truly significant magnitude: $1 million per year.)

(2) Increased duration of industry commitment to university programs.

(3) Increased efforts at collective industry support of university research.

(4) The structuring of multi-company support of university research in ways allowing active participation of company scientists in the technical aspects of a program.

(5) The founding or redirecting of university associated research institutes to conduct research programs on behalf of industry.

(6) Expansion of university activities designed to commercialize results from university research.

The outcomes of university/industry coupling are also multi-faceted and can include spin-off companies as well as publications and the production of Ph.D.'s oriented to an industrial career (see Chapter VII, p. 43). However, in our sampling of cases, we could rarely identify instances where a commercially marketable product or process was an immediate and direct outcome of a research interaction.

Because of the recent formation of many programs, it is too soon to tell if there will be a shift in the extent of traditional outcomes, the production of Ph. D.'s and publications, and an increase in non-traditional outcomes, patents and commercial products, processes or services.

E. University/Industry Research Interactions: A New Era

There have been several significant developments during the past year that bear directly on university/industry research ties. They include changes in federal laws, policies, and regulation, and a resurgence of the venture capital business and the interest of the financial community in investing in "high technology" business ventures.

These developments are apparently affecting the level of activity in developing new university/industry research ties. Our field investigation and a survey of the relevant literature revealed a tremendous number of recently initiated university/industry research interactions. Of the university/industry ties where we could identify a period of existence to 1981 (n=463), approximately 51% were currently being started or less than three years old. Very few programs (10%) reviewed have been in existence for a long period of time (20 years or more). About 8% were in existence for between eleven and twenty years, thirteen percent for six to ten years, and 17% for three to five years (Table 7). Scientists and administrators have stated their increasing interest in university/industry support, and perhaps this is substantiated by the large number of new programs identified in this study. This is no doubt a reflection of a more favorable climate for university/industry research interactions provided by changes in government policy and greater public and private sector awareness of the new potential commercial value of some areas of science, *e.g.*, genetics and computer science.

Over the next few years a major element of policy analysis will necessarily consist of assessing the consequences and implications of these new developments in the financial community, in the maturity of certain sciences, and in policy actions in the area of patent laws. It is to be expected that these new devel-

Table 7

Numbers of University/Industry Research Interactions Existing for Various Time Periods

Types of Interactions	Time Periods (Years) <3	3-5	6-10	11-20	>20
All Categories of Interactions	236	80	60	37	49
• General Research Support	35	11	3	1	2
• U/I Cooperative Research	149	7	37	17	18
• Knowledge Transfer	31	10	5	3	7
• Technology Transfer	21	3	10	11	21
U/I Cooperative Research Programs (Selected Categories)					
• Special Interest Liaison Programs	48	14	6	12	4
• U/I Cooperative Research Centers & Institutes	21	11	14	14	8
• Research Consortia	7	2	3	3	1
General Purpose Industrial Programs	4		1		3

opments will affect the character of university/industry research ties and will bear importantly on the nature of the newly evolving relationships. This was a subject of discussion during many of our interviews. Such discussions served to underscore our perception that university/industry research interactions are currently in a state of flux. Changes in the tax code, antitrust policies, and revisions to the budgets of major R&D agencies of the federal government were frequently mentioned both by company and university representatives as being critical. The new patent law (which went into effect July 1981) provides that all federal agencies must allow universities, along with small business and non-profit institutions, the right to retain ownership and patents arising from federal funding agreements. The legislation provides unambiguous policy guidance, and this allows universities to negotiate licensing rights with companies that partially support their research programs. It thus provides universities with incentives to pursue patenting. Companies feel comfortable in negotiating licensing rights with universities particularly if they can obtain an exclusive license.

In the Economic Recovery Tax Act of 1981, two specific tax incentives are of potential importance to university/industry research interactions: the incremental tax credit for industrial R&D and increased deduction for manufacturers who donate new equipment to universities. Both university and industry representatives stated that they were unsure if in fact these revisions would provide new monies for university/industry research interactions. Several other bills considered (*e.g.*, the Vanik and Danforth bills) were regarded more favorably than the one that actually passed.

A clarification of the U.S. government antitrust policy on the other hand did appear to have significant effect on the character of university/industry interactions. There is now a greater disposition in industry to participate in university-sponsored research consortia (*e.g.*, Delaware Catalysis Center, the Case Western Reserve Polymer Center) and in the collective industrial support of university research (*e.g.*, the Council for Chemical Research and a new program undertaken by the Semiconductor Industry Association).

Among the other events highlighting potential changes in the character of university/industry ties were those relating to the ferment over the role of the university in high technology ventures. A review of four events occurring within the last year serves to stress the rapid rate of change and high stakes in this area.

(1) In October 1980, Genentech, a spin-off company started by two university scientists in 1976, issued public stock. They became millionaires overnight.

(2) In 1980, the Harvard administration proposed that Harvard take equity in a new company being formed by one of its faculty members. A long debate ensued on the proper role of the university in commercialization of university research. Subsequently, in December 1980, Harvard discarded its plans for directly investing in this biotechnology enterprise. The controversy created by the Harvard initiative tended to obscure many other slightly less bold plans and developments. A visit to Harvard and many other schools on the forefront of biotechnology research revealed that most faculty members in this line of research are participating in the development of new ventures.

(3) In the fall of 1981, Stanford University and the University of California participated in the development of a unique and complex interaction involving the establishment of a non-profit Center for Biotechnology Research, and in the creation of Engenics Inc., a for-profit arm of a foundation established by six diverse firms to support academic research in genetic engineering. Engenics Inc. will concentrate on development of commercial biotechnology processes. Neither of the universities will be a direct participant in the non-profit Center for Biotechnology Research or in Engenics, but they will receive $2 million over the next four years from the foundation that set up Engenics. They also expect to share in any financial success of Engenics. Two faculty members from Stanford and one from Berkeley are associated with Engenics. The six firms setting up the foundation have equal portions of a 35% equity in Engenics. The Center for Biotechnology Research holds a 30% interest in Engenics and will use profits from that interest to support university research although not necessarily at Berkeley or Stanford.

(4) In another development in this area also at Stanford, 73 genetic engineering companies from around the world signed up with Stanford for use of its patent covering basic gene splicing and cloning techniques. A gross revenue of $1.4 million for the first year was guaranteed to Stanford by December 15, 1981 through this licensing effort.

The implications of many of these new developments are discussed in Chapter X and their potential effect on the future of university/industry cooperation are outlined in Chapter XI.

CHARACTERISTICS OF THE ACADEMIC AND INDUSTRIAL SECTORS AND THEIR EFFECT ON PARTICIPATION IN UNIVERSITY/ INDUSTRY COOPERATION

A. Institutional Objectives: Implications for Research Cooperation

The functions and objectives of the academic and industrial sectors govern their institutional structures, their organization and management of research, and thus their approach to cooperative interactions. There are real differences between the two sectors. These differences bring about mutual misunderstandings which can be exacerbated by a lack of communication. Open recognition of these differences is essential to successful cooperation.

Academic research institutions exist primarily to educate students and to discover and extend knowledge. As a consequence, freedom of communication and publication is essential. Universities are subject to public and peer evaluations. A university's success is directly related to perceived quality of students and research productivity.

Industry exists to provide the optimum return on investment consistent with stable growth; it does so by producing a product, process, or rendering a useful service. A factor in this process is the development of proprietary knowledge, which often necessitates that patent protection be established. These concerns tend to restrict communication and publication. "Bottom line" considerations are emphasized and profitable return on stockholders' investment is a minimum necessary objective.

Industry's approach to research and development is ultimately governed by the view that research is a long-term investment whose function is to provide eventual payoff in terms of a product, process, or service that will improve corporate performance. The differences in corporate attitudes toward research, *e.g.*, level, direction, division between basic and applied, are governed by a variety of factors: perceptions of relative importance; available capital; traditions of dependence on state or federal entities; and complexity of technology required for innovation. Life cycle phenomena such as stability or growth of markets, and corporate size and complexity all play a role.

Attitudes towards research in universities are governed by their educational and research missions. Most universities start with the notion that research is an integral part of education and training. Both research and training in their view are essential in the pursuit of knowledge for its own sake and for the general long-range benefit of humanity. Universities, both public and private, are also committed to public service and the dissemination of knowledge.

Universities differ in their perceptions of their functional roles in education, training and public service. It is their perceived mission which affects their orientation and attitudes toward cooperation. Some universities regard themselves primarily as basic research institutions, some admit to a greater technological orientation. A goal of many institutions is to graduate professionals while others state they wish to graduate leaders. The founding charter, motto or statement of purpose of a university frequently explains its present orientation. For example, Georgia Tech's purpose is "The advancement of scientific and technical knowledge and achievement;" University of Illinois' motto is "Learning and labor;" University of Chicago's motto is "Let knowledge grow from more to more and thereby life be enriched;" the Stanford motto, "To prepare students for direct usefulness in life." The orientation of a university to some extent will constrain or focus the types of research interactions a university will have with industry.

In general, despite different university orientations, university research has three goals which are rarely in conflict with each other. They are:

(1) To train students in research techniques,

(2) To provide state-of-the-art information in fundamental and applied research, and

(3) To conduct research as a source of financial support.

The pressure on research to generate university income permeates every level of the university. For example, it can influence the way development money is allocated by the central administration. It can cause a scientist engaged in fundamental research to work on one system rather than another. Or, it can cause a shift in direction towards applied research.

At one major private eastern university, an individual doing fundamental research with Nuclear Magnetic Resonance (NMR) chose to work on biochemical problems related to cancer because the funding by the Cancer Institute exceeded that available for structural chemical problems related to energy research. This is not a judgment on whether such influence is good or bad, but simply that it exists.

Yet, universities usually recognize that maintaining broadly based programs is essential to their mission. University administrations allocate income to help maintain scholarship in the sciences, humanities, and the arts. They must be sensitive to those areas that cannot be easily funded because they have no perceived practical value. Net dollar drain from income producing units, however, can set up counter-tensions within the university that may cause it to challenge its own mission and affect its capability of meeting industrial needs.

The respective objectives and functions of university and industry also affect their perceptions of success. University value and reward systems, powerfully reinforced by years of massive federal funding of basic research, it is observed, have operated to show preference for theory building over applications, analysis over design, abstraction over operations. Consequently those things of prime importance to industry frequently receive secondary status at universities. Industrial commitment to basic research has declined since its heyday in the '50's and early '60's, though it is now rising within the past five years. Purportedly its recent commitment has been to incremental improvements on old products and processes (David, 1979; Bromley, 1982).

Thus, there are important mismatches in the respective value systems and time concerns of universities and firms and these can be intensified by a trend in industrial decision-making that favors short-term, low-risk projects (Smith and Karlesky, 1977; Nason and Steger, 1978; Shapero, 1979; National Commission on Research, 1980).

There are, however, common grounds in the objectives of both research systems, and there is precedence for minimizing the gaps between the goals and functions of the two systems and establishing effective linking mechanisms. There have been historical examples of highly productive convergences between the two institutions. The most obvious and dramatic convergences have been achieved in times of war. But there are other examples of successful interactions. In the 1930's, General Electric supported Dr. Bridgman's basic research in high pressure physics at Harvard University. He later won the Nobel Prize for his work and General Electric developed a process for making industrial diamonds.

While the interactions that exist are constrained by the mismatches between the two systems, they are also stimulated by the needs of each type of institution and the way these needs coincide with the capabilities of the other to satisfy them.

Economic need on the part of universities, as indicated before, has been one recurrent pressure towards convergence. Universities have turned to industry and have invented new programs that would be of interest to industry. One such example was the development of MIT's Technology Plan. After World War I, the state of Massachusetts discontinued its support of MIT. This school then devised a program to attract industrial support.

An obvious overlapping interest of the two institutions is the production of well-trained and educated students. Furthermore, industries are continually seeking new ideas, new knowledge, and fundamental concepts, precisely the goals of research at universities.

The differing objectives and functions of the academic and industrial sectors are reflected in their different organizational structures. Universities tend to be more pluralistic. The faculty form the framework of the organizational structure. Industry is structured for goal-oriented outcomes. Therefore, it generally follows a more hierarchical, structured plan. The differences in structure can confuse those areas where objectives and functions of the two sectors do overlap.

Likewise, the regions of overlap of the goals and structures of the two systems have a diversity which is reflective of the many different goals of the institutions subsumed within these two headings. Therefore, seeking out and matching two institutions with mutual interests can be an overwhelming endeavor.

It should be remembered that there are great variations contained within the omnibus headings "university" and "industry." There are more than 2,000 colleges and universities, and 14 million businesses, not counting the subdivisions of corporations. Each has its own structure and organization, and this further complicates discovering areas of mutual interest. However, to put this in more realistic perspective, the bulk of U.S. research is indeed conducted within 20 major research universities and 20 corporations.

In the next two sections, we review the complexities of the structures of each of the sectors. Then we review how these differences can affect university/industry cooperation. In Chapter VIII (p. 47 ff) we consider how differences in goals and structures within each sector can affect research interaction.

B. Institutional Structures

1. *Industry Structure for University Research Interaction*

The diversity of industrial organizational structures interfacing with the university in cooperative research produces an occasional sense of frustration when one looks for a single number to describe the extent of support provided by a single company for university research, or wishes to obtain from a single company representative a reasonably complete description of the scope of such support and cooperation throughout the company. To get a complete picture of a large corporation's involvement with university research, data must, in principle, be obtained from perhaps 20 to 50 individuals within the company, given the many operating divisions of a General Electric or du Pont. Nevertheless, some understanding of this corporate structure is necessary in order to appreciate the richness of interactions that is possible between university and industry, even when we restrict our interests to research.

Although the precise organizational structure varies from company to company, there are general patterns and structures which correlate with the various mechanisms for research interaction. The basic elements that are engaged in university relations are:

(1) *Corporate foundation* for financial support of external activity — charitable, educational, cultural— which may add value to the environment in which a corporation operates, but is not in the direct support of a specific business need.

(2) *Corporate central laboratory*, which normally provides technical support for existing and future products and processes throughout the company calling for specialized or longer range effort, and which can pursue investigations in new technical areas, or in relatively basic science and engineering programs that can be the source of new products and processes, and even new business interests.

(3) *Divisional laboratories*, which provide direct support for the products and processes of a particular division, and develop new products and processes for the established business interests of that division.

(4) *Operating units* of the corporation which manufacture and distribute the products that make up the business of the corporation. (This study covered industries engaged in manufacturing or in providing technical services such as utilities. It has not been concerned with the bulk of the service industry—banking, retailing, entertainment.)

As a reminder, a few of the mechanisms for research cooperation as covered in this study are:

(1) Fellowships which are intended to be used for research personnel by a particular technical department or in a particular technical area.

(2) Research grants intended for a particular technical department, a particular technical area, or a particular research program. (These can include research operating costs and/or equipment.)

(3) Research contracts with specific economic aims.

(4) Joint research programs involving both university and industry activities, and usually involving industry funding of the university portion.

The above are simply highlights to facilitate discussion in this section. The many forms that these mechanisms can take are illustrated in the anecdotal data of this study (Chapter IX).

Let us consider how the principal corporate entities already mentioned engage in these several forms of research cooperation.

Industrial foundation support of university research in most cases is directed toward education and training. Some foundation directors indicated that because they had limited funds, they concentrated on supporting the schools where they hired the majority of their professional staff. A few limited the giving to areas related to their own technical interests, *e.g.*, they would give only to engineering schools. And a few said they gave only to private schools because they felt they already contributed to public schools through taxes, but many who stated that this had been company policy in the past indicated that this was changing.

The corporate foundation will rarely support a project or grant for specific research. It can be the principal source of research fellowships, justifying these primarily because they provide for educational needs of individuals. Nevertheless, the allocation of fellowships is likely to be to those departments, in those areas, and to students of those professors perceived to be relevant to the technical needs of the laboratories and/or of the business interests of the company. Thus, a mining company is not generally a good source of research fellowships for a biology department, nor is a pharmaceutical company a likely source for fellowships in metallurgy.

The corporate foundation may also be a source of funds for a broad research area, *e.g.*, genetics, or for a research center or institute. In such instances, benefits must be perceived as accruing to an entire industry or all industries, and such funds would not be earmarked for a particular research program required by that specific company.

Any research laboratory, corporate or divisional, is normally free to use its own operating funds for any forms of university research cooperation. It is less likely to use such funds for fellowships, since other corporate sources can be called on, particularly when a foundation exists. Since divisional and corporate laboratories are financed in accordance with the separate functions and needs of the respective business units, they will each establish linkages with universities in light of these separate requirements and opportunities, not as a part of a coordinated corporate-wide master plan for supporting university research. This is a fundamental cause for dispersal of data concerning the university relations of a particular company. Of interest to academic scientists is that a corporate or central laboratory is more likely to conduct basic research and be attuned to university research.

Finally, there are many operating units of a large corporation. They may support university research on the basis of either geography or subject matter. "Geography" may be interpreted loosely as being a good citizen of the city or region. Thus, a manufacturing or assembly plant will support the local hospital, the local symphony orchestra, and the local university. General support is not included in this study. However, when the local university is known for a center of excellence in a particular technical area or can make a good case for developing one, the corporate unit may provide some funds on the basis of citizenship rather than subject matter.

But subject matter can indeed be a basis for support by operating units, and the case can be compelling when a university is also close geographically. A manufacturing plant is concerned with product design and with specific manufacturing processes. Support can be justified in areas that bear on productivity, *e.g.*, robotics or control systems, or operating conditions, *e.g.*, epidemiological research related to air and water conditions, and on specific product design components, *e.g.*, material. The point is that operating units throughout a company can support university research, usually in engineering fields and relatively short range, but not necessarily. Such support may not be reported or even well known throughout the company, except in the individual accounts of that operating unit. While corporations will segregate any expenditures when there is a tax advantage in doing so, a research program that is expensed in the year it is paid for, and is therefore simply another item in the cost of sale, offers no such advantage. Thus, there may be a number of independent sources of support for university research from operating units that are not known to a central source of corporate data.

In principle, this multitude of sources within a corporate structure for supporting university research would seem to be simplified by the fact that the larger research-oriented corporations may have an individual or group charged formally with university-industry relationships. Where this exists, coordination acts to facilitate such relations and provide support for separate organizational units when helpful, not to take responsibility for the totality of company actions. In fact, the guiding principle is normally to encourage direct interaction between the research personnel within the company and those of the appropriate university, and thus decentralize such arrangements. Hence, there are usually a large number of linkages proceeding independently throughout the technical structure of a large corporation, the results of which tend to appear within the operating budgets of the individual laboratories or business units.

In summary, then, corporate structure leads to multiple sources of corporate support for university research cooperation. This makes a truly complete picture for the scope of such interactions difficult to obtain.

The information gathered through interviews in this study indicated that indeed companies use a wide variety of mechanisms in support of university research, and that industrial support can come from many organizational units within the company. Most industrial representatives interviewed said that support by their companies was decentralized, and confirmed that it was extremely difficult to get an exact figure of corporate support of university research. However, most seemed to believe that the largest funding for support of cooperative industry/university research came from the corporate research laboratory, and to a lesser extent from divisional research laboratories. Managers in operating divisions were said to be not inclined to support university research unless they had a specific problem to solve, because they were under immediate pressure to justify their operating budgets in terms of output. Most company and university representatives pointed out that the product manager is anxious to spend money on the problems of today rather than long-range ideas. He is not interested in designing new prototypes. One academic investigator thought the company would, under particular circumstances, provide support for a university to build a prototype. He cited the Swan-Gans catheter as an example. If a relationship is established with people who make decisions and have funds, then he thought support from industry for new products was possible, but difficult to obtain.

2. *University Structure for Industrial Research Interaction*

Universities are far fewer than industrial firms and are far more homogeneous. Thus the university structure for administering research is not as diversified as the private sector. There is a faculty responsible for research as well as education, and a central administration (including the dean of the graduate school and the office of academic affairs) which facilitate these research efforts. University faculty initiate, govern, manage and carry out research programs, and can be regarded as the permanent officers of the university. Such a definitive statement about faculty control over administration is not the case at all universities, however, faculty committees usually monitor the overall research efforts of a university. Academic research is carried out under faculty guidance within academic departments, at research institutes, or in specialized research laboratories. It is very rare that a center or institute director does not have a faculty appointment.

The university's central administration normally acts to coordinate administrative procedures and facilitate the research efforts of the faculty. At many universities, there is a vice president for research who is in charge of these activities (Tables 8 and 9). He is responsible to a provost or vice president of academic affairs. In those cases where there is no university research officer, it is the responsibility of the academic vice president to oversee these matters. In a few cases, the Academic Vice President and Chief Research Administrator hold separate but equal positions. Both public and private universities have offices of development which receive gifts only, including those from industry, and offices of sponsored programs which receive funds for externally supported research with a specific purpose. Normally, in both public and private universities, these are two separate offices under separate administrators and with minimal contact between the two. The office of sponsored programs at all the institutions we visited was under the direction of the university official ultimately responsible for the administration of research. At one institution visited, the Office of Sponsored Programs and the Development Office were under the Vice President for Academic Affairs. In another case, there was no office of development per se, and all research was administered by the Graduate Dean.

The Development Office generally receives funds that are put in the trust or endowment accounts of the universities and are applied to a general operating budget of the university. Many gifts are restricted, *e.g.*, earmarked for research, sometimes even for a specific area of research. Funds donated for industrial liaison programs or even focused liaison programs are frequently received by the Development Office. Equipment gifts and loans can be administered through the Office of Development as well as funds for research facilities and endowed chairs.

Development Offices are structured to attract contributions. Their budget is sometimes related to the funds they attract. They must demonstrate activity. Development office figures can be inflated. Sometimes there is double accounting—a corporate grant solicited as part of external fund raising by the development office may go to fill a specific research request and therefore also be accounted for by the Office of Sponsored programs. Foundation grants from companies are not necessarily unrestricted gifts. Foundation grants also come to the Office of Sponsored Research. There is difficulty concerning when to classify such an award as a gift. This is an important issue for the university. If it is a gift, there is no tangible service income (overhead), and the Internal Revenue Service does not make it clear where to draw the line. Many

Table 8

Patterns of Research Administration: Public Universities

University	Research			Development
	Central Administration	Graduate School	Office of Academic Affairs	
U. of Arizona 1980-81	V.P.-Research			
U. of California (San Diego) 1980-81	Academic V.P.			S.D. Campus: Spec. Ass't. to Chancellor: Development
U. of Colorado 1980-81		Assoc. Dean for Grad. & Research Programs, College of Engineering & Applied Science		
Colorado State U. 1980-81	V.P.-Research & President, CSU Research Foundation		Acting Academic V.P.	Assoc. V.P. for Development
U. of Delaware 1979-81		Univ. Coordinator for Research	Provost & V.P. for Academic Affairs	V.P.-University Development
U. of Illinois (Urbana) 1980-82		Assoc. Dean and Assoc. Vice Chancellor for Research (Grad. College) Two Assistants	Vice Chancellor for Academic Affairs and Acting Vice-Chancellor for Research (Campus Officer)	
Louisiana State U. 1980-81	V.P. Instruction and Research		Baton Rouge Campus: Vice Chancellor for Academic Affairs	
U of Michigan. 1981-82	Vice President of Research		V.P. for Academic Affairs	V.P.-University Relations and Development
Michigan State U. 1980-81	V.P.: Research and Graduate Studies			V.P.-University Development

Table 8—Continued

Patterns of Research Administration: Public Universities

University	Research			Development
	Central Administration	Graduate School	Office of Academic Affairs	
U. of Minnesota 1980-81			V.P.-Academic Affairs (Central Administration)	
U. of North Carolina 1980-81	V.P.-Research and Public Service		V.P.-Academic Affairs	Vice-Chancellor, Development and Public Service
North Carolina State University 1980-82	V. Provost and Dean for Research	V. Provost and Dean of Graduate School		
Purdue University 1980-82	V.P. Research, Dean Graduate School			V.P.-Development
U. of Texas 1979-81		V.P.-Research	V.P.-Academic Affairs (Graduate School)	
Texas A&M 1980-81	V.P.-Academic Affairs (Central Administration)			V.P.-Development
U. of Utah 1980-81	V.P.-Research		V.P.-Academic Affairs (Central Administration) Two Assistants	
U. of Wisconsin		Dean for Graduate and Research Programs		
Clemson University		Dean of Graduate School & University Research	Provost & V.P. for Academic Affairs	
Georgia Institute of Technology	Vice Chancellor, Research	V.P.-Research (Institutional Adm.)	V.P.-Academic Development (Central Administration)	V.P.-Institute Relations and Development

academic administrators were concerned because some companies are unwilling to pay overhead. Many times these companies give their support through the development office, which does not charge overhead. Their point is that they wish the full sum of money to be spent on research.

At most state universities, the Development Office is closely linked to, or is an integral part of, a university foundation. These foundations were developed to separate certain university activities and funding sources from state funds and regulations. Developing a better interface with industry was an original objective of one of the first foundations, the Purdue Research Foundation. Several state universities, Minnesota, Colorado, Arizona, and others, have followed this model. Usually these foundations work on their own in solicitation of funds. Sometimes they will have a separate division or a unit for a specific purpose, e.g. development of a research park. In what may be an emerging trend, some university research foundations have established separate entities to handle industrial contract research. One example of such a foundation is at Texas A&M.

The Office of Sponsored Research (or Office of Grants and Contracts) is generally responsible for negotiating agreements for all externally sponsored research. The patent office or attorney is usually allied with this division, and it is within this office that university research administration policies are established and records kept. In their accounting systems, most universities in the past have only kept records on the immediate sources of funds but not on the ultimate source. Thus, a contract from an engineering firm may well be a subcontract from a federal contract with the company. Furthermore, most universities do not distinguish between private foundation, industrial foundation, and industrial funds. They categorize funds as derived from federal, state, local, and private sources. Because of the relatively small percentage of sponsored industrial support in the past ten years, there has been no real need to separate it out.

There are many cases of industrially supported research that does not flow through the normal administrative and accounting procedures. Industry gifts for research are sometimes given directly to individual investigators, research departments, or technical units of universities (schools of engineering, agriculture, etc.), centers, and institutes. This money may or may not be processed by either the development or sponsored program office. Professor X will get a gift and is also engaged in providing some professional services for the company. This has been especially true in the pharmaceutical area.

Occasionally, professors will set up special accounts where they deposit money received for consulting with industry. These accounts may be separate from all other accounts established by the university accounting systems. They are frequently used as discretionary accounts for research. One such account is the "Mercury Fund" at Duke University.

The Mercury Research Fund provides the department with unrestricted money which allows it to hire extra research associates or send students to various places. In one instance, an industrial hygienist was hired to carry out measurements. Although he was originally hired on "Mercury Fund" money, he is now supported on contracts. This fund also allows for faculty salary supplements of up to $8,000 or $10,000. It has a departmental code as a university account but, by gentlemen's agreement, a department member wishing to use these funds has to seek approval from those who pay to the fund most frequently. If the professors who make contributions leave the university, the fund is still the university's, under control of the department.

The advantage of this fund is that it can help to launch projects speedily, or to support projects of an unorthodox nature.

Table 9

Patterns of Research Administration: Private Universities

University	Research			Development
	Central Administration	Graduate School	Office of Academic Affairs	
California Tech. 1980-81		Administrative Comm. System; Chairman, Sponsored Research Committee		
Carnegie-Mellon University 1981-83		Dean, Three Associate Deans		
Case Western 1979-81			V.P.-Undergraduate and Graduate Affairs	V.P. University Development
Clarkson College 1980-82		Dean, Graduate School & Director, Division of Research		Director of Development
Duke University 1980-81		Dean of Graduate School		
Harvard University 1980-81	Associate Director of Financial Systems for Research Administration			V.P.-Development
Lehigh University 1979-81	V.P.-Research	Dean, Graduate School		V.P.-Development
MIT	V.P.-Research			
Princeton U. 1980-81		Dean, Graduate School; Asst. Dean, Engineering & Applied Sciences		
Rensselaer Polytechnic Institute 1980-81			V.P.-Academic Affairs; Provost & Vice Provost for Research	
Rice University 1979-81		Dean of Advanced Studies and Research		Office of Development
U. of Rochester 1980-81	Director of Research and Project Administration	Univ. Dean of Graduate Studies		
Stanford U. 1980-81		Dean of Graduate Studies & Research		
Vanderbilt U. 1980-81		Dean of Graduate School		Executive Director of Development
Washington U. 1980-82		Dean, Graduate School of Arts & Sciences; Two Assistants		
Yale University 1980-81		Dean of Graduate School		University Officer for Development & Alumni Affairs

For example, the Mercury Fund was used to help a student do research on pneumoconiosis, a disease of the lungs. People with pneumoconiosis are exposed most frequently to both silicon and carbon. The question was whether the damage to the lungs was by the silicon or the carbon. A student at the university had a brother-in-law from Sri Lanka and she thought of the idea of going to Sri Lanka to study people who work in the graphite mines there, because these people would only be exposed to carbon, and not to silicon. The Mercury Fund funded her trip to Sri Lanka. Her research showed that the lungs of these people were filled with coal, but the pulmonary function was normal, and she was able to establish that silicon is the problem in pneumoconiosis.

Despite the difficulty in tracking some sources of support, several scientists and administrators have pointed out that the university system of administering grants and contracts has evolved after thirty or more years of dealing with the government agencies, and that even if there is a large increase in industrial support, it must be properly integrated into the administrative system. Others felt that there will have to be some change in sponsored research administration, if there is in fact a large increase in industrial support. One of the reasons given is the great diversity of the industrial firms themselves, as discussed in the preceding section and Chapter VIII. It is helpful to know whom to contact and how to approach different administrative units. This may require special administrative procedures and structures.

C. The Role of Administrative Structures and Units in Fostering University/Industry Relationships

On the university side, as stated in the previous section, there is normally a clear demarcation between the Development Office responsible for expanding the university endowment by raising funds from corporations, alumni, and foundations, and the Research Contract Office, which specifically helps develop and administer research grants. Sometimes this demarcation can be a frustration in developing cooperative university/industry research ventures.

In the past, there has been no barrier to industry directly approaching individual research scientists, with the Research Office playing a role only when negotiating grants or contracts. Most university/industry research interactions still develop, at first, between scientists. But, at many universities, the research contract office has recently been given the task of helping to develop increased research interaction within industry. Out of the 39 universities we visited, approximately 50% had industrial liaison offices or positions, and approximately 50% were newly appointed positions or newly reorganized offices.

As the perception of industrial interest in university activities has increased, the Research Office has become much more concerned with patenting and contractual negotiations with industry. At least one private southern university has made a great effort to develop schemes for profiting from university innovation with the help of an external consulting firm. Many university scientists feel that innovative ideas are not getting out and finding industrial connections. Increasingly, universities have hired patenting officers or industry liaison experts who actively seek out potential innovations and present them to industry. In Chapter IX, we discuss the recent patenting activities of universities in greater detail.

There are few administrative or structural barriers to industrial interaction in the universities, but there are perceptions of barriers (*e.g.*, the universities' departmental structure, patenting, and licensing activities; see Chapter VII). This may well change as universities seek to protect their interest in innovation. An example is the case of the University of California, which claimed patent rights over gene segments and became involved in litigation with the Roche Institute of Molecular Biology. Despite potential areas of friction, most contracts can be negotiated with a minimum of difficulty on the university side.

While most university research units are science and engineering departments, there are also significant numbers of non-departmental centers and laboratories. Many of these are multi-disciplinary and can serve as foci for industrially funded multi-disciplinary efforts. In a few cases, the basic science units and engineering schools are combined into institutes of technology (the University of Minnesota, the University of Michigan, and Case Western Reserve). Two private universities (Chicago and the California Institute of Technology) are organized by division rather than college. Both of these organizational structures were seen as facilitating the initiation of multidisciplinary efforts, but their existence is not necessarily tied to above average levels of industrially sponsored research.

Many believe that in order for there to be substantially increased collaborative work between industry and university research systems, the universities must be able to provide the team and/or a project approach. However, there was no relationship between the number of multi-disciplinary units and the level of industrial support of university research. An encouraging attitude towards multi-disciplinary efforts and flexibility within the organizational units were more facilitating for mutually beneficial collaborative efforts than the fact that such multi-disciplinary units exist.

An important trend in universities is the development of management structures which make it relatively easy to develop collaboration with industry or to create university spawned industrial enterprises. These are usually related to engineering-based enterprises, although in future years they may increasingly become related to molecular biotechnology. These structures include the establishment of buffer organizations, either non-profit or profit, or institutes within the university in which contributions on the part of professors and students can be made directly to the industrial enterprise (see Chapter IX). Examples of these are the University of Utah Research Institute (UURI); the Washington University Technology Association (WUTA), headed by the Dean of the Department of Engineering; and the Center for Manufacturing Productivity and Technology Transfer founded at Rensselaer Polytechnic Institute. Such institutes or centers can be wholly within departments and schools or totally external to the university. They seem to work best when they are under direct control of no more than a few individuals within the university structure.

There are several advantages in setting up such institutes. For directed research, industry generally requires a concentration of manpower brought to bear for a relatively short time in a multi-disciplinary setting. Generally, because of academic constraints, unless the university sets up external mechanisms such as centers and institutes, they cannot respond to this kind of industrial need.

Another advantage of separate institutes and centers is that projects can be readily terminated. The research personnel associated with such projects can be reallocated without affecting the basic tenured faculty pool or the academic calendar. Many universities, however, are still resistant to undertaking those industrial research projects which are time-intensive. They will only take on projects which generally fit into the educational enterprise.

Increasingly, the central administration of universities are beginning to play a role in fostering university/industry relations. For example, the president of one eastern state university is actively negotiating for the establishment of a research park adjacent to the university. Presidents who have cultivated their long term relationships with industry are proving to be invaluable to their constituencies. Many successful university/industry interactions have been cultivated at two levels—president to president and research scientist to research scientist.

While industry has relatively easy direct access to the university research base, access of the university to the industrial research base can vary from relatively easy to bewilderingly difficult. Very often, it is simply due to the complexity of the corporate structure or the lack of centralized information or a formalized channelling system, as noted in the previous section. Sometimes, the difficulty is due to the confidentiality associated with an industrial laboratory.

The need on the part of industry for secrecy or legal documents before communication of industrial technical data or concepts can take place is again sometimes perceptual or traditional, or related to the proportion of scientists in the higher management of the industry. For example, nowhere in the United States is industry as closely allied to the university, or as intricately interactive, as is the chemical industry with universities in Germany. The interaction largely results from a management structure in the German chemical industry which, at the highest corporate levels, contains individuals who are simultaneously university professors as well as corporate executives.

Industries, as described previously, vary widely in the structures they have developed to interact with the universities. Large research-oriented corporations often have the whole range of interactions described, where competitiveness and secrecy needs permit. In one large petroleum corporation, for example, there is no unique entry point into the system for a university-based scientist. That corporation has a constantly updated data bank of outstanding university scientists, and uses that both as a consulting pool and as the basis for making unrestricted grants. Smaller companies generally do not have such resources (see Chapter VIII, pp. 48-49). Corporate administration, objectives, and structures within industries range widely and influence university relations.

The relation with universities is often based directly on the way a particular company regards its own corporate research interests and structured to meet these interests. For example, two large companies in the petroleum industry have very different relations with universities. One focuses primarily on consulting agreements, which are highly individualized, secretive, and very directed. The other spans the broad range of interactions. The difference in this approach is in part tradition and in part the standing of the corporate research entities in the two companies. In the company with extensive university relations, its own research group is relatively autonomous and concerned with new directions. In the other corporation, the research group is a part of the operating structure of the organization, and is more directed and responsive to short-term corporate goals.

In one midwestern consumer product company, research is completely related to the marketing structure of the company. At the beginning of the decade (1970), the company decided to deemphasize corporate research. This company's present contribution to university research is minimal and tied to product development. Other consumer product companies have large commitments to research and development as well as to marketing. One such company has recently made a significant effort to support university research.

Most pharmaceutical houses have extensive direct research connections with the universities, to the point of contracting with universities for statistical evaluation of drugs in medical school patient populations. But one pharmaceutical house is foundation-owned and is structured to do most of its research exclusively in-house. Its support for universities is primarily through fellowships and by providing adjunct faculty free of charge to teach at local universities.

In the computer industry, most companies have well-developed corporate research structures. One large computer firm rivals the universities in the fundamental nature of its own research. Nevertheless, it maintains strong ties to the university, through the whole range of peer interactions, fellowships, and corporate giving. On the other hand, a midwestern based computer corporation prides itself on contracting most of its basic research to the universities. It does not have a corporate research laboratory. Such large differences in corporate outlook, which can be reflected in corporate structures and objectives, sometimes relate to the attitude of single individuals. To what extent these factors responsible for differences within industry can affect the outcome of a cooperative arrangement is a subject for future study. We simply note here that these factors do make a difference. We discuss sectoral differences in university/industry research interactions in more detail in Chapter VIII.

CHAPTER VII

THE INTERNAL DYNAMICS OF UNIVERSITY/ INDUSTRY RESEARCH INTERACTIONS

Through the development of case histories of university/industry research interactions and discussions with key representatives of the university, government, and industry research sectors, we were able to characterize many of the barriers, motivations, and processes involved in forming these interactions. In this chapter, we present many of the recurring themes related to establishing and managing these interactions. We then provide synopses of several unique interactions.

A. Motivations for Interactions

1. *Industrial Motivations*

Because of differing needs and structures, both the motivations for interaction and the perceptions of those motivations differ to some extent between industry and universities.

Company representatives cited many reasons for their interest in establishing research interactions with universities. The following reasons were among those mentioned most frequently (Table 10).

(1) To obtain access to manpower (students and professors).

(2) To obtain a window on science and technology.

(3) To solve a problem or get specific information unavailable elsewhere.

(4) To obtain prestige or enhance the company's image.

(5) To make use of an economical resource.

(6) To provide general support of technical excellence.

(7) To be good local citizens or foster good community relations.

(8) To gain access to university facilities.

Access to high quality manpower is the prime motivation underlying industry's desire to establish joint university/industry research programs. Seventy-five percent of the company representatives asked stated that manpower was a motivating factor in their support of university research (Table 10). Most stated it was the single most important motivator. Companies are particularly interested in access to graduate students who are potential employees. Those industries most concerned about the current shortages in technical manpower (chemicals, energy supply, and electronics; see pp. 54-57, 51-53, 58-61) are among the most vocal and active in the support of new programs for university/industry research cooperation.

Thus, science-based companies that are expanding or have high turnover rates of technical personnel are more likely to support university research vigorously. For example, after considerable concern and deliberation about the "manpower" crisis, Exxon announced a program of contribution, a $15 million grant to be utilized over 3-5 years, to 66 institutions to support graduate fellows and supplement faculty salaries. Atlantic Richfield will distribute $5 million over four years for students in science and engineering departments in over 30 universities. IBM contributes $1 million annually to advanced education programs at universities. The importance of manpower to chemical companies is seen in the following development. The new Council for Chemical Research (CCR) (see pp. 81-82) is basing its membership fees on a formula related to the number of chemists and chemical engineers (B. S., M. S., and Ph.D.) in the employ of member companies and CCR will distribute its research funds to departments based on their production of chemists and chemical engineers.

A large portion of industrial funding impacts students indirectly. Direct funding of research equipment, general endowment money, or departmental unrestricted stipends all provide the kind of flexibility for research and development critical to graduate training at the university.

Table 10

Motivating Factors for Participating in University/Industry Research Interactions as Derived from Interviews with Scientists and Administrators at Institutions Surveyed in NYU Field Study

Motivations for U/I Interactions Cited By Interviewees	Percent of Institutions Surveyed Where Representatives Cited That Such Motivations Existed	
	Universities (n = 39)	Companies (n = 56)
1. To obtain access to manpower (students and professors).	33/as motivating industry	75
2. To obtain a window on science and technology.	13/as motivating industry	52
3. To solve a problem or get specific information unavailable elsewhere.	13/as motivating industry	11
4. To obtain prestige or enhance the company's image.		32
5. To make use of an economical resource.		14
6. General support of technical excellence.	18/as motivating industry	38
7. To be good local citizens or foster good community relations.*		29
8. To gain access to university facilities.**		36
9. Industry provides a new source of money. This helps diversify the university's funding base.	41	
10. Industrial money involves less red tape than government money, and the reporting requirements are not as time-consuming.	28	
11. Industrially sponsored research provides student exposure to real world research problems.	36	
12. Industrially sponsored research provides a chance to work on an intellectually challenging research program which may be of immediate importance to society.	24	
13. Currently, some government funds are available for applied research, based upon a joint effort between university and industry.	8	
14. To provide better training for the increasing number of graduates going to industry.	33	
15. To gain access to company research facilities and equipment.	23	

*Cited more often by administrators than scientists.
**Including opportunities for education and training, adjunct professorships and personnel exchange.

Although access to high quality manpower is the stated primary motivation underlying industry's interest in supporting university research, this motivation has many nuances and can be intertwined with a firm's additional motivations for interacting with universities. Thus, chemical company representatives look toward new employees that will provide a window on new technologies which will help the company initiate new product or process lines. Hence, they will support university-sponsored Industrial Liaison Programs in biotechnology to gain access to potential employees. In another typical instance, a company has an unforeseen problem with a product. After consulting with a local professor, the company hires one of his students to solve the problem over the summer. Alternatively, the company contracts with the local professor to solve the problem and later hires the student who worked on it.

The second most commonly stated reason for a company to interact with a university is interest in obtaining a "window on science and technology." This is a high priority in rapidly changing industries such as genetic engineering and microelectronics, which have recently stemmed from, or have close ties to, the university. For these industries, the technology transfer cycle is very short. They are evolving so rapidly that both the university and the industry must participate in all aspects of the cycle. Frequently, scientists mentioned that access to manpower and obtaining a window on science and technology could not be separated from each other.

Another related motivation is use of the university as a trial base for a new research activity. An industrial laboratory that is considering a new area of research may support such research in the university, where manpower is relatively economical, before making a major investment on its own. For example, one petrochemical corporation that wanted to develop its own resources in laser physics was motivated to support a major project at an eastern private university in order to build knowledge from which to initiate its own program.

Another element of company motivation is prestige. This motivation was not always articulated at first. After considering many cases, the numerous press announcements, and the predominance of the larger programs of support at prestigious universities, it became evident. It was verified upon questioning company representatives that this motivation is not insignificant. Companies interested in a cooperative research venture wish to obtain the "best" expertise. Companies often affiliate with major research universities because of their eminence. Some of the well-publicized, large-scale interactions contain a strong element of the desire to gain esteem. Affiliate programs may also fill this role.

Another aspect of this point is an awareness on the part of companies that support of "pro bono publico" research is good public relations. It will enhance their image. University researchers are happy with this arrangement because they get the benefit of support for research of their choice. One particularly good example where all parties benefitted was a United Technologies program in support of research in laser microsurgery.

> A research employee who had undergone lengthy surgery decided that laser technology could shorten the process and convinced the company to support a research program in this area. The company which had expertise in laser technology but no direct interest in fields related to biomedical technology was commended for its support.

Industry also looks to the university to solve very specific scientific problems in which the university has specific expertise. Large companies have well-developed networks of consultants whom they can call, on very specific problems, in a wide range of fields. Low technology industries may also come to the university for solutions to technical problems.

> For example, one southern state university has an engineering extension program that guides small industry in the state in problems of plant siting, modification, or structure. The function of these services is to disseminate mainstream knowledge and technology, not to generate fundamental new knowledge. The benefit to the university of such services is often general good will, rather than tangible financial contribution.

Finally, and far down the list of motivations for industry and university interaction, is actual innovation. We are distinguishing between new technical advances which may be a contributor to the process of innovation, which industry would certainly welcome, and the development of a usable product or process, which is not normally expected.

Industry rarely looks to the university for technological innovations that directly result in new products or processes. Furthermore, industry does not support university research as a planned stage of product development. In fact, if a company is interested in developing a product and must go outside its own research organization, the company is not likely to support this research at a university because of proprietary concerns and time constraints.

A major petrochemical company, when questioned about what percentage of innovations over the decades had been derived from interaction with universities, answered less than 10% (although some revolutionary technical concepts had come from university sources). Many other company representatives agreed with this figure. Industry has, by and large, not developed mechanisms for seeking out innovative ideas and products stemming from the university. However, as traditional sources of funding dry up, universities are beginning to desire such connections with industry.

It appears natural for the university, which perceives itself as an idea generator, to want to exploit ideas to support itself in needy times. However, except for such unique situations as gene splicing, industry does not have high expectation of receiving a significant number of direct innovations from the university.

The difficulty is partly one of semantics. Innovation to a company scientist usually refers to the total process of generating and introducing technical change, e.g., invention plus exploitation. A "breakthrough" which is frequently the professor's idea of innovation, implies a totally new concept, idea, or approach to a field, a new source of technical change. Those who see how to develop these "breakthroughs" to fit society's needs, and/or wants, and who have the knowledge and background to do so, are usually found within the company while the breakthrough itself often emerges at the university.

2. *University Motivations*

The reasons universities choose to interact with industry appear to be simpler. An oversimplification is that universities seek money. The range of reasons is more sophisticated and includes the following:

(1) Industry provides a new source of money. This helps diversify the university's funding base.

(2) Industrial money involves less red tape than government money, and the reporting requirements are not as time-consuming.

(3) Industrially sponsored research provides student exposure to real world research problems.

(4) Industrially sponsored research provides a chance to work on an intellectually challenging research program which may be of immediate importance to society.

(5) Currently, some government funds are available for applied research, based upon a joint effort between university and industry.

(6) To provide better training for the increasing number of graduates going to industry.

The strongest motivation in the university for interacting with industry, far above all the others, is the desire to obtain funds to strengthen basic research and graduate training, and to support the facilities that make that research possible. This is expressed in many ways, but frequently (41% of the time) researchers state it is important to diversify their sources of funding for basic research and industrial money is currently helping them accomplish this goal (Table 10).

As government conditions absorb more of the scientist's time in non-technical tasks, he is increasingly motivated to seek industrial support. Twenty-eight percent of the time researchers said they sought industrial funds to escape government red tape (Table 10). Once a researcher convinces a firm to support his research, there is usually much less detail involved in administration of the program. More time and energy are available for the research itself.

Although it was not mentioned frequently as a prime motivation for interacting with industry, twenty-three percent of the time researchers said they sought interaction with industrial scientists in order to use their research facilities and equipment. Such interaction may increase as equipment obsolescence and shortages become more severe (Berlowitz, 1981).

B. Barriers and Constraints to University/Industry Research Interactions

In our discussions with both university and company representatives, given the assumption that a university/industry research interaction was seen as desirable by both parties, there was a consensus that there are no insurmountable barriers to joint university/industry research interactions, but several obstacles were outlined. The difficulties mentioned most frequently included patent and licensing conflicts, information dissemination restrictions, including prepublication review requirements, and the handling of proprietary information (Table 11).

Others have stated that there are five key barriers which could prevent a given cooperative activity from being initiated (Brodsky, *et al.*, 1979). These include:

(1) Value Conflicts
(2) Distance
(3) Career constraints
(4) Information dissemination restrictions
(5) Patent conflicts

Table 11

Barriers to University/Industry Research Interactions Derived from Interviews with Scientists and Administrators at Institutions Surveyed in NYU Field Study

Barriers to U/I Research Interactions Cited By Interviewees	Percent of Institutions Surveyed Where Representatives Cited That Such Barriers Existed	
	Universities (n = 39)	Companies (n = 56)
1. Patent conflicts (patent and licensing arrangements including whether or not to issue an exclusive license).	100	23
a. Patent conflicts	67	23
b. Legal problems	38	0
2. Information dissemination	100	43
a. Proprietary rights	74	32
b. Prepublication review	33	11
3. Institutional differences	79	52
a. Differing objectives and goals*	18	21
b. Differing administrative structures**	28	13
c. Time frame differences	33	18
4. Personal attitudes	36/13 as a barrier to industry	16
5. Communication networks	28	5
6. Distance	23	20
7. Concern for research facility and management**	21	11
8. Career constraints	21	4
9. Overhead costs*	15	4
10. Decreasing federal funds	0	4
11. Company expertise in a particular area	0	2

*Cited more often by administrators.
**Cited more often by scientists.

Of these, only the last two were consistently mentioned by interviewees as potential barriers, though our studies indicated that this may be more a perceptual than actual barrier. On the other hand, the institutional differences, including value conflicts, which were mentioned as potential barriers by 79% of the universities visited and 50% of the companies visited may be real barriers (see Chapter VI).

University representatives always mentioned three problems encountered when initiating an industry research program (Table 11):

(1) Patents and licensing arrangements
(2) Pre-publication review requirements
(3) Proprietary information

Industrial managers discounted the first two as problems and were only half as likely to perceive the third as a stumbling block. They repeatedly suggested that such issues are negotiable. Many academic investigators who have had extensive interactions with industry said that patents and licensing arrangements are not real problems. However, both partners agreed that negotiation between lawyers tends to bring out the inherent differences between a company and a university. This sets up an adversary climate, delays establishing the interaction, and sometimes even prevents it from occurring. In this study, at least twelve documented cases were noted where legal differences had delayed, or even prevented a collaborative research interaction.

Most universities will allow a company sponsoring research some time to review manuscripts resulting from the sponsored research for comment to ensure that they do not contain company proprietary information. The pre-publication review period allowed varies from university to university, but it is usually for not more than one year and, most frequently, for one to six months (Table 12). Academic scientists conducting

Table 12

Prepublication Review Period at Universities Surveyed in NYU Field Study

University	Publication Review Time
Carnegie Mellon	30-60 days actually willing to delay 1 year
Case Western	usually 6 months, but departments differ
Clemson	N.A.
Colorado State	N.A.
Colorado School of Mines	none
Johns Hopkins	1 month
Lehigh	N.A.
Penn State	40-60 days
Purdue	N.A.
Rensselaer	6 months
Rice	6 months
University of Arizona	variable
University of Chicago	no delay—Fermi Institute, 1 month—Chemistry
University of Illinois	N.A.
University of Maryland	N.A.
University of North Carolina, Chapel Hill	N.A.
University of North Carolina, Raleigh	N.A.
University of Utah	6 months
University of Washington	fisheries—no review, o[illegible] departments "very strict"
University of Wisconsin, Madison	strictly regulated
Washington University	N.A.
University of Houston	N.A.
University of Michigan	negotiated
University of Delaware	held until patent position clarified
Georgia Tech	negotiated but always a time limit
Duke	N.A.
University of Minnesota	no delay—Inst. of Technology negotiated—Hydraulic Lab no research unless release in a "timely way"
Louisiana State	N.A.
Stanford	90 days for Cancer Bio Lab
University of Texas, Austin	N.A.
University of California, San Diego	N.A.
University of Rochester	90 days
University of Southern California	6 mos.-1 year no research without eventual publication
Cal Tech	no delay
Harvard	1 day to 1 month
Princeton	N.A.
UCLA	N.A.
MIT	N.A.
Yale	30-45 days

Note—N.A. = not available

frontier research are very sensitive to this issue, and are inclined to only allow a company to review the pre-publication for one week to one month. Since theirs is fast-moving research, they are in a particular hurry to publish their results. However, most university scientists are generally willing to delay a publication so that it can be reviewed for patent possibilities or, in some cases, for the time it takes to file a patent. Their rationale is that publication of an article often takes place a year or more after it is submitted.

Another difficulty from the university's point of view is that industrial support tends to come in small short-term allotments, *i.e.*, $10-20,000 for one year or less. While this is not a barrier per se it does constrain some university scientists in the effort they are willing to put forth to solicit industrial funding for their research. Government grants on the other hand tend to be for larger amounts and longer terms (Shapley *et al*, 1980). Companies at least in the past have rarely been able to make long-term commitments to university research. Short-term commitments can negatively affect the quality of a given research program. At present, most companies appear not to be geared towards planning for long-range basic research efforts. Some have commented that strategic long-range planning is sorely lacking in industry. Others suggest that science cannot be planned, though such statements call for careful definitions to avoid semantic misunderstandings.

In many academic fields, there appears to be a psychological barrier to interacting with industry. The more basic the research, the greater the feeling is that industry will, in some way, impede the ability of the individual investigator to follow his own perceived optimal course. This psychological barrier on the part of university scientists is even true, in part, for industries which have had minimum constraints on grants and whose principal focus has been on new graduates. This applies to chemical, petroleum, and computer companies, for example, which provide grants-in-aid, fellowships, and stipends with little red tape. While professors who have received such funds recognize their importance and value, they still hesitate to enter into cooperative research programs where they perceive that industry, through their directives, will constrain their research.

C. The Origins of University/Industry Research Interactions

There are many ways to initiate university/industry research interactions. We have noted cases where a government official brought two parties together; cases where the president of a company decided it would be useful to give greater support to universities and directed the research vice president to develop appropriate programs; cases where industrial scientists catalyzed an interaction; cases where university presidents and corporate executives provided the initiative for a cooperative program; cases where a product manager sought the assistance of university scientists; cases where an industrial scientist and university scientist, through a joint effort, developed a program, and so on.

It is not unusual for the seeds of joint efforts to begin in discussion at informal social affairs. One large program can be traced back to discussions between a university official and company official who had summer cottages next to each other. Another program is reputed to have been started after discussions between a university scientist and corporate president while they waited on a gas line. Discussions at conferences are also important in initiating future interactions. Tables 4 and 5 summarize the different factors involved in the origins of various categories of research interactions.

In the overwhelming majority of cases, the initiative to establish a university/industry cooperative research program comes from within the university. Tracing the origins of over 214 cases of university/industry cooperative research showed that in only about 15% of cases reviewed did the company start the interaction (Table 13). However, there are many instances when a company wishes to interact with uni-

Table 13

Variation in Origins of U/I Coupling by Categories of Interaction*

Categories of Interaction	Percent (%) of Total Cases: University as Initiator	Industry as Initiator	Mutually Initiated	Other**
General Research Support	41.2%	47.1%	8.8%	2.9%
Cooperative Research Support	66.4	15.4	8.9	9.3
Knowledge Transfer Mechanisms	69.0	28.6	2.4	0
Technology Transfer Mechanisms	85.1	4.3	2.1	8.5
Cooperative Research				
Centers & Institutes	69.6	15.2	4.3	10.9
Grants and Contracts	55.1	21.8	15.4	7.7
ILP & Research Consortia	84.9	5.5	2.7	6.8
Other	47.1	35.3	5.9	11.8

*Expressed as a % of Total Cases in Each Category Where Origin is Known.
**Includes: Gov't. Mediation, Alumni Actions, Community Actions

versities by hiring a consultant: a knowledge transfer mechanism. The company then makes the choice based largely upon the contacts and information of its own technical personnel, and this can serve to initiate a continuing interaction.

As a general guideline, relationships between individuals are therefore most often the informal starting point for these interactions. The specific evolution of such initial contacts into working programs can, however, follow different paths, as discussed in the following situations.

1. *The Origins of a Cooperative Research Venture*

An academic investigator will frequently consult for the company with which he desires to develop a cooperative research program. Although he may be the first to propose a cooperative research program with the company, we point out again that consulting arrangements are most often initiated by a company. These consultancies are then often the nucleus of a larger university/industry research program.

Industry makes an effort to identify young, promising investigators. Frequently a company will initiate an interaction by asking this investigator to consult in a specific area. Then he may receive a small research grant from the company. Industry will work to build up a bond of trust with this promising scientist. In time he becomes more familiar with company needs and interests and can identify areas for cooperative research. If a good working relationship is established, industry will have confidence in him and be willing to support a larger cooperative effort. This confidence and sensitivity to industrial needs may also have developed because the investigator has worked previously for industry. In over half the cases we reviewed, the major academic participant had a past history of working in industry.

Thus we may view the initiation of joint university/industry programs as a two-step process:

(1) The company takes the initiative to find good people for consultancies, and

(2) Consultants use these contacts and confidence to generate cooperative research relationships.

As interest and awareness of the value of joint university/industry research programs grow, there is a growing number of instances where both university administrators and company managers are providing incentives and an appropriate climate to establish joint research programs. For example, the president or vice president of Johns Hopkins or the University of Chicago will contact top level executives at an oil company or cosmetic firm to discuss how their interests and capabilities match. Frequently they establish their contacts through university alumni. Sometimes university alumni who are now corporate executives suggest discussing joint programs. In these cases, a two-step initiation process still exists, but may be more generally stated:

(1) Courtship: Exploring the feasibility of a match between university scientist and company program,

(2) Marriage: Building a research relationship through scientist-to-scientist technical exchange.

In summary, a university/industry cooperative research interaction is more likely to come about after there has been an interaction through an informal or non-institutionalized knowledge transfer mechanism.

2. *The Origins of an Industrially Funded Institute or Center*

A university/industry interaction can be the basis for establishing a center or institute oriented toward industrial research interests or at least a definable technical mission, *e.g.*, corrosion research. Several centers (or institutes) at universities came about in the following ways:

> A member of the faculty with industrial ties became interested in a particular area of interest to industry and he contacted five or six scientists across campus. Very frequently they participated in an Industrial Liaison Program together, or the formation of such a program was antecedent to establishing the center. The scientists determined through their industrial contacts that they would gain support by having an institute or center providing a focus to their work. They then made a proposal to the research council or university administration.
>
> A research council is usually an elective group and includes faculty as well as scientific administrators. The council considers proposals in terms of several criteria. The prerequisite is that the future of the research area will evolve, it must be a subject worthy of investigation in the future, not a transitory subject. On industry's side, there is a desire to have a critical mass of scientists capable of doing the work. Sometimes there is industry concern with the university's administrative capabilities and available research facilities.
>
> After the university council establishes that the center focus is in an area of research worthy of studying in depth, it must consider criteria for the center director. This was regarded by company and university administrators to be critical. If the conclusions are favorable, the council recommends the formation of an institute or center to the university President. The President and the academic or research Vice President review the proposed center from a financial point of view. If approval is met, then the proposal goes to the trustees and the trustees are likely to concur at this point. Then it is up to the scientists to maintain their industrial contacts and support. Forming an advisory board of company members is one way of facilitating or providing the necessary continuity.
>
> In another example, this time at a public university, a strong faculty member supported by NSF sought to do catalysis work but needed spectroscopy equipment. He convinced the university to buy sophisti-

cated equipment with its endowment funds. This attracted additional NSF support. Then, with the aid of a retired company scientist, several university scientists, some of whom had consulting ties with industry, organized a program and asked a few high level company research directors to advise them regarding the research direction of the center. This became the core of a highly successful industrially funded research program.

Several important points were made to the university researchers by their advisory board, as follows:

(1) Industry recommended emphasis on long-range basic research. One company executive said, "Throw up lots of balls into the air, and the companies will take home the ones they want."

(2) They advised that the support level from industry should be sufficiently high so that a commitment is made, and that this support should come from someone's budget, not through the education foundation. For this program, a fee of $25,000 a year was set, and all companies paid the same fee.

(3) The board suggested that they aim for twelve member companies, but that it could not function as a closed club.

A critical element in the development of many of these programs, as in the program example above, is government seed money. Most of the large, industrially funded programs were funded, to some extent, by the government in the beginning. Of the 220 cooperative programs we reviewed, approximately 219 had some government support in the first year of operation. Another important point in the structuring of these programs is that both producer and user companies be solicited as members.

D. Administration of University/Industry Interactions

Although funds in support of university research are processed in the office of sponsored programs or the development office in practically all cases, it is the faculty scientist who is responsible for management and administration of the conduct of university/industry programs. This includes final say on the program design, project selection, and allocation of resources. On occasion, the faculty member will also have a consulting arrangement with the company to help manage or give advice regarding the company programs related to the university sponsored research. This is particularly true in the case of programs that involve very sizable funding levels.

Industry's technical input into the program is frequently not through formalized channels. Rather, the principal investigator and colleagues will solicit suggestions regarding areas of emphasis from company sponsors. They then design the research program. Usually this is done on a yearly basis. Many times there is no formal commitment to project reports, only to yearly oral presentations. This is changing, however, as is the informality of company participation in university/industry projects, especially in the larger, longer term projects more generously supported by industry.

Many of the industry oriented centers now have advisory boards which include company representatives. They meet once a year to discuss policy and programs with the principal investigator. A few of the larger programs have two separate boards: one is a policy board made up of industry and university officers; the other, an advisory board composed of company and university scientists to aid in project selection.

However, usually one faculty member, the principal investigator, still has veto power and ultimate say about project management and research design. Several of those interviewed have suggested that they found through experience that university/industry programs do not work if they are administered by committee. In one case where an attempt was made to conduct a program through committee, the program did not begin until one faculty member was appointed director. We heard of only one instance where a company scientist managed a university research program. This occurred because university scientists did not have the scope of knowledge or the time to manage this project. Usually, if a company wants a university to be part of a larger program, they subcontract a specific portion to the university. Only this part of the program will be managed and directed by the faculty member.

As projects become larger and more comprehensive, this may become an issue. Many of those interviewed pointed out that companies were frequently dissatisfied with a professor managing a research program because of his other commitments at the university. Some have suggested that a post-doctoral student or research associate be given the responsibility for day-to-day program management and coordination. However, the ultimate responsibility for research programs and the allocation of resources will continue to lie in the hands of the faculty scientist.

In industry, the ultimate responsibility for management normally resides at a level above the research scientist. This difference in the structure of research management in academia and industry may continue to cause frustrations and difficulties in cooperative research, at least in the initial stages.

E. Characteristics of University/Industry Research Programs

1. *Successful Programs*

The most successful interactions are almost always initiated and nurtured by a key individual who is energetic and has a belief that the success of this program is essential to his professional development. This individual must demonstrate management capabilities as well as excellence in science. Very rarely do programs succeed which are developed conceptually at the top levels of university administration. There must be enthusiastic faculty support of the program.

In several successful cases, university foundations or endowments were used to establish a program which they tied to the university's capability of obtaining government support, which was then instrumental in attracting industrial support. Industry is much more apt to support a program which is in place than to initiate a whole new area of research at a university.

Indeed, federal leveraging of cooperative funding is critical to many successful programs. While the relationship between universities and corporations is of a strictly voluntary nature, the federal government frequently plays a role in influencing conditions under which such linkages may develop. We observed several cases where direct grant awards to the university catalyzed the establishment of significant university/industry cooperative ventures (*e.g.* the MIT Polymer Processing Center, the Materials Science Center at Lehigh University). Programs of support and encouragement focused on specific industries (*e.g.* the role of the government in the communication and information industry) may also generate successful university/industry programs.

In characterizing successful interactions, we would like to point out that many of the present significant interactions are new. In many instances, participants stated that it was too soon to tell if the interactions would stimulate further industrial activity, or produce new and non-traditional outcomes (see p. 43, this chapter, and Chapter V).

2. *Unsuccessful Programs*

In an attempt to shed light on the difficulties of university/industry research cooperation, the research team identified a few case histories which could be characterized as failures. These were difficult to identify because most would only characterize a failure as an interaction that did not occur. One such example follows:

> The director of a research institute at a public university and representatives of an oil company, including the company research director, discussed developing a solar energy research program to be funded at a level of $1 million a year. They considered several ways of interacting in-house, or teaming with the university. The director of the university research institute talked with top level technical, legal, and management people at the oil company. After having spent his time with them, he discovered that the oil company was not seriously considering funding this project. They had even talked about such details as patent rights before the university scientists realized that the oil company never had any intention of interacting with the university.

Other "unsuccessful" interactions were attributed to lack of continued company commitment.

> In one case a professor's research was supported by local industry. The company supported the program for a Ph.D. candidate, and in the interim, the company licensed a product which made the project irrelevant. The student had to find a totally new thesis project and a new company to support him. This is a recurring problem with thesis work supported by a company. There is an inability to guarantee company support for completion of the thesis.
>
> In another case, an aerospace company subcontracted research to a prestigious eastern university and then lost interest in the project because the government changed its funding priorities. Although the contracted research was completed, the university scientists thought the program insufficient because of the lack of company commitment.

Most other failures documented are those cases where there is an expectation for success and the result did not sustain this expectation.

> For example, a chemical company withdrew funds from a large research project because the results indicated that a commercially viable product would not be forthcoming, at least in the foreseeable future.

There are several instances of university/industry research interaction that could be characterized as failures because the university scientists promised more than they could deliver.

> In one instance, a company gave $1 million for a period of two to three years to a Canadian university professor and obtained no valid data in return. The difficulty was partly the investigator's fault and partly the company's fault. If a company expects a specific outcome from the project, it must be precise about the program design and monitor the project continuously.

The research team was rarely able to document a case where a university/industry research interaction had failed because the two parties could not come to an agreement concerning patent ownership and distribution of royalties. However, one investigator, at a marine sciences institute at a public university, did state that he had to back away from one grant because he could not come to an agreement with the company on patents. Some universities refuse to interact with certain companies because of their policies on patent rights, licensing, and publication delay. Companies, in some instances, do not choose to support universities because of their policies. For years, IBM and the University of California system have been trying to come to an agreement over patents.

In summary, most unsuccessful university/industry research interactions can be characterized by a communication gap resulting from a lack of time and effort put into building up a trust relationship between the two parties.

F. Outcomes of University/Industry Coupling

Data indicative of the numbers and types of specific outcomes of university/industry research collaboration are generally difficult if not impossible to obtain. But as an illustration of possible results of a cooperative research program we provide the data in Table 14 on outcomes of selected U/I cooperative research centers.

Most programs have produced Ph.D. students and publications. Graduates associated with university/industry cooperative research programs generally take jobs in industry. As university/industry cooperative programs increase in number, there is a belief that the number of Ph.D.'s oriented to an industrial career will increase, or at least new Ph.D.'s will be better prepared to meet industrial needs.

University/industry research interactions yielding specific results in the final stages of useful applicable results directly related to technical change are rare, if they occur at all. However, the data gathered in our study indicate that university/industry research programs are not initiated with that objective in mind. Most companies recognize the role of the university in basic research and in training students. Their interest is in students and access to new ideas rather than to a specific product, process or service. Frequently, companies hire students that they have, at least in part, sponsored in a university/industry cooperative research program. Faculty are also hired after participation in these programs. We documented at least three cases where the director of a highly successful university/industry research program was subsequently hired by a company sponsor.

G. Model Interactions

The following are a few representative examples of the programs we reviewed. A complete listing of university/industry programs identified is given in Appendix III. Chapters VIII and IX provide descriptions of several other interactions.

Harvard-Monsanto Agreement. Under a twelve-year agreement initiated in 1974, Monsanto agreed to provide $23 million to the Harvard Medical School (including a sizable contribution to the Harvard endowment) to support the work of two medical scientists engaged in basic cell research related to understanding the growth of tumors. The agreement provided for Monsanto to receive patent rights to any useful results from a specific area of research on a particular biological substance under investigation by the Harvard researchers. In addition to seeking a concrete basis for corporate growth, Monsanto was motivated by a desire to gain access to Harvard's capabilities in biological research, an area in which Monsanto sought to increase its in-house capabilities. The agreement reportedly places no constraints on the Harvard researchers' rights to publish the results of their research.

Exxon-MIT. In April, 1980, Exxon Corporation and MIT announced a ten-year agreement under which Exxon will provide $8 million to support basic research

Table 14

Outcomes of Selected University/Industry Cooperative Research Centers

Twenty-Two Yr. Old U/I Cooperative Research Centers Located at Public Universities		Seven Yr. Old U/I Cooperative Research Center Located at a Public University		Three Year Old U/I Cooperative Research Center Located at a Private University	
Center 1		• Graduates		• Graduates (associated with Center)	
• Graduates:	267	— B.S.	100	— B.S.	25
— M.S.	173	— M.S.	20	— M.S.	25
— Ph.D.	94	— Ph.D.		— Ph.D.	15
• Publications (in 10-13 yrs.)	375	• Publications	60	• Publications	285
• Visiting Scholar Residences		• Visiting Scientists &		• Visiting Scientists &	
(1970-1980)	12	Residences	2	Residences	13
• Conferences & Short Courses		• Conferences & Short Courses	25	• Conferences & Short Courses	34
Activities (1978-1980)	12	• Commercial Outcomes	0	• Commercial Outcomes	
• Commercial Outcomes	0			(Commercial Products)	4
Center 2				(Patents Pending)	8
• Graduates (over 20 yrs.)				(Licenses Sold)	3
— M.S. (directly assoc. w/ Center)	100				
— Ph.D. (directly assoc. w/ Center)					
• Publications	554				
• Visiting Scholar Residences (1970-1980)	10-15				
• Conferences & Short Courses Activities					
(Designated training)	400 (people)				
• Commercial Outcomes (products, licenses)	7				
• Spin-Off Companies	12				

at MIT in combustion processes. Research is to be conducted on the burning of coal, coal liquids, shale oil, and heavy crude oil. The agreement provides for MIT to hold patents to technology arising from the research with Exxon, and to share in any royalties resulting from third-party licensing. Exxon will have a royalty-free, non-exclusive license to use such patents. All research results under the Exxon-MIT agreement can be openly published. In announcing the agreement, both the company and the university emphasized the long-term nature of the commitment and its emphasis on long-term, relatively basic research.

du Pont-Harvard. In June 1981, the du Pont Company and Harvard University announced a $6 million, five-year research agreement with the Harvard University Medical School, under which du Pont will receive exclusive rights to use any resulting patents from the research. Harvard will hold title to the patents. The du Pont agreement is focused on genetic research, an area in which the company is investing heavily in a long-term program of building in-house research capabilities.

Hoechst-Massachusetts General Hospital. The largest financial commitment for industry-university research collaboration is contained in a May 1981 ten-year, $50 million agreement between the German chemical corporation, Hoechst, A.G. and Massachusetts General Hospital. The Massachusetts General research program will be carried out jointly with Harvard Medical School in a new laboratory facility to be financed by a separate $15 million gift from an American donor. Hoechst was considering developing its own research institute but apparently could not find a researcher of sufficient stature to head the effort in biotechnology. The agreement provides for open publication of research results, for ownership of any ensuing patents by Massachusetts General, and for exclusive licensing by Hoechst.

Mallinckrodt-Washington University (St. Louis). In September, 1981, Mallinckrodt, Inc., a chemical company in St. Louis supplying medical products, entered a three-year, $3.9 million research agreement with the Washington University Medical School. The focus of the research is on "hybridomas," a technique for producing useful biological materials such as antibodies. In keeping with the general pattern of agreements in biotechnology discussed above, the Mallinckrodt-Washington University agreement provides for open publication of research results, for the university to hold title to any resulting patents, and for the company to have an option for exclusive use of the university patents.

Celanese-Yale. In February, 1982, the Celanese Corporation and Yale announced a $1.1 million, three-year research contract under which Celanese will support basic research on the composition and synthesis of naturally occurring enzymes. Yale will hold title to the patents but Celanese will pay for the patenting and will receive exclusive rights to use any resulting patents from the research. The Yale researchers will allow Celanese to review their publications for up to forty-five days. Thereafter, Yale researchers have unlimited publication rights. This is the largest contract ever made by Celanese to a university, according to corporate officials, and it is Yale's first venture with an industrial agreement of this sort. The money will be used in part to support approximately four post-doctoral fellows.

University of Michigan—University/Industry Program in Microbiological Processes. The University of Michigan interaction with Upjohn in microbiological processes is part of the NSF University-Industry Coupling Program. Upjohn's contribution to the program involves manpower and facilities rather than monetary contributions.

A University of Michigan professor, who had previously worked in industry, was responsible for getting the grant. The importance of personal contacts is illustrated by the professor contacting someone at Upjohn, whom he knew was interested in university-industry cooperative research. The chairman of his department had had contact with Upjohn previously through a consulting arrangement and so the company was responsive to the younger professor's approach. Additionally, they were involved with another IUC program.

There was a need to find an area of overlapping research interest. That overlap was uncovered through a desire to develop process improvements for two products already being produced at Upjohn. In addition to Upjohn's contribution to the project, they had already assembled information for the research that saved the Michigan researcher a substantial amount of preparatory research. The agreement reached between Michigan and Upjohn granted 10% of the sales revenues generated through process improvements to the university. Upjohn was granted exclusive license to any patents developed but would pay for the patent process, although the actual patent would remain with the university. An added feature of the agreement permitted Upjohn researchers to publish along with the university researchers.

MIT-Whitehead Institute. A unique situation in the development of biotechnology research programs concerns the Whitehead Institute and MIT. Through a $7.5 million gift from Edwin C. Whitehead, MIT will be involved with the establishment of a $120 million research institute.

The importance of this institute concerns the dual status that twenty professors will hold with MIT and the Institute. Equal power over screening and appointing these new professors and their students will rest with both institutions. Concern exists with regard to MIT losing control over faculty appointments, graduate students and research directions. The willingness to accept this situation appears to be influenced by the expectation of shrinking federal support.

Purdue-Computer Integrated Design, Manufacturing and Automation Center. The Computer Integrated Design, Manufacturing and Automation Center (CIDMAC) at Purdue developed out of a CAD/CAM project with the Control Data Corporation. The computer aided design laboratory (CADLAB) was started as a research project in computer graphics and computer aided design by a professor in mechanical engineering in 1969. Ten years later, this professor, who had left Purdue, was on the Board of Directors of CDC. He did consulting work for them and later involved one of his ex-students at Purdue in consulting for CDC.

When the company decided to go into CAD/CAM, the decision was made to go to the university, rather than develop a program on their own. The program was initiated in 1980, with a three-year grant from CDC for $2.8 million: $1.5 million for facilities and $430,000/year for researchers. In addition, CDC bought computer graphics and commercial quality software, which it owns but leaves at the university. Research topics were not determined until after the initial funding. CDC gets non-exclusive rights to programs developed through the project but determines the royalties on licensing.

The CADLAB is a research laboratory affiliated with Purdue's Institute for Interdisciplinary Engineering Studies. As a result of the influx of CDC money, the Dean of Engineering sought the development of a broader, much larger program; CIDMAC.

Five companies have been enlisted as sponsors for the Center. The names of those companies will be released by the school in the coming months. Purdue is asking for $1.2 million over five years from each company. The first year's funding will include upfront money in the form of either cash or equipment. Although separate contracts were negotiated with each, Purdue gets patent rights while the companies get exclusive license. Additional funding has come from NASA and NSF.

CIDMAC will draw upon the design faculty from CADLAB, the Advanced Automation Research Laboratory, the Laboratory for Applied Industrial Control, manufacturing and computer aided manufacturing research in the School of Industrial Engineering and the Business School. There will be extensive student involvement and the Center seeks to develop projects that may be used as thesis projects.

Lehigh-Materials Science Research Center. The Materials Science Research Center was the first center started at Lehigh (1962). Important in getting started was a large metallurgy development grant from NSF for five to six years. The next step was the initiation of an industrial liaison program in materials science to bring industry to the university and develop the exposure necessary for facilitating cooperative research. There are approximately twenty companies involved in both the Center and the affiliates program.

Research faculty may have dual appointments to the Center and an academic department. The Center draws faculty from amongst several departments: metallurgy, chemistry, physics and materials, mechanical, chemical, electrical and computer engineering. In addition, there are non-academic appointments, with the center paying 50% of the salary and research contracts paying the other 50%.

The Center has participated in personnel exchange, with Center personnel having spent time at Allied Co., IBM and the National Bureau of Standards. Less than 10% of the center's support comes from industry. Of that industry support, most of it tends to be local companies providing funding, on the order of $10-20,000.

Although researchers may pursue any direction they desire, as long as it is supported, there are advisory committees. As is required of all Lehigh centers, there is a visiting committee, made up of industry and government representatives. Additionally, there is a Materials Research Council, consisting of senior faculty, providing advisory and communications support. The director of the center, as well as most of the technical staff, have worked in industry, providing an understanding of industry's perspective.

Innovation Center-University of Utah. The Innovation Center at the University of Utah was established in 1978 with a grant from NSF for $900,000 over three years. The goal of the program is to assist in the development of new companies. Between 500 and 1000 ideas are reviewed per year, arising mostly from independent inventors outside the university. The initial screening process is informal. In reviewing the submitted proposals, the Center looks for those ideas that might lead to the founding of a company in the geographic area, based on an advanced technology and for a person with the capability to run the company that will eventually arise. There is a waiting period for potential projects that lasts 2-18 months. The second phase in the process of fostering the development of these new technical ventures consists of those steps that can be accomplished in six months for about $5,000. This includes prototype improvements, market research, patent research, or performance research.

If the Innovation Center decides to continue with project, the next phase is finding seed capital, which is easier to acquire for the entrepreneur associated with the Innovation Center than on his own because of the credibility the Center lends to the project. If this capital is acquired, then over the next 12-18 months the product must be produced in prototype form, a business plan and objective written, and a team established.

The fourth phase is the assembly of key management and bringing the product to the commercially ready stage. The fifth phase involves assistance in obtaining start-up capital.

Two companies have reached this stage of the program. Representatives of the Center state that its equity in the two companies will exceed NSF's original investment within a year.

Robotics Institute-Carnegie Mellon University. Carnegie Mellon has for the past two years operated the Robotics Institute, a multi-disciplinary program involving the computer science, electrical and mechanical engineering departments. The main source of funding for the Institute comes from Westinghouse, which is providing $1 million per year for five years. Additional funding is supplied by Advanced Research Projects Agency (ARPA), Office of Naval Research (ONR), and a small National Science Foundation (NSF) grant. Another sponsor is a consulting firm headed by the chairman of the computer science department and another professor. The Institute does contract work for companies willing to support a major project. The sponsors receive all non-proprietary data and computer programs on a royalty-free, non-exclusive basis. Bi-annual "research-in progress" reviews are held to update sponsors on research activity.

Institute objectives include: scientific advance in robotics science, technology transfer to industry, and training of engineers and scientists. To facilitate the technology transfer, an affiliates program is maintained.

The Institute was initiated at the behest of the university president. The man put in charge of raising the funds had worked for Westinghouse. Right from the beginning equipment was available from the various academic departments. Although an informal group of advisors exists, researchers largely decide what they will work on. The staff includes full-time research scientists as well as faculty with dual appointments between the departments and the Institute.

University of Arizona-Office of Arid Land Studies. The Office of Arid Land Studies at the University of Arizona has existed for sixteen years but only for the last two has it had any industry support. It was started with support from the Rockefeller Foundation and operated out of the College of Earth Sciences. The Office was later moved to the Division of Interdisciplinary Studies in an effort to pool together a multidisciplinary research team. It is important to note that the Office is not an academic department. Students are considered a resource for research efforts.

Currently, one-third of the financial support comes from industry and the rest from the federal and state government. Personal contacts were very important in initiating cooperation with industry. The major portion of industry support comes from Diamond Shamrock, with Phillips Petroleum just recently joining the program. Strong leadership has played a crucial role throughout negotiations on industry involvement as well as particular aspects of research agreements.

Any patents originating out of the cooperative research stay at the university with Diamond Shamrock receiving exclusive license in return for royalty payments. Some problems have arisen due to proprietary rights but have been overcome due to the strong positions of the industry and university representatives. Monthly project meetings are held as well as advisory committee input.

Rensselaer Polytechnic Institute-Center for Manufacturing Productivity. Rensselaer Polytechnic Institute's Center for Manufacturing Productivity is a unique form of university/industry interaction. The Center is solely supported by industry funding. Started in 1979, it was initiated through the efforts of the university vice president and dean of engineering. They sought to rectify existing deficiencies in productivity growth in manufacturing, as well as increase university/industry interaction at the university.

Although the Center is within the engineering school, is has no faculty of its own. The key to the program is the use of project engineers from industry that are hired at the Center for a maximum of five years.

It is not a generic program. All projects are the result of a specific need by a particular company and are conducted according to contract agreements. Contract costs are in addition to sponsor fees.

The sponsors are divided into two groups; the Founders Group, consisting of five companies contributing $250,000, and an Associates Group, consisting of five other companies contributing $10-50,000 annually, based on the size of the firm. Membership in the Founders Group provides a spot on the Advisory Board, a policy making committee.

University of Washington—Ocean Margin Drilling Program had been a part of the proposed Advanced Ocean Drilling Program. Initiated by the government in 1977, the decision was made to involve the petroleum industry in the program. Of the 24 companies approached, only 10 made a positive commitment. The first-year costs were shared equally between the National Science Foundation and the industry participants. The cost for industry was $5 million.

A Science Advisory Committee was established with representatives from the 10 petroleum companies, 10 universities that were to be involved in the program and various representatives from government. A substructure was created to develop contracts for the research program based on the scientific plan developed at a conference in late 1980.

At the end of the first year of planning, the industry participants made the decision to discontinue participation in the program. The primary reason for the decision was due to a feeling that per company costs were too steep. The anticipated costs were $500 million over ten years. Originally there was an expectation that other industry sponsors would be enlisted during the planning stage. However, this did not come to fruition. An additional speculated reason for their discontinued participation was that the world oil glut made it difficult for petroleum companies to justify program expenses with a long term profit potential. Therefore, the program could not meet this requirement.

CHAPTER VIII

DIFFERENCES IN TYPES AND INTENSITY OF COOPERATION WITHIN AND AMONG SECTORS

Successful research interaction between two sectors having differing but not competitive goals and outlooks depends on their preconceived and real degree of complementarity and the mutual benefit to be derived. The highest degree of complementarity between the universities and industry is clearly in high-technology research where technology transfer is rapid and requires close apposition both for fundamental and product-oriented research. Current examples of such research are microelectronics, polymer science, materials science, and molecular biotechnology. There are indeed many joint programs in these areas.

The potential for high complementarity exists in some universities but not in others, in some companies but not others. Approaches to cooperation differ according to the objectives and traditions of each institution (see Chapter VI, pp. 24-25).

A. Variation Among Industries

1. *Characteristics of Industrial Support*

Different industries vary greatly in their attitudes toward supporting university research and in the types of programs they tend to support. This is in part a result of interests related to their products and in part related to the nature of their business. Specific differences among industries in their participation in university/industry research will be discussed in Sections A.3.a to A.3.h of this chapter.

The companies that tend to support research interactions with universities are frequently (N-50% of the time) members of the *Fortune* 500. Most are research-oriented companies and are listed in the Business Week R&D Scoreboard. Firms listed by Business Week must spend at least $100 million on R&D annually. The industries most frequently represented in sponsoring university research spent from 2-6% of their sales on R&D. Those industries interacting less frequently generally spend less than one percent of their sales on R&D (Table 15).

Though a great many companies hire university graduates, a small percentage of the total number interacts directly with the university by recruiting or by expressing needs regarding the nature of educational programs. Typically, between 200 and 500 companies recruit at a given campus. Only 500 companies do any recruiting on campuses at all, approximately 0.3% of the 150,000 companies that have more than 500 workers.

Indeed there are a limited set of industries, each dominated by a relatively few companies, that have any significant research interaction with universities (Table 16). Of the 464 programs reviewed, about 292 companies were involved in the support of over 60% of the programs documented. In these programs, about 97 different companies were represented more than once. All of these had more than 500 employees. This is about 0.06% of those companies that have more than 500 workers, *i.e.*, those not considered to be small business. Additional data suggest that in the cases where we did not list company participants, a similar spectrum of participation exists.

The industries that fund research at universities are, as expected, those that are more dependent on research and development and who perform research and development themselves: chemicals, pharmaceuticals, electronics and computers, fuels, aerospace, automotive (Table 17). However, even among those industries, a very small percentage of their research and development dollar is spent in universities. Pharmaceutical companies, for example, spend less than 10% of their R&D funds outside their walls, primarily for clinical testing of drugs. Less than 3% of that 10% goes to basic research at universities. However, the pharmaceutical industry does have extensive interactions with universities, primarily through exchange of research personnel and information. They provide adjunct professors, participate in conferences and seminars, and invite distinguished faculty to partici-

Table 15

Research & Development as a Percent of Sales

Industry	Ranking	1977	1978	1979	1980	Average
Aerospace	7	3.5	3.7	4.2	4.5	4.0
Appliances	19	1.4	1.2	1.5	1.8	1.5
Automotive (cars, trucks)	8	2.6	2.8	3.2	4.0	3.2
Automotive (parts, equipment)	18	1.5	1.4	1.5	1.9	1.6
Building Materials	22	1.0	1.1	1.1	1.1	1.1
Chemicals	12	2.5	2.5	2.3	2.4	2.4
Computers[1,3]	1	5.9	6.0	6.1	0.4	6.1
Conglomerates	16	1.5	1.7	1.6	1.8	1.7
Containers	23	1.1	0.9	0.8	0.8	0.9
Drugs	3	4.9	4.7	4.8	4.9	4.8
Electrical	11	2.4	2.5	2.8	2.8	2.6
Electronics	10	3.0	2.6	2.5	2.9	2.8
Food and Beverage	27	0.5	0.5	0.5	9.6	0.5
Fuels	29	0.4	0.4	0.4	0.4	0.4
Instruments (measuring devices, controls)	5	4.7	4.1	3.9	4.2	4.2
Leisure Time	4	4.3	NA	4.2	4.2	4.2
Machinery (farm construction)	9	3.2	2.5	2.7	2.7	2.8
Machinery (machine tools, industrial mining)	17	1.7	1.6	1.6	1.6	1.6
Metals and Mining	25	1.0	0.6	0.5	0.9	0.8
Miscellaneous—Manufacturing	13	1.9	1.8	1.7	2.1	1.9
Office Equipment[2]	6	4.0	4.1	4.2	4.3	4.2
Oil Service and Supply	21	1.1	0.9	1.7	1.6	1.3
Paper	24	0.9	0.9	0.8	0.8	0.9
Personal and Home Care Products	15	—	1.6	1.7	1.8	1.7
Semiconductors	2	5.8	5.8	5.7	6.0	5.8
Services (engineering, data service leasing)		0.3	D.C.	D.C.	D.C.	—
Steel	26	0.6	0.6	0.6	0.6	0.6
Telecommunications	20	1.9	1.9	1.0	1.0	1.5
Textiles, Apparel	27	0.5	0.5	0.6	0.5	0.5
Tires and Rubber	14	1.7	1.7	1.7	1.8	1.7
Tobacco	29	0.5	0.5	0.3	0.3	0.4
Information Processing[4] (peripherals, serv.)					5.9	

[1] In 1978—changed to Information Processing (computers, peripherals).
[2] In 1978—changed to Information Processing (office equipment).
[3] In 1980—changed to Information Processing (computers).
[4] In 1980—separated from Information Processing (computers, peripherals).

D.C.—discontinued category.

Source: Business Week annual R&D Scoreboard.

pate in programs of varying length. They support graduate students. With the advent of molecular matchmaking, they are just beginning to develop a whole range of cooperative interactions. The task of routine drug testing, although willingly performed by some universities, is not closely allied with the fundamental goals of the university. Highly repetitive, not innovative, and labor intensive, such research may be inappropriate within university academic units.

Several manufacturing companies said that they preferred dealing with contract research laboratories (e.g., not-for-profit research institutes such as SRI or Battelle) when they decided to sponsor research outside their own organization. They found that such organizations could mobilize more easily to complete work on short schedule, and proprietary information could be dealt with more readily. Sometimes these attitudes are based more on perception than reality. The differences in attitude among companies towards development and cooperation with universities were described in Chapter VI, Section C.

2. *Firm Size and University/Industry Coupling: Differences Between Small and Large Companies' Programs*

We have already observed that there are a limited number of companies that have much research-related interaction with universities and that only the larger companies as defined in terms of employees and annual sales tend to participate in cooperative university/industry research programs (see Table 16). Very rarely did we discover an instance of a smaller company providing funds for university research. Of the 287 documented cases of cooperative research, only one program has been funded by a company with sales of less than $10 million. Recently, this company was bought by a larger food processing company.

Smaller companies, if they interacted with university researchers, did so by participating in knowledge transfer programs. Even then, organizers of such programs said it was difficult to attract the interest and participation of small companies. Several directors of engineering extension programs, or programs directly set up for smaller companies, stated that these companies came to the university only as a last resort. In order for a program to work for the smaller company, a university researcher had to seek out their participation energetically.

In summary, there are several barriers to university research cooperation with smaller companies:

(1) Smaller companies are primarily interested in solving specific problems, many of which are not considered to be of sufficient challenge by university professors.

(2) Smaller companies frequently do not have the research organization or personnel necessary to foster technical contacts between itself and a university.

(3) Smaller companies must husband their resources. They do not have the funds to spend on academic research programs.

The exceptions are small high technology or instrumentation companies where corporate officers are themselves scientists and may have begun their career in universities. Such companies, even when they have little liquid capital, are often interested in providing services in kind to universities, personnel support, internships, equipment loans, and other services.

3. *Differences Among Industrial Sectors in Collaboration with Universities and the Modes of Interaction Favored by Different Sectors*

The motives and modes of interaction with universities of companies within each industrial grouping are based on the specific commercial interests of the group, tradition, and differing technology bases. Each industrial sector is characterized by a product cycle. How well developed the technology associated with a given product is influences the kinds of research interactions in which a particular industry engages. The maturity of a scientific concept, the economic climate, and serendipity all play a role in the readiness of an industry to cooperate with university researchers. The time must be right for cooperative commitment to occur.

The primary industrial groups inclined towards research interactions with universities are, as stated previously, petroleum, chemicals, automotive, elec-

Table 16

Summary of Companies Actively Supporting University Research

		NSF Industry University Cooperative Research Program (FY 1978-81)		
Ten Leading IUCR Performers	Industrial Sector	Projects* (No.)	Value of Awards** ($1,000's)	Share of Total Awards (%)
IBM	Information Processing	15	2,326	7.8
AT&T (Bell Labs)	Information Processing	8	993	3.3
Hughes Aircraft	Aerospace	6	2,491	8.4
Westinghouse	Electrical	6	1,570	5.3
Exxon	Fuel	5	721	2.4
Lockheed	Aerospace	4	1,480	5.0
Martin-Marietta	Aerospace	4	598	2.0
du Pont	Chemicals	3	1,449	4.9
GE	Electrical	3	914	3.0
Hercules	Chemicals	3	811	2.7
		NYU Field Study 1980		
Eleven Leading Participants NYU Field Study	Industrial Sector	Projects* (No.)		
IBM	Information Processing	20		
Exxon	Fuel	17		
GE	Electrical	17		
Ford	Automotive	15		
du Pont	Chemicals	13		
Xerox	Information Processing	12		
Burroughs-Wellcome	Drugs	9		
Chevron	Fuel	8		
Boeing	Aerospace	8		
Dow	Chemicals	8		
Hughes	Aerospace	8		

*Some research projects have received more than one grant. These figures do not count continuation grants.
**Includes matching funds provided by other NSF Divisions.

Table 17

Distribution of U/I Research Interactions into Business Week Industry Groupings

Industry	Number of Firms Participating: NSF IUCR* Program FY 1978-81	Voluntary** Aid to Education 1980	NYU Field Study 1980
Aerospace	4	2	10
Appliances	none	1	1
Automotive	3	6	10
Biotechnology Company	none	none	3
Brokerage	none	none	1
Building Materials	none	1	6
Chemicals	9	29	26
Conglomerates	4	2	5
Containers	none	1	1
Drugs	3	7	17
Electrical	3	5	3
Electronics	3	1	7
Engineering	none	2	7
Food and Beverage	none	11	12
Fuel	6	15	26
Information Processing (computers, peripherals, office equipment)	5	4	13
Instruments	3	1	6
Insurance	none	19	2
Leisure Time	1	none	2
Machinery (farm construction)	1	2	6
Machinery (machine tools, etc.)	1	5	3
Metals and Mining	2	11	7
Miscellaneous—Manufacturing	none	none	5
Oil Service and Supply	none	none	none
Paper	1	10	7
Personal and Home Care Products	2	none	1
Semiconductors	1	1	3
Steel	3	4	5
Telecommunications	2	4	none
Textiles and Apparel	none	3	3
Tires and Rubber	1	4	none
Transportation—Equipment, Ship Building, Railroad	none	4	3
Utility	none	9	9

*Source: Program award sheets NSF
**Source: Council for Financial Aid to Education, *CFAE Casebook* (11th ed.)

tronics and computers, aerospace, food and pharmaceuticals (Table 17). Chemical companies have the longest history of actively contributing funds to university research and participating in cooperative research programs. The mining and minerals industry, and construction industry, have in the past been less inclined to fund or be involved in cooperative university/industry programs. In general, poor capital-intensive industries find the sort of research programs conducted at universities not well suited to their needs. Their funds may be limited, their needs more immediate, and technical decisions may require expensive and specialized equipment.

To illustrate the differing views and modes of university/industry research interactions in different industries, the following sections will present an overview of such interactions within the aerospace, energy supply microelectronics, chemical, pharmaceutical, mining and mineral, and construction industries. Each is operating under a different set of financial and market conditions which have a definite influence on each industry's interactions with universities.

a. *Aerospace Industry*

An industry which is devoted exclusively or primarily to producing aerospace products is dependent to a great extent on the uncertainties of government defense spending. The frequent "boom and bust" cycles have had a negative impact on the long-range research commitment of the aerospace industry, and consequently on its involvement in university/industry research cooperation. Nevertheless, a few aerospace corporations have maintained a continuing commitment to research and, to one degree or another, most are involved in some type of university interaction involving research, usually very specifically product oriented.

The most common research interactions between the aerospace industry and the universities are consulting by individual professors and membership in industrial affiliates programs or research centers. Personnel exchanges are not uncommon, most typically involving industry-based scientists or engineers working at least part-time in universities. Such personnel exchanges sometimes involve formal joint appointments at both institutions.

Collaboration in contract research is sometimes discouraged because of proprietary rights. However, corporations with a commitment to research, the few aerospace firms which support their own central research facilities, collaborate extensively with universities. This collaboration sometimes extends beyond the confines of the central research facility to other corporate divisions.

The most common types of university/industry relationships in aerospace research facilities involve government-contracted joint research projects. A variety of government funding agencies are usually involved in supporting cooperative research projects including DOE, AFOSR, DARPA, ONR, and NSF. Many aerospace industry research programs have resulted from government-sponsored collaborations. A typical mode of cooperation involves the industry partner as the prime contractor and the university as the subcontractor. This seems to be preferred by both partners. Industry has greater control over project management, which it prefers, while the university partner does not have to handle the burdensome paperwork involved with government contracts. Nevertheless, the paperwork required by some agencies can be a barrier to encouraging greater university/industry cooperation in government-contracted research. Although aerospace firms cite past encouragement of university participation in research by the Department of Defense, they report a recent drop-off in cooperative support from DOD funding agencies.

Aerospace firms receive discretionary independent research and development (IRAD) funds from the government, based on a percentage of their federally sponsored work. Some aerospace firms use part of their IRAD funds to contract with university researchers, either as individual consultants or in university-based projects. Such IRAD-supported university/industry collaboration seems to be preferred over government-contracted research cooperation because of the minimum of paperwork involved, especially in the proposal stage. One major aerospace firm claims that a barrier to greater utilization of IRAD for university research is that only two-thirds of it can be recovered as part of the overhead on federally-sponsored work. Total recovery of IRAD funds was suggested as an incentive for increased IRAD funding for university research. It is not clear, however, whether such a change would encourage those aerospace firms which only utilize their IRAD funds internally to switch some of these funds to support university research.

Top corporate commitment is critical to the support of university/industry interactions and may even override the lack of a strong research facility. A typical indicator of such a commitment was the assignment of a top executive to the responsibility for developing interactions with universities. One such executive indicated that his performance would be determined by the degree to which he is successful in increasing university interactions. A strong corporate research facility usually implies a strong commitment to university/industry cooperation at the top corporate level which goes well beyond the collaborative activities of the research facility. However, the lack of such a facility does not necessarily imply a lack of commitment to the support of university/industry collaboration. In at least one aerospace firm, which has downgraded its own research laboratory, corporate commitment to university/industry collaboration appeared at least as strong as in firms which strongly supported their own research facilities. In several other firms, the greatest increases in research support focus on university collaborations. However, corporate commitment in the aerospace industry to increase university support appears to be the exception rather than the rule.

Occasionally, individual aerospace firms have pooled their resources to support university programs which were of crucial concern to the industry. For example, when several companies felt that there was a need for a manufacturing engineering research program utilizing CAD/CAM technology, and support from the federal government was not forthcoming, the firms themselves initiated the development of such a program at a western public university. The companies established an advisory board and agreed to divide responsibility for providing specific components, personnel, hardware, and software to help develop the research program. One firm even established an endowed chair.

It was no coincidence that the CAD/CAM program was established in a California school. Since much of the aerospace industry is concentrated on the West Coast, especially in southern California, most of their university interactions are focused in that geographic area. This is perhaps a unique example of the importance of propinquity for a whole industry establishing interactions with local universities. West Coast universities develop research expertise and produce graduates who are up-to-date in areas of science and technology relevant to the industry. Despite the importance of proximity, some aerospace firms will seek out expertise in universities as far away as the Northeast.

b. *Energy Supply Industry*

The energy industry, as a whole, is one of the most active participants in university/industry cooperation.

The vast array of energy research directions is the subject of over 15% of the cooperative university/industry ventures in the sample matrix (Appendix III). The industrial participant's main area of business, however, may not be energy. An auto manufacturer and in insurance company both conduct energy research with universities.

Some of the earliest university/industry interactions have involved the energy industry. The longest running interaction (75 years), a fellowship program, involves a Great Lakes area gas trade association and a large state university. That cooperation has accelerated within the past ten years.

The increased attention the energy industry has given to university research capabilities has resulted from the oil shortages experienced worldwide during the 70's. These shortages underlined the importance of developing new sources of energy, whether conventional or alternative, and the need for long-range fundamental research.

The dramatic increases in oil prices have had a mixed effect on industrial research support. The increased oil prices have helped the fuel suppliers (i.e., oil companies) but have hurt the fuel users (i.e. utilities). The utility companies, some of the most active participants in the early university/industry interactions, have limited cash for research expenditure because of the higher fuel and construction costs. For example, a New England program established to foster university/industry cooperation and specifically targeted to the utility companies, failed in part because of this cash squeeze. Other contributing factors were:

(1) A competition for funds with the programs of the Electric Power Research Institute (EPRI), a collective industrial organization formed to conduct and sponsor research; and

(2) A hesitancy by companies to spend their own funds on research projects when government agencies gave the impression that they would provide support.

The utility companies in response to limited cash and an urgent need to be up to date regarding new technological developments banded together to collectively support R&D in 1972. This marked the beginning of the Electric Power Research Institute (EPRI). With the formation of EPRI, the utilities refocused on short-term applied research expenditures. Only 7-8% of their total research expenditure is now directed to universities. Many universities have difficulty accommodating to EPRI's patent and equipment purchase policies. EPRI often asks for the return of equipment at the end of a project, preventing university laboratories from maintaining research continuity.

Another collective industrial organization formed in response to current energy research needs is the Gas Research Institute (GRI), formed in 1976. GRI, a not-for-profit organization, plans, manages, and finances a coordinated R&D program in gaseous fuels and their use on a national level. Additionally, it manages and funds the cooperative research of the American Gas Association.

GRI is supported by 197 companies on the basis of a funding formula. Many programs are coordinated and co-funded with government and industrial organizations.

The research program is in four major areas and includes fundamental research. GRI contracts out all project work to leading research organizations. Unlike EPRI, nearly half of GRI's program is conducted at universities, through grants and contracts. In 1980, 38 university grants were awarded graduate students for thesis work in gas-related research. The trend of university funding has been increasing: from $600,000 in 1979 to a projected $3.2 million in 1982.

As the large oil companies take over an increasingly large share of the energy industry, they have also stepped in to take the place of the utilities in financing new energy projects. This includes the financing of university/industry research cooperation as well as industrial exploration development and research projects. Many oil companies, of course, were already accustomed to working closely with university research personnel and were highly research oriented. During the years prior to OPEC the utilities exploited oil industry research propensities. They often financed projects by smaller oil companies in exchange for guaranteed supply contracts.

Increased university/industry interaction with energy supply companies also results from the shortage of manpower affecting the energy industry. With the increased efforts in oil and gas exploration and development and alternate fuel development, there has been an ever increasing need for geologists and engineers. Universities have been hard pressed to meet these demands. The implications for the universities have been been quite significant. With the supply shortfall, salaries for university graduates have increased dramatically. Such demand for faculty and graduate students causes immediate problems at the universities in terms of retaining quality teaching and research. It is becoming of increasing concern that such a drain will result in a long-term problem for industry. Future engineers and geologists may be inadequately trained. In response to this problem, several types of university/industry interactions are being utilized; consulting, extension programs, internships, fellowships, personnel exchange, and institutional consulting, as well as direct salary supplements.

Education extension programs have developed to keep industry people abreast of the quickly developing technologies and issues related to the energy industry. At least one of these programs is using videotape presentations to permit the flexibility that industry often requires for retraining its personnel.

Institutional consulting has been an infrequently utilized type of university/industry interaction, only two instances noted in all the interactions studied. However, in both of these, the industrial participants have been from the energy industry. One of the programs utilizes student consulting teams for short-term projects. The other has the objective of bringing consulting onto campus rather than having the professor leave campus to consult. Student involvement is required under this project.

Because of the varied nature of energy research, university flexiblity across disciplines is particularly important. Twenty-nine percent of the energy related university/industry programs involve two or more disciplines. Additionally, of the 24 research institutes, organizational structures established to facilitate multidisciplinary research, over one-third are related to energy projects.

Another attribute of the energy industry's utilization of university/industry interaction is the non-proprietary nature of the technology. Because of this, patent rights appear to be less of a problem. There is a disproportionately large amount of multi-company cooperation in university/industry projects. Such cooperation may occur through trade associations, research consortia, or other multi-company interactions. The energy industry frequently utilizes joint ventures and cross licensing agreements and is at ease with cooperative situations when dealing with university/industry programs. Many of the research programs undertaken, whether involving the university or not, are very costly and therefore companies seek to share the costs and risks of projects. Thirty-one percent of the consortial arrangements cited involve energy related projects.

The objective of spreading the risk and cost of developing energy related technology has resulted in numerous instances of government funding of projects. However, several companies and universities consider government involvement to be inhibiting to the research.

Because basic research in oceanography and geology have the most direct applications to the industry, the energy industry is most open to university/industry cooperation in these fields. Additionally, with the longer time horizon of many energy projects (i.e., synfuels, photovoltaics, fusion), industry can identify many opportunities for the research capabilities of the university.

Because of the potentially lucrative returns from energy projects, many companies normally outside the energy industry have initiated programs with universities on energy research.

Numerous spin-off companies in the energy industry have arisen as the result of university based research. One northeastern university has a program to help these companies get started by housing them on campus and allowing them access to equipment and faculty. This program is not limited to energy related companies, but so far they are the most frequent participants.

Proximity also appears to play an important role for an energy company seeking out a university research partner, perhaps because of the geographical concentration of oil and gas. Twenty-nine percent of the energy university/industry interaction occurs in the southwest-south central region, where many of the oil and gas companies are located. Schools in this area tend to have well developed engineering and geology programs.

The diversification initiatives undertaken by the large oil companies have led them beyond energy based technology ventures. With a tremendous availability of funds, they have stepped into a new industry, biotechnology. Although some of the biotechnology projects involve techniques to improve enhanced oil recovery and production of methanol, many involve research only indirectly related to the energy industry. One major oil company has bought major seed companies. Basic molecular biotechnology for this company will produce more than energy-related seed stock improvements. Indeed, such companies may be the future repositories for the many libraries of genetic material. How they take their responsibilities towards the world food community will have a direct impact on developing countries.

The avenues of investment have been quite varied. New laboratories have been developed from scratch, joint agreements have arisen with new biotechnology firms, and several energy companies have turned to the universities to tap their expertise.

One such university/industry endeavor has been quite creatively designed. A non-profit foundation was established which holds an equity interest along with the industry participants in a for-profit organization. The profits associated with the non-profit center's equity interest would be used to sponsor university research. Faculty from each of two West Coast universities are associated with this for-profit organization.

c. *The Building Materials and Construction Industry*

The building materials industry, and in particular the associated residential construction group, has experienced neither significant federal procurement nor much federal research and development support for either basic or applied work. Analysis of the residential construction industry indicates that, unlike agriculture, it has neither the constituency interested in establishing applied research and development relevant to their needs, nor a sound scientific basis underneath its technologies (Quigley, 1982). This appears to be true to some extent for the building materials industry, though far less so. There, activity is evident in developing new products and applications.

These industries lack a broad university scientific base oriented to their needs, which might provide new options for applied research and development activities. One company manager said his company looked to European university research programs when they needed basic research results related to company interests.

Research and development as a percent of sales in the building materials industry averaged 1.1% over the last four years (*Business Week*, 1977-1980). Their ranking in this category out of 29 *Business Week* groupings was 22. However, in the Nason-Steger study (1978), the building materials industry reported that they spent 6.4% of their total research expenditures ($47M) on basic research.

Regulatory regimes strongly influence the technological advance of these industries. The response of the building industry to regulation has been conservative. Building codes and standards have stayed fairly close to prevailing technologies and materials,or simple modifications thereof (Quigley, 1982). One constraint on change has been the position of unions, a strong factor in the construction industry.

There would appear to be research of interest to building materials companies at university-based materials science centers, and perhaps in CAD/CAM and robotics programs. Of the programs we identified in this study, approximately 1% were supported by the building materials and construction industry. However the importance of regulation to these industries and the way it is interpreted tends to put them in a defensive research mode. They are generally geared to favor contract research to solve specific problems when they find it useful to support research outside of their own companies. Thus, they tend to look toward contract research institutes to supplement their own research programs. Further deterrents to the support of basic research at universities are that these industries are sensitive to the immediate economic climate and large fluctuations in the demand for housing and construction significantly dampens incentives for innovation in building construction.

One university research scientist interested in developing a cooperative program with the construction industry also pointed to his difficulties and frustrations on account of the atomistic nature of this industry. Several scientists and administrators involved in the development of the NSF sponsored Furniture Institute at North Carolina State University-Raleigh suggested that the difficulties in developing this program were in large part due to the fragmented nature of this industrial sector.

d. *The Chemical Industry*

The chemical producers as a group continue to be one of the most active, if not the most active, supporters of university research and training. Research interactions between academia and the chemical industry has a long and respectable history (Thackray, 1982). Historically, the chemical industry has been an innovative one, particularly in process technology (Brown, 1981). Important to this effort is research and development, particularly basic chemical research which can open up new areas. To this end, the chemical industry continually seeks windows on new technology. The industrial research laboratory appeared first in chemical and electrical companies.

Research and development, including basic research, continues to be an important element of the chemical industry. As a whole, the industry spent $5.3 billion on research and development in 1981, and $4.7 billion (89.5%) of this was company funded (*Research Management* 1981). In 1980, chemical producers spent $4.6 billion on research and development (*Chemical and Engineering News*, 1981). Typically the industry spends 2.4% of its sales on research and development (*Business Week*, 1977-1980). In 1975, the chemical industry spent 10.9, 37.9 and 51.2 percent of total company R&D expenditures on basic, applied and developmental research respectively (Nason and Steger, 1978). Among all industries, the chemical industry spent the largest percent of total research and development expenditures on basic research. Nason and Steger's estimate of the average proportion of industrial budgets allocated to basic research was 4.2%, less than half the proportion reported to be spent on basic research in the chemical industry.

Basic research performed at universities continues to be extremely important to the chemical industry (Brown, 1981). There are strong historical links between industry and academic chemists. Throughout the twentieth century, the majority of American chemists and chemical engineers have worked in industry (Thackray, 1982). In 1980, chemists accounted for about 45% of all scientists in manufacturing industries (NSF, Scientists, Engineers and Technicians in Private Industry: 1978-80, (1981)). Although the long term importance of industrial employment of Ph.D. chemists and chemical engineers to the American chemical community has not been researched (Thackray, 1982), the large number of industrially employed chemists suggests a partial explanation of the continuing interest of chemical companies in university research and training.

The mechanisms the chemical industry uses in its interactions with university research span all the categories we identified.

The chemical industry has always been generous in providing unrestricted grants to chemists and chemical engineering departments (See Chapter V). During the last decade, the chemical industry had the greatest number of companies represented each year of all industries reporting voluntary aid to education (Table 18). Of the companies reporting that they gave voluntary aid to research, the greatest proportion were chemical producers. In terms of total dollar expenditures on research, the chemical industry total was second to the petroleum refining and related industries.

Table 18

Number of Firms in Each Industrial Sector Reporting Voluntary Aid to Education*

Industrial Sectors	Year				
	1970	1972	1974	1978	1980
Advertising	1	1	N.A.	1	1
Banks	17	19	26	16	17
Business Services	3	3	6	1	2
Chemical & Allied Products	23	24	44	25	29
Electrical Machinery & Office Equipment	13	14	28	15	12
Engineering & Construction	2	2	5	2	2
Fabricated Metal	5	5	8	N.A.	N.A.
Food, Beverage & Tobacco	3	7	16	11	11
Insurance	14	16	20	17	19
Machinery	9	4	9	8	8
Merchandising	2	3	8	6	7
Mining	2	2	2	3	3
Paper	11	8	17	10	10
Petroleum Refining & Related Industries	15	15	23	18	15
Pharmaceuticals	N.A.	N.A.	N.A.	5	7
Primary Metals	13	12	17	13	10
Printing & Publishing	3	3	2	5	6
Rubber	N.A.	3	5	3	4
Stone, Clay & Glass	5	3	3	1	1
Telecommunications	2	3	5	3	6
Textiles & Apparel	4	5	6	5	3
Transportation	3	4	7	4	3
Transportation Equipment	11	12	14	9	8
Utilities	11	13	16	9	9
TOTAL	172	181	287	195	198

*Source: CFAE Casebooks 1970-1980

N.A. = Not Available

In our study, which included cases of voluntary aid to research and contract research, the chemical companies were represented in over twenty percent of the cases we identified. Of the approximately ten existing university/industry partnership contracts where companies have committed annual sums of more than a million dollars over a period of years, approximately 70% are sponsored by chemical companies. The participating companies include: du Pont, Monsanto, Celanese, Hoechst, Diamond Shamrock and the Allied Chemical Corporation.

The chemical industry is a strong supporter of generic research centers at universities in polymer science, catalysis and materials science. Chemical company support of generic research centers may be a reflection of the growing complexity of the technical base underlying this industrial sector, and recognition of a need to solve complex multidisciplinary research problems. Many of the centers supported by the chemical industry follow the cooperative industrial center mode where an industrial affiliates program is an essential part of the continuing base of research support (See Chapter IX, pp. 79-81). A description of a representative sample of these programs follows:

> *University of Delaware-Center for Catalytic Technology.* The Center for Catalytic Technology at the University of Delaware is located within the Chemical Engineering Department. There are approximately twenty companies represented from the oil and chemical industries, each contributing $25,000/year.
>
> Personnel exchange is facilitated by industrial sabbaticals of three to six months within the Center.

Proprietary contracts have been undertaken at times.

Because the Center is located within the Chemical Engineering Department, they have had to restrict the size of the program to maintain a balance of departmental teaching and research capabilities. Additionally, this departmental affiliation has caused problems when the Center sought to bring chemists into various research projects.

There has been a certain degree of technology transfer from the Center, but this is a secondary consideration for the companies. They are more concerned with access to students.

Currently, one-third of financing comes from industry, one-third from NSF, and one-third from mission-oriented agencies.

Case Western Reserve-Center for Applied Polymer Research. A new program at Case Western Reserve is the Center for Applied Polymer Research. This program is supported by a $750,000 NSF grant over five years. Again, as in several other NSF grant programs, the aim is to become self-sustaining at the end of one grant period. Unlike several other similar centers with many industrial sponsors (e.g. the MIT Polymer Processing Program), the university is seeking to get fewer sponsors to put in more money, with the feeling that this will result in greater cooperation by the corporate sponsors and a better return for their money.

The research is to be tied closely to the needs of the sponsoring companies. The company will be involved in each project with a project investigator at the university and another at the company. The companies are granted patent rights. So far they have attracted four corporate sponsors to match the NSF funding.

In addition to this Program, Case has operated a focused liaison program for the past seventeen years. There are twelve members at $20,000 each per year. These funds are discretionary and are used for equipment, seminars and seed money for new projects. Personnel exchange, although not widespread, has been successful, with a sabbatical program bringing industry people to the university and various faculty spending summers working with industry.

The Center of University of Massachusetts-Industry Research on Polymers (CUMIRP)—University of Massachusetts. CUMIRP was started in 1980 with NSF seed money of grants of $1 million over five years. The yearly grants decline over the time period with the objective of achieving self-sufficiency at the end of the five years (*i.e.* dependent only on industrial support). Currently, there are thirteen corporate sponsors each at $20,000 per year. Located within the university's Polymer Research Institute, the main thrust of the Center is towards basic research in network polymers and extended life polymers. Determination of projects is made through a steering committee advised by a board which includes representatives of the sponsoring companies.

The NSF is experimenting with a new approach towards waiving patent rights by the inclusion of a clause in the grant contract in which the university gets the patents and corporate sponsors get royalty-free licenses. An allowance has been made for up to a one-year publication delay. An important feature in the structure of the program is the separation of the technical direction from program management. There are three stages laid out for the NSF funding period; a one-year exploratory start-up, two-year theme definition stage, and a two-year program demonstration stage.

All the members of the Polymer Science Engineering Department of the university must spend 15-20% of the time at the Center. There will also be adjuncts from industry.

Polymer Processing Program-MIT. The MIT-Industry Polymer Processing Program is another program begun with NSF seed money. Started in 1973 with a five-year grant for just under $500,000, the program managed to achieve a goal of self-sufficiency after the NSF grant expired in 1978. This program is directed towards polymer processing as distinguished from the basic polymer industry. Research projects center upon the manufacturing of plastic and rubber products.

The research is carried out by graduate students under the direction of faculty. Problems are identified by the director, with sponsor advice and consent. Technical review meetings are held quarterly to discuss the progress and directions of the projects. The sponsors get royalty-free, irrevocable, non-exclusive license to patents developed while they are members. If a company wishes to use patents developed prior to their joining the program, it must pay licensing fees which are shared between MIT and its corporate sponsors. Allowance is made for pre-publication delay with the understanding that publication must be permitted for graduate student theses.

Industry support is determined by a formula, depending upon the level of the firms' own plastics output, of between $20,000 and $80,000.

Center for Composite Materials-University of Delaware. The University of Delaware's Center for Composite Materials was the first center at the university, created in 1974. However, it was not until 1978 that industry was brought into the program. The academic base was initially established through a Unidel (University of Delaware foundation) grant of $250,000. Over a two-year incubation period, the Center received government grants and support. The objectives of Center programs are to advance composite materials technology, train scientists and engineers, and transfer technology to industry. There are two aspects to the program; the normal research function and a design guide which documents the state of the art in composite materials technology. This guide serves both to transfer technology and to illuminate gaps in the existing technology. In addition, workshops and progress reports are issued frequently to enhance this technology transfer.

There are thirteen corporate sponsors who each contribute $30,000 per year. About 25% of the sponsors are chemical companies. The directors of the Center sought out companies that could contribute technically to the research at the Center. The director and associate director both previously worked in industry. To avoid any constraints on research activities, government funds are kept separate from industry-funded projects. Additionally, the university does not seek patents in order to avoid any conflict of interest with the corporate sponsors.

Recently the chemical industry as a whole has taken a very innovative step in the formation of the

Council for Chemical Research (CCR, see Chapter IX, pp. 81-82). The rationale of many participants was that in the long run the health and even the viability of the United States chemical industry was dependent on the basic chemical research carried out at universities. There was a perception among chemical manufacturers that such research was seriously underfunded. Therefore, chemical manufacturers should form an organization to funnel extra financial support from industry to the academic chemistry community. There has been a recent change in the emphasis of the program toward providing support for the training of graduate students.

In keeping with Thackray's thesis of the importance of individual scientists in the history of university/industry research relationships in chemistry, this endeavor had a strong leader, Mr. M. E. Pruitt, a former Vice President of Research from Dow Chemical Company. He initiated the original proposal, and served to bring together the initial corps of industrial and university representatives required to develop a consensus for action.

e. *The Instrumentation Industry*

The United States remained the world leader in exporting instruments in 1980. Shipments of scientific and laboratory equipment continued to grow through 1981 (U.S. Industrial Outlook, 1981). Technical advances are the essential roots of this industry. The instruments industry has on the average invested 4.2% of sales over the last four years in research and development (*Business Week*, 1978-1981). The National Science Foundation reports that in 1979 the professional and scientific instruments industry ranked second to office computing and accounting machines in terms of company R&D funds as a percent of net sales (NSF, Science Outlook, 1981). The 1981 company funded R&D was $2.3 billion for the industry as a whole (91.3% of total company R&D expenditures). Figures available for 1975 (Nason and Steger, 1978) indicate that the instrumentation industrial sector spent 5.3, 7.7, 87.0 percent of total research expenditures for basic, applied and developmental research respectively.

Some researchers make the case that the instrument companies do not invest enough money in basic research to develop new instruments and are therefore dependent on academics or scientists outside the company to develop new instruments. Out of the total interactions we identified (465) only 6 instrumentation companies were involved, and none participated in cooperative research interactions involving monetary support of university research.

The technological innovative capacity of this U.S. industry, recognized world-wide, can, however, be related to the strength of our university system. The conceptual basis for the instruments frequently comes from university scientists who require a unique measurement capability to solve a problem.

A recent study of 111 improvements of basic scientific instruments used in chemical and biological research reported that, of the 44 innovative concepts which were later incorporated successfully into commercial products, 81% had been initiated by instrument users rather than by instrument manufacturers. Of these users who contributed the concepts, 72% were employed by universities or affiliated research institutions rather than by private manufacturing firms or other non-university organizations (Hippel, 1978).

Indeed, an outcome of the university research can be the joining of university personnel with other entrepreneurs to form spin-off companies which carry innovative instrumentation developed at universities to commercial development. Foxboro is an example of an MIT spin-off company. Spin-off firms played major roles in the development of such modern instruments as the CAT scanner, state-of-the-art computer graphics devices and a variety of medical diagnostic instruments. Of the 144 spin-off companies we specifically noted in our present study, 10 involved development of a new instrument. We note here, however, that these were not necessarily a direct outcome of university/industry interactions.

It is evident from our study and others (Berlowitz, *et al.*, 1980; Hippel, 1978) that university researchers play important roles in the development of new scientific instrumentation through its use. The unique relationship between the instrumentation user to the producer is suggested in several anecdotes presented in this report (Chapter IX, pp. 69, 72-73).

Researchers often provide the specifications for special features to manufacturers, or modify instrumentation altogether. The electron microscope was first developed by a beginning graduate student and its development was continued for many years by university researchers. This on-going process of development and modification at the university level eventually resulted in the perfecting of a very powerful tool for the investigation of molecular structures. However, universities or university scientists frequently receive little or no industrial monetary support for such research or funds in return for their efforts.

> One scientist, in telling of modifications he made on the electron microscope, which he published in a scientific journal, pointed out that the instrument companies picked up on what he had done through their literature reviews. His research had been supported by the Department of Energy and this agency held the patent, but did not claim royalties. He made no money on his invention and said he did not want to get involved. This attitude, while typical of the past, may be changing.

A significant amount of instrumentation development occurs at medical schools (see Chapter IX, pp. 72-73).

In instrumentation technology development, it is sometimes difficult to sort out the relationship of the scientific methods or technology to the instrumentation hardware. This makes it particularly difficult to determine questions of proprietary rights and freedom of communication. Thus, while the instrumentation company values the interaction with the university researcher, circumstances may require complex research arrangements. This may be particularly true in the field of medical instrumentation development.

> One medical researcher described a case where he was given funds to develop a frontier research instrument. The company wanted no other funds involved, in order not to jeopardize its patent rights. Therefore, the company which owned a laboratory in the participating medical research institution, assembled the equipment in that laboratory so that it would be readily available to the university scientist, and at the same time not jeopardize the company's proprietary rights.
>
> This was a difficult interaction for all participants. The university scientist expressed concern about the speed with which he was allowed to publish his work and how he was allowed to present his research results. Yet he was anxious to be involved in development of a leading-edge scientific instrument.

The exact relationship of university and industry in the development of scientific equipment and instrumentation will be the subject of a future study. But it is our present hypothesis that personal knowledge transfer mechanisms (university scientist participation on company advisory boards and consultancies) and active, aggressive marketing play the major roles, at this time, rather than cooperative research. Part of the aggressive marketing techniques include equipment donation and requesting researchers to communicate any equipment difficulties and/or modifications. This may change as universities and industry devise new mechanisms for sharing instrumentation.

> One example is the recently established "People Exchange Program" at Purdue University. These arrangements allow university and industry scientists to work together on projects of joint interest and to learn each others' techiques while sharing sophisticated equipment.
>
> Another example is the new practice of acquiring top-of-the-line equipment such as electron microscopes and computers, through debt financing and retiring the debt through user fees (see Chapter IX, p. 69). This may also encourage this shared instrumentation use.

Shared equipment use may result in new cooperative arrangements and have important consequences for equipment for development and manufacturing as well as help the university maintain access to state-of-the-art equipment.

Recently deep concern has been expressed that scientific instrumentation obsolescence in research universities and inadequate resources to replace this equipment may impede the unique relationship between universities and the industrial sector. Industry statistics indicate that in the period from 1976 to 1980, sales of instruments shifted away from the educational market. In 1976, 18% of instruments sold went to educational users; by the third quarter of 1981, the figure had declined to 11%. One of the major manufacturers of state-of-the-art high-field nuclear magnetic resonance (NMR) equipment states that they have not had a new instrument order for a year. The actual amount spent on instrumentation by universities has not kept up with inflation. This has resulted in manufacturers shifting their production away from the type of state-of-the-art equipment which is required for research, and which is likely to be refined by university users, and toward more routine instruments. State-of-the-art instrumentation becomes even more expensive as fewer units are being produced.

Instrument manufacturers as indicated above have always participated in the production of frontier equipment with little commercial prospect in order to maintain their ties with academic scientists and stay at the forefront of their fields. As capital becomes less fluid and as universities become a smaller share of their market, manufacturers are less likely to do so. Expensive hand-made prototypes will then become even more expensive to acquire. In addition, the transfer of new ideas from state-of-the-art equipment to routine product lines will be slowed and U.S. manufacturers may lose their international competitive edge. Thus, providing the climate to maintain university/industry interactions within the instrumentation industrial sector may be of particular importance for business development and international trade, as well as a means of technology transfer.

f. *Microelectronics Industry*

In contrast to many other industries, research in microelectronics has been traditionally dominated by industry. Research and development as a percent of sales over the last four years is highest in the computer and semiconductor industries, 6.1 and 5.8% respectively (*Business Week*, 1978-1981). For many firms in Silicon Valley this figure is closer to 10%. A more detailed description of the microelectronics industry is given in a book by Nico Hazewindus (1982). University scientists have always maintained ties with this research base but, in response to a number of factors, they are now making greater efforts to develop broader university based research programs. A small number of universities have developed multidisciplinary centers for microelectronics research in cooperation with firms in the industry.

There are a number of reasons why these centers developed:

1. The rapid growth of the industry has increased demand for graduates and a manpower shortage developed (see Chapter VII, p. 34).

2. The laboratory facilities at the universities lagged behind the state of the art, so that new graduates were not trained in current techniques.

3. Industrial positions seemed to attract present and potential faculty at higher pay.

States have acted to attract high technology companies strengthening the university structure through support of microelectronic facilities and faculty. The complex technical growth in microelectronics is straining the resources of even major firms to pursue all directions of interest, leading to collective support for university basic research.

The following is a brief description of the major academic research centers in the U.S. concerned with microelectronics:

Stanford University—Center for Integrated Systems. The Center began formal operation in February, 1981. Three departments at Stanford cooperate in this Center—computer science, physical science and materials science.

Seventeen sponsors from industry are involved. Each sponsor agrees to contribute $250,000 a year over a period of three years for use of the facilities and support of the educational and research activities at the Center. The sponsors receive some privileges such as early access to scientific results. A number of policy matters remain to be decided by the steering group of university and company sponsored representatives; but it is agreed that the industrial members can send individuals from their research and engineering groups to carry forward both research and advanced learning activities in the Center. Presently some members from industry are on campus.

In addition, the Center has obtained an $8 million contract from the Defense Advanced Research Projects Agency (DARPA) to serve as a fast-turnaround facility for very large scale integration (VLSI) research.

Massachusetts Institute of Technology Microsystems Program. Recently, MIT put forward a proposal to increase activities in the microelectronics field. The existing Microsystems Research and Education Program at MIT covers research efforts in a wide range of projects conducted in the Artificial Intelligence Laboratory, the Center for Material Science and Engineering, the Laboratory for Computer Science and the Research Laboratory of Electronics. The subjects include submicron structures, semiconductor processing, large-scale circuit theory, VLSI design automation, VLSI complexity theory and integrated circuit (IC) systems architecture.

The new program will be centered around a new VLSI laboratory, featuring a computer-controlled fast-turnaround processing facility for manufacturing VLSI circuits. Additionally, the existing laboratories would be expanded to accomodate the new research programs envisaged.

The central theme of the efforts will be the integration of the various efforts needed for VLSI production. This requires a thorough understanding of the full range of activities that constitute this process, from semiconducting materials to systems design. This should lead to a comprehensive effort to manage the complexity of large-scale system design.

MIT proposes to finance this program by means of grants from corporations which would participate in a new Microelectronics Industrial Group, either as founding members or contributors. Several exclusive benefits to the participants are proposed, including a program for visiting industrial researchers, workshops and seminars. It is expected that the VLSI research facility will become operational in 1984.

Organizationally, a Microsystems Advisory Council (composed of representatives from the sponsoring industries) will assist the Director of the Microsystems Research and Education Program.

California Institute of Technology-Silicon Structures Program. The Silicon Structures Program at California Institute of Technology was organized in 1978. Initiated by Ivan Sutherland, who had been brought to CIT to start the computer sciences department, the program is organized as a research consortium. The importance of industrial contacts cannot be understated. Sutherland, in addition to owning his own company, has worked in industry. The plan for the program was developed with the help of previous industrial contacts.

Five of the six companies that they had contacts with and asked to join did so (IBM, Intel, Xerox, Hewlett-Packard and DEC). The program receives support from NSF, but this did not begin until the program was already under way. The companies provide money and equipment (12 corporate sponsors are presently involved, each contributing $100,000).

Several potential sponsors chose not to participate due to the university's policies. First, all research occurring at the university is rigorously regarded as public information. Second, the university receives all patents with the companies getting royalty-free licenses.

An important feature of the program is the industrial sabbaticals which last from 1-1½ years. Senior company scientists teach and work with graduate students. A company's success is largely a function of the quality of people they send to the university, as well as the ability of some program participants to continue the line of research begun in the university program when they return to industry.

The objectives of the program are two-fold: one is to develop closer ties with industry, and another is technical in nature, to improve IC design. The program is based on exploring the techniques developed by Lynn Conway and Carver Mead in chip design.

The ultimate objective of the program is technology transfer. There are ties with Carnegie Mellon, MIT, and the University of Washington through the software developed at Cal Tech. At this point, they are looking to set the direction of the second phase of the program.

University of California at Berkeley. Berkeley has a centralized microelectronics technology facility that is shared among many faculty members and students from many disciplines. Its achievements in the past have included:

— computer programs for transistor design, process development and circuit simulations

— novel device concepts, such as switched-capacitor filters

— certain new circuit designs, such as analog-to-digital connectors.

Recently, the Governor of California proposed that the state support the activities of the electrical engineering and computer science departments at Berkeley with a substantial amount of money. An apparent objective of this proposal was to counteract the activities of other states which are actively trying to lure high-technology companies away from California.

A main goal of the program is to enlarge and re-equip the antiquated microelectronics technological facility with the necessary clean rooms and modern equipment for lithography, processing, testing and characterization. This will give Berkeley the necessary facilities to continue its educational and research programs at a more sophisticated level. The intention is to pursue a policy of direct access to the facility for as many people as possible.

Funding of the subsequent research projects would be done cooperatively by the state and industrial sponsors. This so-called MICRO-program (Microelectronics Innovation and Computer Research Operation) could substantially advance the size and level of the future microelectronics and systems activities at Berkeley.

University of Minnesota, Minneapolis. The microelectronics center at the University of Minnesota originated from discussions between university scientists and Control Data Corporation representatives about solid state surface science. The university is well known in this field (NSF established a national center for surface analysis techniques at the campus) and suggested that novel techniques might be applicable to integrated circuit technology.

These discussions led to a grant from Control Data Corporation, later (mid-1980) augmented by grants from Honeywell and Sperry Univac. The purpose of the grant was to establish a basic research program in microelectronics and information science, including surface science. The Microelectronics and Information Science Center (M.E.I.S.) was established to carry out this task. Industry has contributed about $7 million to the Center.

The Center has focused on four areas of microelectronics research: software engineering, design automation, new device physics, and new materials for microelectronics.

The university has first rights to seek a patent from any research coming out of M.E.I.S. Once the university obtains a patent, the Center's patent policy allocates 50% of potential royalties to the university, 25% to the college and 25% to the individual professor or student. However, in the case of corporate sponsors, licensing fees can be written off the initial gift to the Center. The university will license the patent to anyone.

The management structure that evolved after some time includes a management team of a director, assisted by three associate directors. A group of eight representatives from sponsors and participating departments serves as an advisory board regarding the program and policies.

Microelectronics Center of North Carolina, Research Triangle Park. The goal of the Microelectronics Center of North Carolina is to develop an educational and research activity in microelectronics that will establish North Carolina as a national center in this significant technology. The state has actively been seeking to further the establishment of high-technology industries (see Chapter X, p. 109). Earlier, this resulted in the creation of the Research Triangle Institute, a non-profit R&D organization, and the Research Triangle Park, where a number of companies have established research laboratories. In this context, an active and high-level university system is regarded as a major asset, both as a source of manpower and research, and as an intellectually stimulating environment.

The MCNC will be formed by the following parties:

— five universities (Duke University, North Carolina State University, North Carolina Agricultural and Technical State University, University of North Carolina at Chapel Hill, and the University of North Carolina at Charlotte)

— one non-profit institute (Research Triangle Institute).

A close cooperation will be established with the North Carolina Community College System. The Center will have a VLSI computer-aided design facility, which will be connected with data links to the participating institutions. A complete, modern IC fabrication facility will also be located at the Center.

These sophisticated facilities will be used by the participating institutions to improve and expand their educational and research activities in VLSI technology and systems. This will be facilitated by a system of video links allowing specialized classes to be shared by the different institutions.

It is expected that the universities will be able to educate an increased number of scientists trained in VLSI, which may prove attractive to a broad range of high-technology companies. General Electric has been the first company to announce its decision to establish a major research center for chip fabrication in the vicinity of MCNC.

Summary of Academic Microelectronic Research Centers

In reviewing university industry interactions, several different areas of specialization can be distinguished.

— Stanford and MIT intend to secure a leading position in "VLSI-Science." Both have established special organizations to obtain that goal.

— U.C. Berkeley's goal is to be a center of excellence in VLSI techniques. One observer believes that Berkeley's center is more student-oriented than MIT and Stanford. No special organizational arrangement is required.

— The activities of Cal Tech's Silicon Structures Project focus on the problem of VLSI design methodology.

— The research centers at the University of Minnesota and the University of North Carolina provide examples of regional models.

Each of these centers is multidisciplinary and all except perhaps for M.E.I.S. are making forceful attempts to bring engineers and computer scientists together.

The sophisticated integration of these centers may reflect the long traditional interactions of microelectronics companies with academic research and the high general investment in research that has been inherent to the structure and development of this industrial sector.

g. *Mining and Minerals Industry*

The mining industry embodies technology throughout its operations. It draws upon biology, chemistry, physics, electronics, and every branch of engineering. But because it is a mature industry, perhaps second only to agriculture, and heavily capital intensive, its linkages with universities are very different from those industries such as pharmaceuticals or computers.

A mining company normally conducts the range of activities given in oversimplified form by:

(1) Exploration—geology, geophysics.
(2) Mining—mechanical and civil engineering, transport.
(3) Ore processing—comminution, flotation, biological leaching.
(4) Production of metal—process metallurgy, electro-refining, chemical separations.

The products are a few simple shapes, *e.g.*, ingots and wire bars, and occasional metal powder or chemicals for industrial processes. The subsequent steps by which the elementary metal shapes are converted to products such as sheet, tube, and wire composed of a single metal or an alloy are conducted by metal fabricating companies. While many of the large mining companies are vertically integrated and have fabricating divisions or subsidiaries, there is a major metal industry of independents not part of any mining company. Metal fabrication calls upon process metallurgy and the sciences related to the structure of metals and alloys.

In short, the mining industry or, better, the metal and mining industry, has a broad network of contacts with technology generally, and with the technical activities of universities. Yet it is not considered "high technology" and it rates low in terms of its percent of sales devoted to R&D. Let us examine briefly the nature of the technical activities of the industry, its needs and characteristics, and the resulting impact of all this on university interactions.

Since the products of the industry have to be essentially identical in properties with competitors, domestic and foreign, the principal focus of R&D is on:

(1) lowering operating costs,
(2) lowering the capital cost required to add additional facilities, and
(3) improving exploration techniques.

There is considerable activity in certain metal fabricating areas to develop new products and enlarge markets, as in the case of aluminum versus steel for containers, for auto bodies, and so on. Much of this effort also emphasizes lower cost, thinner sheet, different forms of product.

Thus, the industry emphasizes process research. This can fall into several categories:

(1) Modest improvements of present processes
(2) New approaches to present processes
(3) Development of wholly different processes.

The cost of conducting R&D obviously increases as one goes from category (1) to (3). Equally important, the cost of an actual installation of a process change, even of a pilot plant operation, increases dramatically from category (1) to (3).

In practice, then, the metal and mining industry stresses R&D to improve present operating processes. New approaches may be pursued, but pilot plant costs can be a major barrier to implementation. And major new systems as, for example, development of seabed mining, require consortia of the great mining companies to pursue serious efforts. It is therefore not surprising that the internal R&D activities conducted by the metal and mining industry are modest.

But these do not provide the total picture of technical change related to that industry. The industry has constraints related partly to capital requirements, partly to the value added by R&D. These constraints are not necessarily present for suppliers and users, as will be mentioned now.

Traditionally, many advances related to the industry come from suppliers, who can spread their R&D costs over many purchasers, and for whom this R&D is incremental to other efforts. For example, improvements in flotation chemistry are pursued by chemical companies. The development of huge trucks to carry 100-ton ore loads, permitting the elimination of railcars at the mines, required major programs on four-wheel electric drives by the electrical equipment manufacturers. Control equipment, process equipment, to minimize environmental problems, and advanced instrumentation all emerge from those suppliers.

Furthermore, technical advances in material properties normally represent far greater value to the product or system which uses these materials rather than to the producer of a thousand pounds or a thousand tons. The high-strength alloys required for modern jet engines result from research conducted at General Electric, Pratt & Whitney, and the engine manufacturers. Basic research on the electric properties of selenium used in xerography was carried on by the Xerox Corporation not the mining companies which sold only pounds of selenium for each machine.

Finally, since the use of our natural resources has traditionally been a matter of national concern, we must also consider the role of the Bureau of Mines. Its many laboratories, located in key mining areas of the country, do conduct programs that can lead to lower cost processes for the different metals, or serve to conduct the early stages of greatest technical uncertainty for new metals, as in the case of titanium.

It is against this broad background of industrial and government R&D in the metal and mining industry that we must now consider the linkages with universities and the role of university research. This industry is not technology driven and therefore tends to minimize support of university research. Yet the modest amount of basic research in process metallurgy at universities is essentially *the* source of basic research for the industry. Much of the early pioneering research in flotation, the approach which makes open-pit mining of low grade ores economic, was done at MIT. Today, advances in comminution go on at the University of California and the University of Utah, and so on.

The university programs are modest for the same reasons the company programs are modest. Process metallurgy research past the bench stage becomes expensive very rapidly, and any reasonable-size pilot plant becomes a major capital investment decision. Even university-based institutes, such as the Minnesota Minerals Resource Center, have difficulty maintaining the infrastructure and funds necessary to operate its experimental pilot plant. Whether the industry does not want to change rapidly or dramatically is not the issue. It cannot afford to do so, unless the new structural changes resulting from acquisitions of mining companies by oil companies change this status.

What the industry must have is a reasonable attraction for the wide range of technical graduates needed in its operations: research, engineering, production, and so on. Despite the fact that technical activities emphasize process improvements, the conversion of advances in electronics, computer sciences, chemical processes, and the like to the continual upgrading of mining and metallurgical processes can be critical to the productivity and health of the domestic industry. This calls for high quality technical personnel with broad scientific background who might be attracted to more glamorous-appearing industries. This is perhaps another reason that this industry tends to support educational training programs (*e.g.* the Colorado School of Mines) rather than support research directly.

An important function served by industry support of university research in mining and metallurgy is attracting the interest of bright students. How many centers of excellence among mining schools should be maintained is a critical question.

h. *Pharmaceuticals*

In pharmaceuticals, as in agriculture, significant federal monies have gone into basic research and into the establishment and maintenance of programs to train scientists (Grabowski and Vernon, 1982). The pharmaceutical firms, as do research universities, maintain strong linkages to ongoing research at the National Institutes of Health. The pharmaceutical ties are primarily through personnel exchange, personal contacts and participation in scientific conferences and advisory committees.

The pharmaceutical companies do very little government contract research. In 1980, approximately 0.4% of pharmaceutical research and development expenditures came from government grants and contracts (*Chemical and Engineering News*, 1981). Although drug companies have participated in government funded cooperative university/industry research programs, in general, they are not enthusiastic participants in such programs. This pattern of having extensive outside research ties but being reluctantly involved in outside contract or grant research (except in the special case of clinical trials), also holds true in general with regard to the pharmaceutical firm's interaction with university research.

Yet this industry is very actively engaged in research and development. The ratio of research and development scientists and engineers per thousand employees is quite high in the drug industry, with an average over the past five-years of 62. In chemicals and allied products, this ratio is 41 per thousand, while the average ratio over all industries is 27 per thousand (*Chemical and Engineering News*, 1981). Drug companies are extremely supportive of basic research, particularly in-house basic research. Research and development (R&D) spending among the drug companies rose from $1.63 billion in 1979 to $1.9 billion in 1980—a gain of 16% (*Chemical and Engineering News*, 1981). Average spending on R&D over the last four years in this industry is 4.8% of sales (*Business Week*, 1978-1981). In 1975, the pharmaceuticals spent 5.1, 38.6 and 56.3 percent of total R&D expenditures on basic research, applied research, and development, respectively (Nason and Steger, 1978). While the pharmaceutical firms spend large sums of money on basic research in-house, figures we collected indicate that a small percent of total R&D expenditures (0.5-1.8%) is spent in support of university basic research. There is a continuing compromise between the tendency of drug companies to cooperate in basic research and to draw back because of proprietary concerns. This tension is enhanced by the fact that in the past a large number of pharmaceutical innovations have derived from external research (Mansfield, 1971), and the current need to maintain proprietary control grows as competition increases in the new fields of biotechnology. The drug companies, however, must ally themselves with medical schools in order to follow government mandated testing regimes for their new drugs.

Unlike many industries, pharmaceutical firms spend large sums of money for applied research and development at universities (*e.g.* in clinical trials and toxicity testing). The proprietary and regulatory concerns of the pharmaceutical firms are important factors in this practice.

Patents are considered by pharmaceutical firms to be essential if a new drug is to be profitable for the company that creates it. Indeed, the history of the pharmaceutical industry indicates that the present structure would have been different had the courts ruled that antibiotics as natural substances could not be patented (Grabowski and Vernon, 1982).

Since the effective life of a patent in the pharmaceutical industry depends on the relationship between the issue date of the patent and the date of the commercial introduction of the product, pharmaceutical firms tend to seek outside research help after they have established their patent rights or when the research is very far removed from a product. Thus, legal protection of proprietary rights is extremely important and hence may explain the smaller amount of cooperative research sponsored by this industry than one would expect from such a highly science-based sector. In funding contracts and grant research at universities, drug companies are frequently adamant about obtaining exclusive licenses, if not patents. In our sampling of cases, pharmaceutical companies were represented in 21 of the cases, 81% of which were cooperative research programs. There may be a growing tendency for pharmaceutical firms to support basic research at universities because of growing interest in recombinant DNA technology.

It is also evident that drug company participation in liaison programs is increasing, particularly in new biotechnology and biochemistry programs. In keeping with the large numbers of scientists and engineers within this industry, drug companies contribute significant amounts of graduate research fellowship support.

Through personal contacts, the drug companies are very much in touch with the university research system. The level of participation in these activities is probably greater for the drug industry than most other industries. Many drug companies have 100 or more university consultants on retainer. In comparison to other industrial sectors, many drug companies supply on company salary, free to the university, a relatively large number of adjunct professors (30-75) to university departments.

Pharmaceutical companies sponsor many scientific and technical meetings and they also send their scientists regularly to such meetings, seminars and workshops. It is also our observation that this technical area is characterized by a high degree of university/industry sectoral mobility.

The pharmaceutical firms look to universities for screening of compounds. In 1979, screening, testing and clinical studies took 40% of the drug industry total R&D expenditures, while synthesis and extraction took 15.6% in outlays (*Chemical and Engineering News*, 1981). The exact amount spent at universities on screening, although unknown, may be on the order of $100 million. The amount spent on testing and clinical trials can be estimated to be $100-300 million.

Pharmaceuticals is an industry marked by complicated regulatory procedures, as pointed to above, which significantly affect its cost of R&D. Several different company representatives pointed out to us that the industry may spend up to 3% (a figure which is contrary to data we received) of its total R&D expenditures on university basic research, but a much larger amount (up to 10% and consistent with figures reported to us) is spent at universities on clinical trials, in response to government regulations.

Drug company R&D spending by U.S. firms doubled between 197– and 1980. A partial explanation is the increasing cost in meeting government regulation. Recent studies have shown that regulation has significantly increased the R&D costs and delayed the introduction of new drugs compared to the date of introduction with different regulatory regimes (Grabowski and Vernon, 1982). A few scientists (from industry and academia) suggested that basic research money had been reallocated to research designed to meet government regulation.

The money spent at universities for clinical trials and meeting government regulation is usually in the form of applied contract research. However, some scientists stated that these large contracts also provided them with enough funds to continue their basic research programs as well (see Chapter VI, Section C).

B. Variation Among Universities

Universities and departments within universities differ widely in the kind of research interactions they will have with industry. For example, one chemistry department far from the top, as ranked by their peers, perceives itself as a pure basic research department that will only take non-contractual funds from industry. That department considers polymer chemistry, for example, too applied for its interests. It would like to have a scientific affiliates program but is not viewed as an elitist institution by industry.

Where elitism is mutually perceived, universities generally have little difficulty attracting a wide range of industrial funding. A president of a prestigious university is approached directly with offers of support or cooperative agreements. Sometimes the projection of elitism is found grating by industry scientists, who resent being treated as second-class citizens. They will prefer working with a university whose self-image allows it to become absorbed in the industry's interest.

Engineering-oriented schools of comprehensive universities with large engineering faculties are most apt to devise practical and applied research programs which can be supported by contract research. Indeed, the size of an engineering school can be related to industrial support at a university (Table 19). There is a prevalence of interest at these institutions in devel-

Table 19

Average Industrial Funding of University R&D Expenditures and Average Size of Engineering Schools Over a Period of Five Years (1976-1980)

University	Average[1] Industry Funding (thousands of $)	Engineering School Size[2]: Average R&D Expend. Within Engin. School (thousands of $)	Engineering School Size[2]: Average Number of Graduate Students Enrolled
Massachusetts Institute of Technology	6,669	67,391	1,697
University of Rochester	6,639	10,962 **	218
University of Michigan	5,031	16,650	1,046
Carnegie Mellon University	4,848	6,138	530
Pennsylvania State University	4,610	11,297	510
Georgia Institute of Technology	3,973	22,700	893
University of Arizona	3,433	3,723	432
Purdue University (all campuses)	3,350	14,603	914
Harvard University	3,235 E	2,622	160
University of Southern California	3,143	13,373	1,173
University of Minnesota	2,855	6,648	634
University of Illinois (Urbana)	2,665	18,878	1,541
University of Wasnington	2,378	5,280	745
University of North Carolina (Raleigh)	2,134	6,116	527
University of Wisconsin (Madison)	2,013	8,425	695
Colorado State University	1,659	8,496	384
Stanford University	1,496	22,079	1,430
Case Western Reserve	1,304	7,810	409
University of Maryland (College Park)	1,243	3,635	507
University of Utah	1,121	5,553	436
University of N. Carolina (Chapel Hill)	1,006	1,599	128
Rensselaer Polytechnic Institute	968	5,615	797
University of Texas (Austin)	939	8,942	898
California Institute of Technology	922	7,044	330
Washington University	827	5,099	293
Duke University	825	1,466	92
University of Delaware	782	2,401	221
University of Chicago	742	NA	NA
Lehigh University	713	3,885	449
Clemson University	600	3,393	220
Princeton University	526	6,187	220
Louisiana State University	522	2,471	218
University of Houston	456	1,607	660
Colorado School of Mines	441 *	2,859	443
Yale University	439 E	2,094	78
Johns Hopkins University	363	967	127
Rice University	186 E	1,527	130
University of California (Los Angeles)	89 E	6,439	NA
University of California (San Diego)	0 ***	NA	NA

[1] Source: NSF, *Expenditures for Scientific Activities at Universities & Colleges, 1975;* NSF, *Academic Science, 1976-1980.*
[2] *Engineering Education*, "Engineering College Research and Graduate Study," March, 1980 & 1981.

* 4 year average 1977-1980
** 4 year average 1976-1979
*** University of California does not collect this information.

E = Estimated

oping centers devoted to research in manufacturing, robotics, industrial control, computer aided design, integrated graphics, and bioengineering. A developing, bustling, smaller institution may be well placed to corner the market in specialized areas, using such opportunities as a strategy for growth.

The importance of top level administrators in setting the tone for university/industry research cooperation and encouraging such interaction has been alluded to several times in this study. In several of the institutions visited, both public and private, new administrators had recently been hired with specific directive to foster university/industry research ties. At one mid-western public university, the president, a former faculty member, stated that he had received enthusiastic response to a speech he had given on university/industry research cooperation. Although he, as a faculty member, had not perceived any real barriers to university/industry research cooperation, the letters he received from his constituency indicated that many faculty members perceived otherwise. During visits with faculty members at this university, reference was continually made to the new president's support of university/industry research cooperation, which was felt to be a change from the previous president's policy.

Many major universities which have a continuous high level of industrial support have cultivated some special interest area. Table 20 shows the five-year average industrial funding at the 39 universities included in this field study. At least the first twelve universities ranked in order of industrial support have industrially funded programs in what can be characterized as specially cultivated areas of research strength.

Regional economics and local industry are sometimes reflected in the educational focus of a university. For example, the premier department in the world for petroleum engineering is found at the University of Texas at Austin. The most comprehensive university-based microelectronics research program is to be found in Silicon Valley. A major eastern university has an excellent aerospace department which has grown in conjunction with the local aerospace companies.

Sometimes local industry can influence the state legislature to allocate state resources to form an insti-

Table 20

R&D Expenditures at Selected Universities Given as Five-Year Average of Total Funding, Federal Funding and Industrial Funding for the Years 1975-79

	Thousands of $		
University	5-year Average Industry-Funding	5-year Average Total Funding	5-year Average Federal Funding
1. University of Rochester	5,456	50,586	33,256
2. MIT	5,268	108,442	90,884
3. University of Michigan	4,642	85,515	54,527
4. Carnegie-Mellon	4,508	20,233	13,030
5. Penn State	3,304	48,752	29,899
6. University of Southern California	3,143	40,708	37,691
7. Georgia Tech	3,037	29,843	16,596
8. Harvard	2,705 E	75,191	57,350
9. University of Arizona	2,584	40,180	21,030
10. Purdue—all campuses	2,441	44,339	26,822
11. University of Minnesota	2,287	85,644	49,936
12. University of Illinois, Urbana	2,119	63,470	39,722
13. University of North Carolina, Raleigh	2,075	30,982	10,766
14. University of Washington	1,792	79,994	66,790
15. University of Wisconsin, Madison	1,787	105,483	60,087
16. Colorado State	1,388	30,759	22,172
17. Case Western Reserve	1,123	27,869	20,300
18. University of Utah	1,033	29,887	25,072
19. University of North Carolina, Chapel Hill	1,012	30,933	25,056
20. University of Maryland, College Park	1,008	27,343	17,035
21. Stanford	867	81,300	73,592
22. University of Delaware	813	10,179	5,83[illegible]
23. University of Texas, Austin	808	53,564	33,220
24. RPI	773	7,602	5,719
25. Washington University	769	41,090	34,331
26. Duke	742	31,221	27,138
27. University of Chicago	731	59,583	45,472
28. Johns Hopkins	670	63,293	52,484
29. Lehigh	[illegible]	6,942	3,692
30. Cal Tech	548	29,368	25,510
31. Princeton	518	22,971	17,076
32. Clemson	469	13,410	3,898
33. Colorado School of Mines*	441 ***I	2,594	1,816
34. Yale	35[illegible]	46,685	43,167
35. Louisiana State University**	344	3[illegible],891	10,147
36. University of Houston	340 I	7,41[illegible] I	4,872 I
37. UCLA	115 E	67,535	54,500
38. Rice	93 E	6,391	5,129
39. University of California, San Diego	0	89,9[illegible]7	80,343

Source: NSF, *Expenditures for Scientific Activities at Universities and Colleges FY 1975-79*, Tables B-18, B-17, B-19, B-10, B-16.

*4 year averages
**3 year averages
***approximate

E = Estimated
I = Imputed

tute that will serve its needs. Examples include a sugar institute at a southern university, a minerals resource institute and a hydraulics institute at a midwestern university. Such institutes are particularly prevalent in fields related to agriculture, food and nutritional research, forestry and textiles, all relating to local or regional industries.

This kind of regional educational focus is less apt to occur at the major private universities. Regional differences in coupling interactions will be discussed in more detail in Chapter X, Section B.

Both climate and opportunity for industrial interaction may differ between private and state-supported universities. Generally, private universities have more flexibility in their ability to negotiate contracts, patents, and royalties. Some states have highly restrictive rules about industrial interactions. If institutions which are now engaging in molecular biotechnology are not careful to buffer proprietary research from state-supported research, they can expect even stricter arrangements.

On the other hand, there are several states that have carefully created climates propitious and encouraging to university/industry interactions, providing support to both partners to make the match, or encouraging the development of industrial research parks on land adjacent to universities. State-supported agricultural or engineering extension services are the oldest state-supported university/industry entities.

In general, until recently, there was certainly a greater awareness of the need for industrial support at private institutions for obvious reasons. Company representatives themselves said that in the past they were more likely to support research at a private institution, that they felt they already supported state institutions through their taxes; they also felt more comfortable with the private university's freedom to deal with the issues of patents, royalties, publications, and proprietary rights.

Faculty in public institutions seem to be more vocal about proprietary rights issues and secrecy agreements. It was mentioned several times at the state universities that faculty were very hesitant to engage in large amounts of industrially supported research because of these concerns. This was rarely mentioned at the private universities.

The private universities are most actively pursuing changing their patent policies and exploring ways of generating money through patent licensing and royalties. Of the 12 patent policy revisions in the last years, 8 were at private universities (Table 28, p. 100). At least 3 private schools were in the process of organizing new patent offices. This was happening at only one public school. Private universities are more willing to negotiate patent rights and licensing agreements than public universities.

Private universities tend to respond more quickly and directly to industrial needs, but they expect industry to pay more. While the public university finds it difficult to respond as quickly, in general it can do the research more cheaply.

Some of the most successful research universities in the country are those which have both large private endowments and state funding, with the flexibility that such a system allows. Many state institutions have relied on federal dollars to fund research. As federal dollars dry up, such institutions will find themselves increasingly turning to industry for support, and pressure will be on state governments to create a more permissive atmosphere.

CHAPTER IX

A TYPOLOGY OF RESEARCH INTERACTIONS

In this chapter, we present examples of the entire array of current university/industry interactions. For convenience, we have divided the interactions into four major categories by primary objectives:

- General Research Support
- Cooperative Research
- Knowledge Transfer
- Technology Transfer

For descriptions of these major categories, see Chapter V. In this chapter, we describe types of interactions within these major categories. Table 21 presents the variety of interaction we observed in matrix form, according to major function of support and by administrative mechanism. Table 2 (p. 16) lists representative examples of the major types of interactions we observed. In Appendix III, we list the research interactions documented in our field study. This chapter follows the categories of interactions listed in Table 21.

GENERAL RESEARCH SUPPORT

General research support usually consists of industrial gifts of money and/or equipment in support of university research. The major objective is to provide support to maintain university research excellence, rather than to strengthen research ties (see Chapter V, p. 15).

A. Institutional Gifts in Support of Research

These are unrestricted gifts to a technical department, to a technical unit or university or college (*e.g.*, engineering school, agricultural school, environmental science institute).

1. *Monetary Gifts*

Monetary gifts from industry are valued highly by university scientists because they provide the flexible seed money for new projects and start-up funds for young scientists. They also provide funds for travel to conferences, for temporary support of graduate students and for bridging research contracts. Several professors said that "grants-in-aid" (*e.g.*, gifts) to the department are critical in their impact on graduate programs. Scientists frequently stated that these funds are worth five times their face value. There are few, if any, other sources of such flexible funds.

Despite these statements, there is a growing feeling that unrestricted gifts or grants-in-aid do not promote interactions between the two sectors and, therefore, are not an optimum mode of industrial support of university research. Industry's emphasis on this type of support in the past may have been due to proprietary concerns. Changes in patent laws and clarification of anti-trust laws have changed the climate. There is recognition that other more interactive modes of support may accomplish similar purposes. There is a growing belief in industry that by integrating such funds into a more formal research structure, industry can provide a more reliable source of funds for university research. Creating a stable link between industry and university can allow industry interests related to research and curricula to be more fully considered.

Figures prepared by the *Digest of Education Statistics* (1979) show that, over the past 60 years, private gifts and grants have provided a consistent but small proportion of the current fund income of U.S. colleges and universities, between 3.8% and 6.8%. However, several scientists interviewed commented that unrestricted funds from industry were rare and/or difficult to obtain. Most of these gifts, they said, are small amounts, in the $5,000-10,000 range. The largest unrestricted gift documented in our study was for $500,000 to a computer science department at a public university. This is an unusual amount for unrestricted gifts, especially to a public university. In another case, a gift of $2 million was given to a department of engineering. Although a gift, it was designed for a research facility.

Table 21

A Typology of Research Interactions

General Research Support	Cooperative Research Support	Knowledge Transfer	Formal Technology Transfer
A. Institutional Gifts in Support of Research 1. Monetary Gifts 2. Equipment Donation 3. Contributions for Research Facilities	A. Institutional Agreements 1. Contract Research 2. Equip. Transfer & Loans 3. Grants to a Professor 4. Graduate Fellowships Support 5. Gov't. Funded U/I Cooperative Research	A. Personal Interactions 1. Personnel Exchanges 2. Mechanisms for Personal Interactions: Advisory Boards Seminars, Speakers Programs, Publication Exchange 3: Adjunct Professorships 4. Consulting	A. Product Development and Modification Programs 1. Extension Services 2. Innovation Centers
B. Endowment/Annuity/Trust Funds 1. Research Facilities 2. Endowment Chair	B. Group Arrangements 1. Special Purpose Industry Affiliate Programs (Focused & Discipline Programs) 2. Research Consortia	B. Institutional programs 1. Institutional Consulting 2. General Industry Associates Programs	B. Univ. and/or Industry Associated Institutions & Activities Serving an Interface and/or Foundation for U/I Research Interactions 1. U/I Research Coop. & Technology Brokering & Licensing Activities 2. University Connected Research Institutes 3. Industrial Parks 4. Spin-Off Companies & U/I Research
	C. Institutional Facilities 1. Coop. Research Centers 2. Univ.-Based Institutes Serving Industrial Needs 3. Jointly Owned or Operated Facilities & Equipment	C. U/I Cooperation & Educ. 1. Univ. Serves as Source of Graduates for Industry: Internships, U/I Coop. Training Programs 2. U/I Coop. in graduate curriculum development; Alumni Initiation of Research Interactions 3. Continuing Education is Utilized to Initiate Research Collaboration: Short Courses, Personal Contacts 4. Industry-Funded Fellowships	
	D. Informal Cooperative Interaction: Co-Authored Papers, Equipment Sharing	D. Collective Industrial Interactions 1. Trade Associations 2. Ind. Educ. Affil. 3. Ind. Sponsored R&D Org. 4. Ind. Res. Consortia	

2. *Equipment Donation*

Most corporations we visited had equipment donation programs and most of the universities we visited receive equipment gifts from industry.

Very frequently, equipment gifts are not included when administrators account for industrial contribution to university research. For example, the computer science department at a southern university received a $115,000 computing system from a local computer manufacturer. This gift was not treated as research money, although that was its purpose. It is difficult to determine to what extent this type of giving is a source of support for university research.

Academic scientists stated that industrial equipment gifts, except under special circumstances were not extensive. Several cases were cited where companies donated equipment but not the money to maintain it. Many academics stated that company-donated equipment was useful for teaching but not for research. Company representatives themselves alluded to the inadequacy of their equipment donation programs. This is not always the case.

Extensive industrial gifts for university research were frequent within one industrial sector, the information processing industry. Over 50% of the universities visited indicated that they had received significant gifts of computers or computer related equipment and systems.

Widespread donation of other types of research equipment is not evident, and seems to be idiosyncratic. Several scientists emphasized the importance of the problem. One investigator needed a $500,000 electron microscope for his research in materials science, but did not think that industry was a likely source for it. He believed that the National Science Foundation was his only recourse for support for such equipment, and expressed concern that foundation equipment funds are becoming increasingly difficult to obtain. University scientists in general were understanding of companies not being able to supply equipment in the $500,000 range, but many said that industry should be able to supply equipment ranging in cost from $20,000-100,000, but for the most part did not.

The circumstances surrounding equipment gifts are often complex.

In one case, an information processing firm, after hiring a number of top university graduates, decided to repay these universities in frontier research equipment. The firm gave each of three private research universities a system of personalized computers. There were other motivations involved. The donated equipment was a tax write-off, as is all donated equipment. Perhaps more important to the company was that the next generation of computer scientists would be familiar with the firm's new equipment and help modify it for future markets. (See this Chapter, pp. 72-73). A difficulty with this donation was that those universities not receiving equipment accused the company of having an elitist attitude.

Companies frequently give equipment to local universities to upgrade research and training in an area of direct interest to the company. Several instances were reported where a major company (especially in electronics, information sciences, or petrochemicals) moved to a new geographical area and donated several hundred thousand dollars in equipment to a local university to build up the university's technical capability in fields of interest to the firm. This was also seen as a way to foster good community relations.

A semiconductor firm that moved to the northwest gave the University of Washington several hundred thousand dollars worth of high technology equipment. When a computer firm moved to South Carolina, they gave Clemson University over a million dollars worth of computer equipment on a discounted basis. Likewise, when several high technology companies moved to Colorado and Arizona, they contributed equipment to local universities, and when a food processing company moved to a southern state, they gave the agricultural school gifts of equipment to help them set up a program in food processing.

A few universities have laboratory equipment funds to which industry contributes.

In the engineering school at one public university, a special committee was formed to foster projects which would be of mutual benefit to the university and industry. This committee, the Technology Improvement Plan Committee includes four industrial representatives. The Committee solicits funds from industry to support projects in computers and machine control. In particular, they solicit equipment gifts. The Committee's efforts have provided the school with a digital computer laboratory and several additional computers and machine control systems. One investigator commented that, although the Committee has been quite successful, it required a crisis situation before industry responded.

Another mode for supplying equipment is the loan agreement. In this, a company loans equipment to the university but retains title in order to depreciate the value of the equipment. At the termination of the agreement, the equipment reverts to the university. Under certain conditions, the loan mode is a problem to the university. The company might take back the equipment, without which the researcher might not be able to complete his research.

One example of a sophisticated loan agreement occurred between the University of Washington and an aerospace firm. The university had a wind tunnel that was built in the late 1930's. By 1978, it had fallen behind the state of the art. The aerospace firm was aware that the wind tunnel could not meet its needs in the future. Company use was about 80% of the total use of this facility. A new arrangement was structured. The aerospace firm bought $1.5 million worth of software, and then donated $2.5 million to the university under a loan agreement to up-date the wind tunnel facility. The agreement helped the company provide a state-of-the-art facility for the faculty at the university, which then formed a stronger base for student training and experience. The interaction made it possible to have courses in which the students could use the equipment and the company's software programs, and it was in the company's interest to have the university provide course work compatible with the company's system.

Equipment gifts can form the nucleus, or be critical to the formulation of university/industry cooperative research programs (see p. 73).

3. *Industrial Contributions for Research Facilities*

Companies occasionally give funds to build research facilities or buildings. Sometimes this is an outcome of a university's general fund-raising effort. Usually, companies contribute only part of the money necessary to build the facility, and this is typical at both public and private universities.

During the University of Michigan's sesquicentennial campaign, it was given money ($5 million each from two car manufacturing companies) to build a Highway Safety Research Institute.

In another case, the idea of building a combined engineering and business school attracted industrial support at Louisiana State University. Companies contributed more than $2 million toward building such a facility.

In the past, several large corporations, rather than directly interact or cooperate on research with a local university, gave substantial foundation funds to build research facilities. Such gifts came about because of the linkage between local companies and a university's board of trustees.

For example, a medical supply company, several years ago, gave $3-5 million for a research building at a private midwestern university, and then gave $1 million to its Institute of Radiology. More recently, the same university and company initiated a $3.8 million, three-year, industry-funded cooperative research program.

Despite the occasional contribution for research facilities, most said that such funds were not common, and that since the '50s and '60s, most new buildings were built with government funds. In the last ten years, government funds have also become less available to build research facilities. Figures from the *Digest of Educational Statistics*, (1979, p. 131), indicate the changes in industrial contribution to capital funds. These figures show that between 1920 and 1940, private sources form one-to-two-thirds of the capital funds for colleges and universities. During the 1940's and 1950's—a period of rapid expansion—the private source portion of capital fund receipts dropped to between 1/6th and 1/7th of the total.

Currently, capital is tight for many American corporations, or so we are told by many company representatives. Gift contributions fluctuate with the fluidity of capital. It is entirely possible for a company foundation to pledge funds for building a university research facility and then not be able to meet its pledge if the company business does not fare well the next year.

One administrator cited another difficulty with the use of corporate funds to build facilities.

> He cited a case where a company built a facility at a university and then wanted to use the facility in cooperation with the university for the company's own research purposes. This created a difficult situation, yet to be resolved, for the university, and a conflict of interest for many university researchers.

B. Endowment Funds and Annuity and Trust Funds

This section is concerned with funds given to a department or technical unit of a college or university which can be used in on-going general research support.

1. *Construction of Research Facilities*

Endowment funds donated by industry are only peripherally related to the subject of university/industry research interaction. However, we did identify a few instances where an industrial endowment provided funds to build a research facility which then later attracted active industrial participation.

> For example, money originally given by the family owners of a large chemical company to an eastern state university was used to buy equipment and start a catalyst program at this university.
>
> In another case, one-third of the endowment funds of a private university were used to build their research facilities in computer integrated graphics. Both these programs are now highly successful and industrially sponsored.

2. *Industrially Endowed Chairs in a Technical Unit of a University*

Industrially endowed chairs can be another source of support for university research. The scientist who holds the industrially sponsored chair or professorship is apt to be sensitive to the needs of that company. Frequently, he will set up meetings for company representatives and encourage discussion of their problems and interests.

Many universities are actively seeking to increase the number of industrially-endowed chairs within their science and engineering departments. There appears to be a prevalence of research chairs in the area of medicine and pharmacology. Several newly endowed chairs have been set up in chemical engineering departments. Despite new initiatives, most universities have few industrially endowed research chairs (usually less than six). However, a few universities have been particularly successful in attracting this sort of money. Harvard has about 259 endowed chairs, (1979/80 academic year), 48% of which are for faculty in a technical area; and MIT has approximately 126 chairs, 55% of which are in science or engineering. Not all of the chairs are fully endowed. At MIT, 99 are fully endowed, 20 are career development chairs, which go to support more junior faculty and 7 are term chairs, which must be renewed periodically. It was reported to us that at 1½most universities, a fully endowed chair costs anywhere from $750,000 to $1 million, while an endowed professorship, or partially endowed chair, requires about $100,000 to $300,000. Thus, endowed chairs can be a significant source of research support.

COOPERATIVE RESEARCH

Cooperative research interactions require some degree of cooperative technical planning, at least in the initial negotiation phase. The major objective of such support is to strengthen company and university research ties. All the mechanisms presented in this section are not necessarily always instruments for university/industry cooperative research interactions. There is truly a broad spectrum in degree of cooperative research (see Chapter V, p. 17). We present here those categories of research support and interaction that can, for the most part, provide for [illegible]ement of cooperative research interaction.

A. Institutional Agreements

Institutional agreements are instruments for formalizing university/industry research cooperation. They are usually developed only after a scientist-to-scientist rapport has been developed. It is in the discussions pursuant to the development of these agreements that some cooperative technical planning can take place. To a large extent, however, matters of a non-technical nature must also be considered. Most frequently, these discussions concern allocation of resources and disposition of the outcomes of joint research efforts. These agreements must take into account university procedures and policies developed in the university's office of grants and contracts (see Chapter VI, p. 29), and industry's objectives and proprietary concerns. These agreements form the basis and foundation for subsequent university/industry research cooperation.

1. *Industry Funded Contract Research: Specific to a Research Program or Project*

Contracted agreements to an individual investigator generate strong person-to-person interactions that favor technical cooperation. They are the basis for most university/industry technical cooperation. Over 50% of industrially supported research at universities is by way of contracted research. Such industrial support in the past has generally been for small amounts ($20,000-50,000) on a project-by-project and year-by-year basis. It is the specific limited nature of such contracts that makes them easier to negotiate but more susceptible to cuts. In difficult economic times, these projects may be the first to be cut off, and they are particularly dependent on the continued presence of one individual within the supporting industrial firm.

> For example, in several cases, an ongoing understanding was developed between an industrial project manager and the university's scientists. Then the industrial manager was promoted or put on a different industrial project and the contracted university project was discontinued.

Contracts with specific economic aims are subject to discontinuation if it becomes apparent that the potential economic value is not sufficient to justify the project (see Chapter VI, p. 42) but projects need not have such limited aims.

It is in contract research programs that issues reflecting the different objectives of the two parties must be addressed (see Chapter VI and Chapter VII), such as those related to real academic and corporate differences in research objectives, in the time frame for obtaining and reporting results, in information dissemination and appropriate means to ensure proprietary advantage. Thus, in developing contract agreements, publication, patents and proprietary rights issues can be thorny problems, and negotiations over rights frequently delay the signing of the agreements, or sometimes redirect the scientist's wishes. In our discussions with academic and industry scientists and administrators, we sensed a real willingness to negotiate such matters. However, a few academic scientists reported cases where the university administration made it difficult for them to finalize their research agreements with industry, and in a very few instances, negotiations led to the total abortion of the project. Some of the present difficulties in negotiating contracts may reflect the transitional state of many university policies pertaining to industrial support of research. Many universities are presently reviewing and changing many of these policies (e.g. whether or not they will grant a firm an exclusive license and for what period of time).

Contracts between university and industry are negotiated for the conduct of a broad spectrum of research activities from basic to applied to development work. However, in the area of applied contract research and development, universities face strong competition from industry, government laboratories and non-profit research institutes, and have few comparative advantages in relation to these other performers.

A new development is the negotiation of long-term partnership contracts containing high level company commitments to support university basic research in return for some proprietary advantage (*e.g.*, an exclusive license, lead time in a new research area). The large, prestigious research universities in particular are seeking and receiving this type of support. The prototype for this kind of contract is the Harvard-Monsanto agreement signed in 1975. Such large, open-ended research contracts with university scientists, however, are still rare. About eight such contracts were reviewed in this study. Six were in the biomedical area, and two focused on energy production and use. A review of the literature indicates that there are probably fewer than ten such contracts presently in existence between university and industry research divisions. Examples include: Monsanto-Harvard; Dupont-Harvard; Hoechst-Massachusetts General Hospital; Celanese-Yale; Mallinckrodt-Washington University; Exxon-MIT; Allied Corporation-University of California, Davis.

An integral part of these contracts is the frequent contacts made between the university and industry scientists and provisions for exchanges of scientific personnel. The principal investigators of these programs almost always have a separate consulting agreement with the sponsoring company. In all cases we reviewed, the scientist has had previous research interactions with representatives of the sponsoring company. Several company representatives said they would not even consider such arrangements unless they knew the university scientist extremely well. Another prerequisite to such arrangements seems to be the desire of a company to extend their research capabilities into new fields.

One stated difficulty with such partnership agreements is that the expectations of both parties are raised unrealistically beyond the normal research outcomes. This can cause friction within the institution, and may in fact affect the conduct of the research. . is the publicity surrounding such agreements, because of their newness and the substantial amounts of money involved, that may be more of the cause of the friction and rising expectations than the open-endedness of the contracts.

Cooperative research agreements are thought by many industry scientists to be the most capable of contributing to the industrial innovation process because these programs provide a superior match to the long-range time frame in which innovations take place. Such programs require a consistent level and continuity of funding. This requires considerable commitment on the part of university and industry. The new long-term partnership contracts suggest that at least in certain fields both partners are capable of making such commitments. Senior university scientists said that the program continuity and consistent funding levels provided by these contracts enabled them to assemble unique multi-disciplinary research teams and to hire technical personnel not directly related to their immediate research goals. Some said it provided them with an opportunity to circumvent departmental structure. All emphasized the importance of continuity and commitment to allowing pursuit of research difficult to "sell" to government agencies, or for which there otherwise would have been insufficient time.

> One assistant professor listed the following reasons for joining such a partnership program:
>
> (1) He liked the director
> (2) He knew of the long-term industrial connection.
>
> He said that the security of the long-term commitment was his "bottom line" for coming to the university. He felt that the long-term commitment allowed him to be more productive in research since he did not have to spend his first year at the university writing grants. He also stressed that his participation in the program provided him with access to otherwise unavailable resources.

2. *Industry Funded Equipment Transfers and Loans and/or Construction of Research Facilities*

Transfers and loans of equipment are made to universities as part of the ongoing process of development and modification of a firm's equipment. Scientists from industry and university cooperate in the development of this equipment and agreements are made about the outcomes.

Frequently, but not always, this research is of an extremely applied nature.

A great number of these types of interactions occur within medical schools.

> As one example, the Radiology Department of a private school had an agreement with a computer hardware company. A professor at the university, using the company's hardware, developed a management control process for radiological imaging reports. The university is now developing the software for this investigator's process, and the company is building the equipment to implement it. When the equipment is fully developed for market, the university expects to receive money in return, $500 per terminal for every one sold in the United States.

The Radiology Department in the above example has extensive interactions with companies. They bargain for equipment. For example, they identify a need or research interest, set down technical specifications and negotiate with a company for an equipment grant. In return, they help the company develop their equipment.

> In one case, a drug company gave this same radiology department a scanner. The negotiations for this interaction took one year. University scientists talked with scientists at several companies interested in developing scanners. The university researchers wanted to find out which companies were on the cutting edge in development. The university investigators narrowed it down to four companies and said to each: We will work with you in developing your equipment if you will donate the equipment to us. One company came forward. The formal agreement took two months for company and university lawyers to negotiate.
>
> A close relationship continued between the partners for several years, as they developed the scanners. The company benefitted from the department's use and development of their equipment. The hospital associated with the university was able to purchase equipment at a lower cost than otherwise because of this interaction. But no dollars changed hands in support of the program.

Despite these fruitful interactions, the Director of the radiology program said he has not been very successful in generating money from the companies to fund activities, aside from equipment development.

In some instances, such as those cited below, equipment is given for general research, but the nature of the equipment leads to particular areas of cooperative research and almost necessitates interaction.

> The School of Agriculture at a southern public university has received several machines on loan. In one case, researchers at this school were interested in computer-based automatic control systems for combines. The American Presidents Association gave them money to conduct the study, and two equipment manufacturers loaned them the $50,000 combine. In another instance, a company in Nebraska loaned the department irrigation equipment for three years. The company then sold the used equipment to farmers and replaced the system at the university. In another case, the department worked with a company to develop a tobacco harvester. At another state school, a researcher was given a wet processor vat to allow him to develop chromotographic wet processing procedures for textiles.

In most cases, when the agricultural school, or the textile school, does the modification, design and development of a piece of equipment, it has the option of patent ownership. But if industry bears the full cost for the project, schools generally concede full proprietary rights. At least one southern school has conceded such rights though it is a state university. Most schools are very careful about such proprietary arrangements. Some difficulties may arise if a company wishes university scientists to help develop research equipment for which a company patent is pending (see Chapter VIII, pp. 57-58).

Equipment transfers and support towards building research facilities can be an integral part of a company's efforts towards helping to develop a new cooperative research program.

> Three CAD/CAM cooperative research programs at an eastern, a midwestern and a western state university were recently developed largely through equipment donations. A petroleum laboratory is being built at a private midwestern school through equipment donations from a petrochemical company. An objective of the program developers is cooperative research.

Several cases (8) were documented where industry, as part of a cooperative research effort, helped a university build facilities in specific research areas, e.g., energy and biotechnology, in order to provide a foundation for the program.

> For example, a pharmaceutical firm is providing a private eastern university with several million dollars to build an institute of preclinical pharmacology. An employee of the company will be the Institute's director. The Hoechst Chemical Company of Western Germany, as part of its agreement with Massachusetts General Hospital provided funds to build a molecular biology laboratory.

3. *Industry Funded Research: Grants to a Professor*

Grants are most frequently used to support exploratory research, or research which advances the frontier of a particular technical discipline. This often results from an unsolicited proposal by a professor based on an original concept. The opportunity for cooperative interaction arises if the mechanism of selecting the proposed research for funding provides for the establishment of scientific contacts which lead to future scientific interaction. For example, these contacts may lead to discussions and actions between university and industry scientists concerning how the basic science is related to problems of technology relevant to company interests. The company's technology problems subsequently may suggest new avenues of basic research.

In the past, industry has not, to any large extent, funded unsolicited proposals submitted by individuals with whom they had no previous technical interaction. Thirty-two of the companies visited said they almost never funded such unsolicited research proposals, although they frequently received up to 100 per week. This is not to suggest that industry does not support university basic research programs. As noted previously, industry, through unrestricted gifts (see Chapter IX, p. 67), supports research of a general nature with few strings attached. Such funds are continually used by university scientists as seed money to explore new research areas. When coupled with personal scientist to scientist friendships cooperative basic research activities can develop. We also heard of at least three cases where a significant grant (e.g., $1 million over three years) was awarded to university scientists and the description of proposed research was no more than a paragraph.

Despite the above, some university scientists perceive that government grants are less encumbered than industrial funding. According to some scientists (particularly biologists and basic medical scientists whose funding largely comes from government granting agencies, e.g. NSF and NIH), government grants are given to pursue research in a general area, rather than on a specific topic as in industrially supported research. A problem from the industrial point of view is that without some mechanism for reviewing basic research proposals internally, it loses an opportunity to select basic research projects in areas underpinning their own interests. Indeed, in the past, industry has, for the most part, foregone this opportunity for cooperative research interaction with university basic research programs by supporting university basic research programs through unrestricted gifts. A difficulty for industry support of university basic research is how to maintain or establish a cooperative interaction in broadly based basic scientific research without confining the research while ensuring maintenance of high quality research of interest to the firm.

The quality of government grant supported research is thought to be controlled by peer review. This was a frequent subject of discussion regarding industrially funded research which, as noted above, usually makes no provision for peer review. Many researchers in university and industry expressed some dissatisfaction with the present system of peer review. It is the perception of several of these individuals that the peer review system becomes conservative as funds for research become more restricted. When there are limited funds for research, there may be a hesitancy to fund exploratory research of an unusual or non-traditional nature. Furthermore, the established scientists who do the reviewing tend to reinforce their own experiences and this can be a deterrent to fundamentally new or innovative areas of research. One scientist expressed the view that, in earlier years, an exploratory grant of $100,000 to a university would, in ten years, lead to something useful, but thought such funds were no longer available. "Funds for seeding speculative ventures in the university have dried up and have not been replaced," he said. Whether factual or not, this perception was expressed on several occasions during this study. In the course of exploring new ways of supporting university/industry cooperative research efforts in basic science, several firms have designed programs to help redress these perceived deficiencies.

During 1980, two companies, the Dow Chemical Company and the Procter & Gamble Company, announced trial grant programs. The objective of both programs is to support exploratory basic research related to areas of interest to industry. Each company instituted an internal mechanism for proposal review. In recognition of the growing dissatisfaction of some scientists with government peer review, each company tried to devise mechanisms to address some of the criticisms of present government systems of peer review. Both companies desired to increase their cooperative research interactions with universities.

The Procter & Gamble program began in the fall of 1980. The company Vice President for Research wanted to strengthen the company's research ties with the academic science community and have them become familiar with the technical base of the company. Company representatives from the corporate research and development laboratory visited ten universities gave presentations, and said: "This is the type of research we are interested in. Do you wish to submit a research proposal to us?" Faculty thought this approach unusual, because few companies let them know their research interests, and most had never participated in a company research presentation.

The company sought proposals that would broaden the horizon of research, *i.e.*, exploratory research proposals. They wanted to fund programs with great uncertainty for success, but high potential rewards if successful. They were looking for proposals difficult to defend based on the present system of peer reviews. However, this approach was viewed as an alternative to peer review programs, not as a replacement. They hoped to select the best proposals through advocacy.

The company received 88 proposals from 11 universities. They convened a Selection Committee of company senior R&D managers to review the proposals. After an initial review, advocacy developed for about 14 proposals. The internal advisory board reduced the number of successful proposals to seven. The winners appeared to be those with an energetic champion. Each of the 7 professors was invited to give a seminar. The professors came, were exposed to the laboratory, facilities and staff, and made friends in the process. The company sponsor believed that if company and university scientists interacted, the research programs would be enhanced and the foundations for a cooperative interaction would be established. The company selected three to be funded by the new grants program. The awards were for $40,000 each. In addition, another two of the seven were funded by a separate division that had a particular and immediate interest in these programs.

All the investigators in this program can publish. However, the university scientists must allow the company one or two months to review their publications for potential patents. But the company does not really expect that a patent or a product will develop out of this program. On the other hand, the company does expect to extend the scientific interests and management of science within the company to new areas and/or opportunities. It is also the company's objective to strengthen their recruiting program as well as their cooperative research interactions with university scientists.

The *Dow Chemical Company* sponsored its grant program as a result of the discussions held at the first Council for Chemical Research Conference in 1979 (See pp. 81-82). After this meeting, the company set up a foundation with $5 million. The intent was to use these funds or the interest generated each year in support of basic research.

The mechanism the company developed for reviewing proposals was based on that of the Petroleum Research Fund and other foundations, such as Research Corporation, the Welch Fund, and NSF. Despite the fact that they were following these other procedures, they made an effort to alter them in order to speed up the overall process of proposal submission and granting. They had the principal investigator send a preliminary proposal outline. Company scientists evaluated it in terms of its basic scientific quality and as to its worth as a potential project. After this screening, they submitted it to subsequent peer review and promised to answer within three months. Scientists at the company were told not to view the proposals in terms of an opportunity for the company and to treat the proposals with all confidentiality. Lawyers were not involved.

Before the program was a year old, the company was inundated with proposals and could not accept any more. To some extent, the company decided that this was an inefficient way for a company to fund universities, but was still firmly committed to developing cooperative basic research interactions with universities, and did not want to do away with their commitment to basic science because they were dissatisfied with the grant program. Now, they are looking at other ways to support basic research at colleges and universities.

Although both these programs have been well received within the academic and industrial communities, it is recognized that they are only small programs, and most companies do not have the resources at their disposal for such programs. Even if several other companies develop programs to fund basic science aimed at developing cooperative interaction, industry could not, with this level of support, replace or fulfill the historical role of government agencies in maintaining the current U.S. base in basic sciences. Furthermore, mechanisms for proposal review are time-consuming. Most company representatives stated that industry does not have vast sums of money for funding basic science at universities, yet they believed that most basic research activities should be conducted at universities and wanted to tie their own R&D programs into university basic research programs.

4. *Industry Funded Research: Graduate Fellowship Support*

Industrial support of graduate research can be a mechanism for strengthing cooperative research ties. In the past, General Electric and Westinghouse had Early Talent Search Early Awareness grants. These were primarily grants for graduate and post-doctoral research and did not emphasize cooperative research programs, but were often the basis for future cooperative interactions. With a large amount of money available in federal fellowship support, these funds became diluted. In general, though, many suggested that these were good models for industrial support of research. Many said they would like to see this type of industrial support increase.

The following are examples of how graduate fellowship support can be an integral part of a university/industry cooperative research interaction:

> A professor in a chemical engineering department had a consulting arrangement with a company. This company also supported one of his graduate students and funded his research through a grant. In a geology department, two or three graduate students were supported by oil companies. A portion of the money, a gift, went to the research assistants' salaries, and the rest of the money in the budget was itemized for supplies and travel. This type of graduate support is not formal, it is not exactly a grant, and it is understood that the graduate student will be working on a specific area of research relevant to company interests.

Thus graduate fellowship support can be an integral part of a more extensive cooperative university/industry program as noted above (see also Chapter V, pp. 17-18). It is also a mechanism used by companies when they have limited funds to spend on university research and wish to join their support to company programs. Some companies find that it is a way to get the greatest value for their limited research and development funds.

> For example, several companies offered to pay the difference of a salary of a graduate assistant and the pay the student would get if he were working for the company. One company is giving a $4,000 Ph.D. fellowship supplement, and intends to give ten such fellowship supplements. In each of these cases, the student will spend time working on company research programs.
>
> In another case, a textile company will fund a graduate student in chemical engineering. The student will work at the company research laboratory in the summer, and in the fall he will attend classes and be paid $1,000 a month by the company. The company will have some input into the thesis topic of the student. An alumnus of the university who is working for the company sponsoring the fellowship, was instrumental in initiating this program. He was interested in relating his research program to that going on at the university. This sort of research support at universities seems to be on the increase. But it is not dependable, and requires extra efforts on the part of the university principal investigator.

There are several new general fellowship programs being started by companies which are not tied to a principal investigator. These will be discussed in a subsequent section of this report (p. 95).

5. *Government Funded University/Industry Cooperative Research: Grants and Contracts*

Government funding for cooperative university/industry research is provided by many government agencies, including the Department of Defense (DOD), the Department of Commerce (DOC), the National Science Foundation (NSF), the Department of Energy (DOE), and others. The government-funded cooperative research model has existed for some time, for example, the government-sponsored agricultural extension program (Rogers, 1976). During the early 1960's, the Department of Commerce, through its Civilian Industrial Technology Program, sponsored programs aimed at the textile industry. In recent years, there has been an increased effort in all government agencies towards finding ways of using government funds to facilitate university/industry cooperative research programs.

In the traditional university/industry coupling mode, the government, in the role of matchmaker, brings the two parties together and provides the funds so that one institution becomes the prime contractor and the other the subcontractor. This practice is widespread, and DOD and the National Aeronautics and Space Administration (NASA) have used it to a considerable extent. Frequently, these programs are tied in with government procurement.

> For example, in the aerospace industry, where the government is frequently the main customer, a typical mode of university/industry research cooperation involves the industry partner as the prime contractor and the university as a subcontractor (see Chapter VIII, p. 51). A case in point is a company under contract to the federal government to design a new generation of helicopters, subcontracting the research to a university to develop dynamically scaled models for flight simulation.

Sometimes the government brings universities and industry together to conduct research as part of a national effort in a particular area.

> For example, in the past, the Department of Energy has been interested in cost shared technology demonstration programs and accompanying programs to help achieve the adoption of energy conservation techniques. Accordingly, the key contractors in this work are usually industrial firms. However, in some cases, university research groups offer appropriate technical capabilities for performing portions of the work either by themselves or in

collaboration with an industrial partner. In one ten-year program involving the development of a solar tower, the university was initially the prime contractor and industry the subcontractor. This reversed as the research neared the development stage.

As another example, three university groups have DOE contracts to operate energy analysis and diagnostic centers, which provide direct assistance to small and medium size industrial plants. This is seen as part of the national effort to encourage energy efficiency.

Government interest in an area critical to the development of defense-related projects can bring the two partners together.

For example, switching mechanisms are important to many DOD projects. A scientist from Tracor, an electronics firm, gave a talk at a conference attended by an official of the Office of Naval Research In his talk the Tracor scientist discussed the work of a University of Texas professor on sequence estimation. The ONR officer was interested and suggested that ONR would like to support research in the area described. The Tracor scientist got together with the university scientist who had given a course at the company in estimation theory. They agreed to develop a joint program in which the university scientist would suggest approaches and employ graduate students in the research, while the company scientists would evaluate the approaches using classified data. The professor had access to the company research through a consulting arrangement. ONR has separate contracts with the university and with the company. The joint research effort permits Tracor to guide the university thinking and it permits the professor to train students. Tracor hires most of its employees from the University of Texas at Austin.

Recently, groups like NSF and DOC have been attempting to identify through experimentation in a variety of modes the conditions which promote successful cooperative endeavor. Much of this experimentation has involved the establishment of cooperative research centers.

One program, the NSF Industry/University Cooperative Research grant program (IUCR) was particularly well received by most of the investigators with whom we talked.

The objectives of the IUCR Program are:

(1) to strengthen the fundamental research in science and engineering in order to enhance future industrial technological opportunities, and
(2) to improve the linkage between universities and industrial firms.

Cooperative industry/university research proposals are prepared jointly by academic and industrial researchers and submitted jointly by their respective institutions. Thus this encourages work which is jointly defined and conducted. Criteria for project funding from this program are:

(1) strong and active research collaboration between university and industrial researchers in the performance of the proposed project;
(2) significant cost-sharing by the industrial participant for the industrial participation in the proposed research as evidence of the industrial relevance of the research;
(3) quality of proposed research.

The administration of the program requires the IUC research proposal to be peer reviewed in competition with other proposals (cooperative and non-cooperative) in the same area of research. These peer review procedures are the same ones that apply to any research proposals received by NSF.

Funds provided by NSF through the program are not intended to substitute for funds the firm would normally commit for research but, rather, to provide for new and expanded cooperative research programs with universities. NSF normally pays for the costs of university research in the cooperative projects. In about one-half the projects, industry pays for their own participation, and in about one-half, NSF provides some funds to industry. It is current policy that NSF will pay only up to 50% of the industrial participant's costs (except for small businesses, up to 90% of their costs). The rationale of requiring industry to pay a significant portion of their research costs in cooperative projects is that it ensures that the proposed research is industrially relevant to the firm's management.

NSF is flexible in its contracting arrangements for this program. Of the NSF university/industry programs reviewed in this study, three different modes of contracting were identified. In one instance, NSF funded the company and the company subcontracted to the university. In other cases, this was reversed—NSF funded the university, and the university subcontracted to industry. In other examples, NSF contracted separately with the company and with the university. Investigators seemed to prefer a program where both the industry and the university had separate contracts with NSF.

The NSF industry/university cooperative research (IUCR) activity has grown from a program of eight awards totalling $1.4 million in 1978 to a program of 79 awards totalling approximately $7-8 million in 1980. The initial response to the program was slow. (Interviews confirmed the one or two-year lead time needed to negotiate university/industry cooperative agreements.) But all those interviewed in our study who participated in the IUCR program were enthusiastic about it. One investigator stated that without his university/industry coupling grant, which gave him access to industrial resources and data, he would have been set back a year in his research.

By the end of its first four years, the program had awarded 231 competitive research grants totalling nearly $30 million. Grants have been provided to 79 universities to carry out cooperative research projects with industrial researchers in 88 companies, including many of the leading sponsors of industrial R&D in the United States.

Table 22 provides a summary of industrial involvement in the IUCR program, based on total population of grants awarded through Fiscal Year 1981. Four of the top ten industrial R&D companies, based on the July 1981 *Business Week* survey, are included among the top ten IUCR-performing companies (Table 15). Several large companies (*e.g.*, IBM, Bell Labs, Hughes Aircraft, Westinghouse, and du Pont) have been actively engaged in the IUCR program, with multiple projects funded and total shares of the IUCR program exceeding their company percentage shares of U.S. Industrial R&D as reported in the *Business Week* statistics. The leading 100 R&D companies together account for about 58% of the total value of IUCR awards with the balance of the awards going to firms that spend less than $50 million/year on R&D. Two of the top ten IUCR-performing companies (Hercules Chemical and Martin-Marietta Corporation) are not included among the top 100 industrial R&D firms. Thirteen companies in the awards lists are formally identified as "small businesses" using the NSF award definition (having less than 500 employees). These small companies account for about 7% of the total value of awards granted in the IUCR program.

Table 23 provides a comparable data summary for assessing the involvement of the major "research universities" in the IUCR program. The pattern of university involvement presents an interesting picture, in which the leading research universities (as measured by total value of R&D performed in FY 1979 from all funding sources), are well represented, but by no means dominate the distribution of IUC awards. The leading IUCR universities are, for the most part, universities with national reputations—but the ten leading IUCR-performing universities include only Stanford in common with the list of top ten research universities in the United States. The latter group, however, is well-represented on the list of IUCR awards—all but two of the top 20 research universities have received at least one IUCR award, as have 37 of the top 50. Taken together, the top 100 research universities account for 84% of the value of total IUCR awards.

Indicative of the way many of these programs started, one investigator described the origin of his NSF university/industry coupling grant in the following manner:

> The professor was interested in potential uses of gallium arsenide in chip formation. He attempted to develop interaction with a microprocessor company, but found it difficult. He discussed his work with company representatives and scientists, but discovered it was hopeless to initiate an interaction until he developed a friendship with an industrial scientist who was interested in what he was doing and was willing to put time in on the project on his

Table 22

Distribution of IUCR Program Into *Business Week* Industry Groupings**

Industry	IUCR Program (FY 78-81) Firms (No.)	Projects (No.)	$ Awards* (000's)	Shares of Value of IUCR Awards* (1978-81)	Average Industry R&D as a % of Sales (1977-80)
Aerospace	4	13	4,326	14.5%	4.0%
Automotive (cars & trucks)	3	5	722	2.4	3.2
Chemicals	9	22	4,397	14.8	2.4
Conglomerates	4	8	1,423	4.8	1.7
Drugs	3	5	665	2.2	4.8
Electrical	3	11	2,664	8.9	2.6
Electronics	3	3	392	1.3	2.8
Fuel	6	14	1,920	6.4	0.4
Computers	5	22	3,161	10.6	6.1
Instruments	3	3	371	1.2	4.2
Leisure Time	1	1	32	0.1	4.2
Machinery (Farm Construction)	1	1	77	0.3	2.8
Machinery (Machine Tools, etc.)	1	1	48	0.2	1.6
Metals & Mining	2	2	175	0.6	0.8
Miscellaneous Manufacturing	—	—	—	—	1.9
Paper	1	2	253	0.8	0.9
Personal & Home Care Products	2	2	128	0.4	1.7
Semiconductors	1	1	246	0.8	5.8
Steel	3	5	759	2.5	0.6
Telecommunications	2	9	1,063	3.6	1.5
Tires & Rubber	1	1	167	0.6	1.7
Total Above	58		22,999	77.1	
Not Distributed	31		6,840	22.9	—
Grand Totals	89	165	29,771	100.0	

*Includes matching funds provided by other NSF Divisions.
**NSF, Industry/University Cooperative Research Projects Program.

Table 23

Summary of University Involvement in IUCR Program

	IUCR Program (FY 78-81)		Percentage Shares of	Rank**
	Projects (No.)	$ Awards* (000's)	IUCR Awards (1978-81)	(In Top 100)
Ten Leading IUC Performers:				
Stanford	10	2,832	9.6	6
UCLA	3	1,585	5.4	14
Delaware	2	1,410	4.8	100
Purdue	7	1,076	3.6	28
Rochester	3	1,024	3.5	23
Florida	4	1,016	3.4	32
USC	4	955	3.2	24
Cal. Tech	2	848	2.9	41
Pittsburgh	4	840	2.8	59
Carnegie-Mellon	5	803	2.7	69
Concentration of Funding:				
Leading IUC Universities				
Top 10	44	12,389	41.9	
Top 20	78	18,336	62.1	
Top 50	131	26,641	90.3	
Top 79 (all performers)	165	29,771	100.0	
Leading R&D Universities				
Top 10	40	6,798	24.2	
Top 20	60	10,768	36.4	
Top 50	102	18,971	61.8	
Top 100	139	25,853	84.2	

*Includes matching funds provided by other NSF Divisions.
**Universities ranked by total value of all R&D performed in FY 1979 (based on NSF data).

own. It was difficult for them to develop this interaction formally. Such interaction was not encouraged by the top level company managers. According to the professor, the way the system worked at the company made it hard. Time and money had to be justified and there was a feeling in the top management that there was no benefit to working with someone who would publish everything.

However, the professor continued his interaction with the scientist at the company. Finally, the company provided him with a small level of support, $20,000 for two years. He had access to the company's instrument labs, and the money he received was flexible. The professor was impressed with the company research efforts. He then proposed that they submit a joint proposal to the NSF industry/university coupling (IUCR) program. Their proposal was funded. The government program is based on a three-year interaction between the company and the university. There are provisions for exchange of personnel, support of three graduate students and a post-doctoral scientist. Six researchers at the company will be involved. The professor felt that this program was very cost-effective for the company, and that the NSF funding was having a very significant effect on his interaction with the company. He believes that the NSF program attracted interest within the company to his research. An important aspect of the university/industry coupling program, according to this professor, was that it gave them a chance to address at a basic level something that is important for the national need as well as the company's need. Impurities in chips are a limiting problem for device applications. The university will provide the company with samples that they can test for these impurities.

The difficulty of the individual university scientists securing access to key industrial research managers who can support a project, as alluded to in this anecdote, was frequently mentioned as a problem in initiating university/industry research programs, and was mentioned particularly by those academic scientists interested in initiating government funded cooperative research efforts.

In conjunction with the increased interest of government in university/industry programs, extensive debate has occurred over the issue of the necessity for a government funded cooperative research effort. One approach is that such support is not needed because if industry and universities really developed mutual interests, they would get together independently. Analysis of the origins of several of these cooperative government funded programs indicated that this is not necessarily so.

In the previous example, the difficulty of company and university scientists eliciting formal company encouragement for cooperative research in a program not perceived to be of immediate interest to the company was alluded to. In several other cases, both company and university researchers stated that if the IUCR program didn't exist, then the company would not have funded university research in that area.

In one case, researchers stated that they went to the government because the company "couldn't protect its own interests" and to do the research justice they needed additional funding and more general support.

In support of government-sponsored university/industry coupling programs many scientists from both industry and university suggested that such programs allow industry an opportunity to investigate theoretical aspects of their commercial interests. It was suggested by company representatives that participation in these programs boosted the morale of scientists in industry and they welcomed the chance for joint authorship in scientific publications. In many government sponsored university/industry cooperative research programs, including the NSF IUCR Program, the government requires cost sharing. A few of the company representatives interviewed said that these cost sharing requirements were a significant barrier to their participation in such programs.

The structure and criteria of government sponsored coupling programs affect the participants, subject matter and commitment of both parties.

Private universities have been more active participants in the NSF IUCR program than public universities. Of the universities visited by the research team, the private universities had 15 of the NSF university coupling grants at 9 universities in 1979, and had 26 of the grants at 13 universities in 1980. The public universities had 10 NSF IUCR grants at 7 schools in 1979, and 12 at 6 different schools in 1980.

Basic science research aligned to commercial interests in fields otherwise minimally supported by industry may be fostered by the NSF IUCR program. In the first year of the NSF IUCR program, all but one or two grants could be characterized as basic engineering research. This was true for the second year as well. In 1980, almost 50% (19 out of 38 programs) of the coupling programs at the schools the research team visited could be characterized as basic science research as opposed to basic engineering research. The information gathered in this study indicates that very little industrial support (approximately 30% or less of the total industrially supported university research) goes to science programs in physics, math and biology. And about 60% of industrial support of university research is in engineering. (See Chapter V, pp. 20-21.) Thus, the relatively high level of cooperative research in these areas of basic science within the industry/university coupling program could be an indication that the criteria of the NSF IUCR program serve as incentives for industry to couple its needs to new areas of basic university science.

In the Office of Naval Research Programs, where the coupling procedures and criteria are different, and funding is primarily through subcontracts, most of the programs were in engineering. Eighteen of the 39 schools visited by the research team participated in 30 of the 41 university/industry programs in which ONR participates. Fifteen programs were at 7 of the private schools visited, and 15 programs were at 11 of the public schools visited. About 61% of the programs were in engineering. (Table 24.)

B. Group or Consortial Arrangements Fostering Cooperative University/Industry Research

Research funding for a university program by an association of companies is apparently of growing interest to industry as well as universities. Such interactions can include support through focused industrial liaison programs, multi-company support of a research center or laboratory, collective industry support of research, and an association of a group of companies and universities in order to conduct research. The growth of these types of interactions may be related to the increasing complexity and cost of scientific research, as well as to the recent clarification of U.S. anti-trust laws regarding basic research. (See Chapter V.)

1. *Special Purpose Industrial Affiliate Programs (Focused Industrial Liaison Programs.)*

Focused industrial affiliate programs must be distinguished from institutional or general purpose industrial associates programs (see Chapter IX, p. 92) to the extent that these programs involve a degree of technical focus or cooperation by the partners involved. To some degree, this is difficult to determine because there is a spectrum of focus in industrial associates programs and a spectrum of degree of interaction. Examples of focused industrial liaison programs include: The Electromagnetics Propagation and Communications Affiliates at the University of Illinois; The Metal Cutting Industrial Affiliates Program at the University of Michigan; The Wisconsin Electric Machines and Power Electronics Consortium (WEMPEC) at the University of Wisconsin; The Industrial Systems Control Program at Case Western Reserve; The Emulsion Polymer Liaison Program at Lehigh University; The Optics Industrial Associates Program at the University of Rochester; The Geosignal Processing Industrial Affiliates Program at the University of Southern California.

As a liaison program becomes more focused and structured around a research program, there is more interaction between parties, and at some point they can be better characterized as mini-research consortia. Sometimes these programs naturally evolve into research consortia. This was the case with several industrial associates programs in the polymer field, and in the fields of electrical engineering and computer science.

From the point of view of the university, a focused industrial affiliates program is a means to create stable industrial support of university research. From the industrial point of view, it is a chance to gain a window on technology, have ready access to students, and play

Table 24

Distribution of Selected Government Funded U/I Cooperative Research Programs

Directorate/Program	NSF IUCR* Program (FY 78-81)			Current ONR** U/I Cooperative Programs***
	Grants (No.)	Average Value ($000's)	% of Total IUC	Grants (No.)
Astronomical, Atmospheric, Earth and Ocean Sciences	5	111	1.8	2
Astronomical Sciences	2	38	0.2	0
Atmospheric Sciences	2	214	1.4	0
Earth Sciences	1	50	0.2	2
Biological, Behavioral & Social Sciences	10	142	2.8	4
Environmental Biology	2	189	0.6	1
Physiology, Cellular & Molecular Biology	8	133	2.2	3
Engineering	119	174	54.9	25
Civil & Mechanical Engineering	20	187	10.1	4
Chemical & Process Engineering	62	168	27.2	3
Electrical, Computer & Systems Engineering	35	163	15.4	13
Other	2	333	2.2	5
Mathematical & Physical Sciences	97	124	40.4	9
Chemistry	24	123	9.9	1
Materials Research	49	95	15.6	2
Mathematical & Computer Science	12	144	5.8	4
Physics	12	227	9.1	2
TOTAL ABOVE	231	129	100.0	41

*Source: National Science Foundation Industry/University Cooperative Research Program
**Source: Office of Naval Research
***Approximate time frame 3-4 years

a role in suggesting basic research efforts which will underpin their own company research program.

The forerunner of the focused industrial associates program, or special interest industrial affiliates programs, is the liaison program of Stanford University. This program is over 30 years old. Here, membership has always been at the departmental level. At this university, there are over 19 affiliate programs. Each program is managed by faculty members working in their subject discipline areas, rather than by an administrative staff. This facilitates a program developing along the lines of the interest of the scientists and engineers, and the needs of those industries most closely allied to it. Each member company is assigned to a faculty member. Thus, the emphasis is on individual contacts between the representatives of each member company and the faculty, staff, and students in the program. Access to students is the prime reason why the companies join. These programs also provide company representatives a chance to participate in the direction of a research program, and to obtain a window on technology.

Most focused liaison programs provide similar services as general associates programs. Most programs host one or more meetings on campus, provide copies of reports, publications and resume listings, and encourage company campus participation. A few programs provide for annual faculty site visits to a company location. When this occurs, the faculty are generally enthusiastic about the value of such visits, and the opportunity they provide for closer research ties. It is the focus on subject matter that provides opportunities for cooperative interactions to occur within these programs. In many focused industrial affiliates programs, affiliate members are encouraged to bring technical problems of a non-proprietary nature to the attention of the faculty members and to outline what they believe to be the key problems in advancing the state of the art of their fields. Thus members may have an influence on future research directions. As this advisory capacity becomes more formalized, to the extent where the member companies form an advisory board, this activity is better characterized as a research consortium.

A few representative examples of this evolution include the Case Western Reserve Industrial Associates program in Polymer science, the Electrical Engineering Affiliates Program of Stanford University, The Energy Liaison program at Lehigh University, the Geology Liaison program Louisiana State University, The Hydrocarbon Industrial Associates Program at the University of Southern California, and the Chemical Engineering Industrial Associates program at Georgia Tech. A more complete description of this evolution is given in Chapter VII, p. 40.

The membership fees for focused industrial liaison programs run anywhere from $1,000 to $25,000, but most often the fee is approximately $10,000 per company. Some programs are requiring commitment of membership for two to three years.

The current surge of interest in industrial associates programs indicates the extent of increased interest in university/industry coupling, and particularly in cooperative research. Of the 71 industrial associates programs documented in this study, 35% were new programs in existence for less than one year. Only two of these new programs were general purpose campus-wide industrial associates programs, and this type of industrial associates program accounted for only 10% of the total number documented (Tables 3 and 7). Therefore, we suggest that the increase in these programs is not only being viewed as a fund-raising activity, but also as a means for creating more stable cooperative programs of university/industry research through focusing on specific research areas. Approximately 95% of these new initiatives are occurring at public schools. One public midwestern university had 28 programs, of these 29% were new programs (one year or less) and 64% were up to five years old.

There are also many older successful special interest liaison programs. At the universities visited, there are approximately 16 liaison programs that have existed for longer than ten years, and 20 between three and ten years (Table 7). Every private university visited (17) had at least some form of a focused industrial associates program already in existence. Of the (22) public universities visited, no industrial associates programs existed at 6 universities, and 3 of these universities made no mention of interest in starting such programs in the near future. Of the older programs (greater than ten years old), about 60% are at private universities.

Only two industrial associates programs in biochemistry were documented, both less than one year old, and none were documented in physics, math or biology. Approximately 80% of the programs were within a school of engineering. One of the oldest special interest industrial associates programs is a program at a private university in systems engineering which had been in existence for 27 years.

In order to institute a focused industrial liaison program many researchers noted the importance of having a critical mass of researchers. The following provides a description of the initiation of a currently well-established special interest industrial affiliates program.

> This program, an industrial affiliates program in polymer science, was initiated by a professor of macromolecular science at a private university.
>
> The professor made the point that in trying to enlist companies, he had to seek out "enlightened" research directors. Many at the companies approached were those he had consulted for at some point. The other companies were proximate to the university. Additionally, he had worked for DuPont and thereby understood the needs and perspective of industrial managers. Important in establishing the program was the willingness at the university to make an investment. This was accomplished through the application of Ford Foundation funds which had been made available for development of engineering at the university. The professor emphasized the importance of critical mass in starting a program. When he got the companies to join that critical mass barely existed.

2. *Research Consortia*

Research consortia can be characterized as specific mission programs organized to ensure that the generic or mission-oriented research will be carried out. A key to the development of many successful research consortia is an industrial affiliate program. Affiliate programs have led to very successful industrially funded consortial research programs in polymer science, micro-electronics, robotics, and computer science (including computer graphics and computer-aided design and computer-aided manufacturing). (See Chapters VII and VIII, pp. 44-46, and 55-56, 59-60). Many new initiatives are evolving in the biotechnology area. A primary element of the successful development of these research consortia seems to be that the industrial affiliates program allowed a leader to evolve, and the program naturally developed through the give-and-take of personal contacts between the industrial associates members and the university scientists. (See Chapter VII, pp. 41-42.)

Less successful are those consortia put together by a group of organizations, or a group of people who organize programs by piecing their interests together, rather than letting their interactions evolve. During the evolutionary process, researchers find mutual areas of interest and complementary capabilities.

When large consortia are directed by committees and are accompanied by high administrative costs, they tend to be viewed with skepticism by university scientists and industrial scientists. Such programs have been particularly prevalent in the fields of energy and environmental science. Presently, there are initiatives to establish several such programs in the microelectronics field. The complexity of these subjects requires vast resources, and thus there is a rationale for such programs. However, of four committee-run consortia reviewed, sponsoring energy related research, none was viewed as successful in facilitating university/industry cooperative research by those scientists asked, who had a chance to participate in these programs. The problem may have been related to program organization and management. Coordination of effort in these programs often depended on informal meetings for exchange of information, and there was no central facility on which to focus the program.

A new initiative taken by the chemical industry may prove to be a successful model for initiation of large consortial research programs.

This collective industrial action was initiated by a well-respected former vice president for research at a chemical company. He was interested in upgrading technology at the company and wanted to stimulate longer-range research. Out of his concern about engineering and the loss of innovation in education in the United States, he attended three government sponsored conferences on our declining technology; after each meeting, all the participants went home and nothing was done. He decided to do something. He organized a meeting of the directors of research and the deans and heads of engineering and chemistry departments for about $300,000, donated by his own company. At the conference, he asked well-known chemists to speak in the morning, and in the afternoon, he held an open session. The open session was critical at this first meeting. A large number of investigators with whom this initiative was discussed said that the meeting's most important outcome was the opening up of channels of communication between university and industry scientists.

At this first meeting, the attendees set up a Steering Committee, which chose a task force. Equal numbers of representatives from industry and university sat on each of these committees. NSF to some extent, encouraged the initiation of this activity by having the Director of NSF give a talk at this first conference, and in agreeing to support the university people for their participation in the task force set up to explore the mechanisms of cooperation.

The task force focused on the possibility of setting up a research consortium of chemical companies and universities. They determined the goals and objectives of such an organization, and made their proposal to a second large conference of industry and university chemists and chemical engineers. At this second conference, the attendees decided to form the Council for Chemical Research. The central issues then became:

(1) should there be a central fund for support of university research and, if so,
(2) how should the money be distributed?

A third meeting was held in the fall of 1981. A central fund of new money for basic research or education was established. The recommended division of fees for membership were: a company will give 25% of the membership fee to the central fund of the Council for Chemical Research, and the other 75% of the fee will be spent on direct company funding of university programs. However, a company could still be a member of the Council for Chemical Research without paying into the central fund. The membership of the Council for Chemical Research is to be made up of anybody who wants to join. The cost to a company depends on the number of company chemical engineers and chemists. There will be a premium of 4 times for Ph.D.s, *e.g.*, if they set the fee at $100 for each bachelors degree chemist or chemical engineer the fee for each Ph.D. will be $400. Presently, CCR has decided that they will distribute the central fund money according to a formula based on the number of Ph.D.s a chemistry or chemical engineering department produces.

As of March 1982, CCR had 100 university members and 27 company members. The organization expects to have a total of 40 company members by April 1, 1982. To date, (March, 1982), pledges to the central fund exceed $3 million.

The benefits of establishing research consortia such as CCR can be considerable. The founders of the CCR expect that transfer of technology and new ideas should occur more readily, that there should be increased opportunity for industry exposure to breakthroughs from the university, and that CCR should foster stronger research programs that integrate academic pursuit of basic science with engineering.

C. Institutional Facilities

Centers, institutes, and research facilities furnish means for coordinating programs to attract industry. They can provide equipment in a central location. Our studies on university/industry research interactions suggest that certain targeted research centers (Stanford Center for Integrated Circuits, University of Delaware Catalysis Center; Laboratory for Laser Energetics, University of Rochester) are particularly effective in attracting industrial support. Often these specialized laboratories and centers are formed especially to meet industrial needs and concerns (*e.g.*, Center for Manufacturing Productivity, RPI; Minerals Resources Research Center, University of Minnesota; Center for Biotechnology, Stanford University).

The center concept brings focus to research and this may facilitate cooperation with industry. The centers need not necessarily be physical entities, but they must serve as a focus, provide a piece of equipment, or provide coherence for related research efforts conducted in a general area. Many believe that the center and institute structure is a transitional structure between the typical university environment and the outside, or external world. Their administrative structure is viewed as making possible a better interface with industry. (See Chapter VI, Section C.)

At some universities, a substantial amount of research is done in centers or institutes, and frequently the predominance of industrial support is at centers or institutes. (Libsch, 1976.) Several successful industrially sponsored programs have occurred where a center is formed in conjunction with an industrial liaison program. (See pp. 31-32.)

We reviewed 89 centers and institutes which had some form of industrial support. Of these, 76% can be characterized as U/I cooperative research centers, eleven were newly planned institutes, and six were about one year old. About 50% of the cooperative research centers were less than three years old (Table 7, p. 22). By far, the greatest number of centers or institutes interacted with industry through contracted research.

A new feature of the industrial support of many of these newer centers is multi-company support, including companies from several industries.

> For example, one materials science center has support from producer companies including DuPont, Celanese, Hercules, Owens Corning-Fiberglas and user companies including Ford, General Electric, General Motors, Rockwell International and

PPG Industries. A catalytic research center has both oil company and chemical company support, and a polymer processing program has support from the automotive industry, the information processing industry, instrumentation companies and the chemical industry.

For the most part such centers attracting widespread company support are addressing areas of research that cut across and might prove fundamental to several industries. Thus the concept of industry supported "generic research centers" which conduct research that cannot be captured by individual firms is beginning to [illegible]ome well established or gaining acceptance in some areas.

Most centers and institutes reviewed had a combination of state and federal government, industrial and some university support. Only one center was completely supported by industry in its initiation and its subsequent maintenance or operating funds. One principal issue concerning centers and institutes is the extent to which they are aligned with a department. (See Chapter VI, Section C, p. 32.) Of the centers reviewed, those centers closely associated with a department seemed to suit industrial needs of access to students more closely and cause less friction in the academic environment.

1. *Cooperative Research Centers*

Centers having associated industrial affiliate programs where member companies serve in an advisory capacity regarding the direction of research can be characterized as cooperative industrially funded centers.

> Examples of such centers include: The Seismic Acoustic Laboratory at the University of Houston; Hydrocarbon Research Institute at the University of Southern California; Center for Futures Research at the University of Southern California; Center for Applied Polymer Research at Case Western Reserve; Center for Surface and Coating Research at Lehigh University; The Materials Science Center at Lehigh University; The Materials Research Laboratory at Penn State; The Center for Microelectronics at Rensselaer Polytechnic Institute (RPI); The Center for Manufacturing Productivity at RPI; and The Center for Integrated Graphics at RPI.

In over 90% of cases reviewed (68), these centers had agreed to provide their sponsors with royalty-free, nonexclusive licenses.

The use of this mechanism of approach to university/industry research seems to be gaining enthusiasm, but its prevalence is relatively new. The older cooperative centers interact with industry through contracts, and frequently do not have the associated affiliate programs. Furthermore, the older centers tend to be oriented toward a specific industry and receive support from companies within an industry.

Over 50% of the industrially funded cooperative centers (centers which have industrial affiliate programs associated with them) are less than five years old. A distinguishing factor of many of these new centers is they receive multi-company support from several industries. Further, these centers tend to be located at private universities, e.g., 14 out of 20 centers reviewed.

Cooperative funding of generic technology centers, such as was proposed by the Department of Commerce, was not viewed with enthusiasm by any of the companies interviewed. One problem here seemed to be the lack of a mechanism to build strong ties between individual investigators at the universities and industry.

Cooperative research centers, such as those funded by NSF, have been written about extensively. (National Science Foundation, 1981) Examples include:

> The Polymer Processing Program at MIT, the Furniture R&D Applications Institute at North Carolina State University (Raleigh), The New England Energy Development System (NEEDS), The Ohio State Welding Center, and The Computer Graphics Center at Rensselaer Polytechnic Institute. Within the past year, two new centers were established, The University/Industry Center for Robotics at the University of Rhode Island, and a Center for University of Massachusetts Industry Research on Polymers (CUMIRP) at the University of Massachusetts-Amherst.

In helping to establish such research centers, NSF provides seed money to aid the center in commencing its research program. The objective is to encourage industry to join the program and provide increasing support. After a period (hopefully five years) it is expected that companies will be responsible for the complete support and financial operation of a center. The MIT Polymer Processing Program is now completely supported by industry. The two new centers are being established with considerable initial company support.

The cooperative university/industry centers experiment is designed to explore the feasibility of university/industry linkages that will more closely couple the capabilities and products of academic research to the production sector of the economy. The identification of the circumstances that encourage the creation and maintenance of strong, self-sustaining linkages is the overriding objective of the NSF program. Thus, individual grants are structured through cooperative research agreements with the quantitative and qualitative goals that include the attainment of sufficient financial support from industry to continue without subsidy. In this broad framework, NSF is trying a variety of concepts. Of the several such centers reviewed in this study, one had reached the point where it was solely supported by industry, and most others were successfully attracting industrial support. The most critical factor in developing such centers seems to be an energetic leader with a sense of direction. One center reviewed was not successful.

The reasons given were as follows:

(1) there was no strong faculty leader,

(2) the program was structured by administrators first, and faculty second,

(3) the approach of the program was too broad,

(4) the industrial sector this center served was extremely fragmented.

Several academic scientists associated with the program suggested that rather than approach a number of companies, they should have worked with one or two companies. This assumes that others would have followed suit as they saw useful results from one or two companies' interaction with the university.

2. *University-based Institutes Serving Industrial Needs*

Centers characterized as university-based but serving industrial needs most often are supported through substantial government funds as well as industrial contracts. Most of these institutes are firmly established. Many have significant support from state governments. Of those reviewed, all had been in existence for more than three years. University-based institutes (or centers) serving industrial needs tend to be established at public universities. Of about 20 such centers or institutes reviewed, only 4 were at private universities. Frequently, these institutes are initiated after local industry puts pressure on the legislature to allocate state resources to form an institute to serve their needs. These institutes most often receive industrial support or interact with companies classified within one industrial sector. Such institutes are particularly prevalent in fields related to agriculture, food and nutritional research, forestry and textiles. These tend to represent important natural resources and industrial activity of a given region, hence the emphasis within the public institution. Because of the regional focus, propinquity of interested companies, and the strong public service mandate of the institutions where these institutes tend to be located, they provide a strong base for cooperative research activity.

Historically, an important model is the agricultural institute (*e.g*, the Swine Producers Research Institute at the University of Wisconsin, the Food and Nutrition Science Institute at the University of Minnesota, the Institute for Plant Development at the University of Wisconsin, and the Animal Husbandry Institute at Colorado State University), which has been critical to agricultural development and received great support from state and local government as well as companies. Critical to the functioning of many of these institutes has been a close relationship with the U.S. Department of Agriculture Laboratories. Laboratories or centers directed toward the interests of the mines and minerals industry (*e.g.*, the Department of Metallurgy and Metallurgical Engineering at the University of Utah, the Earth Mechanics Institute at the Colorado School of Mines) which have had close relationships with the Bureau of Mines serve as additional examples.

> A typical example of this sort is the Mineral Resources Research Center (MRRC) of the University of Minnesota. MRRC was established as the Mines Experiment Station, a service of the School of Mines analogous to the Agricultural Experiment Station. Minnesota is a state of vast mineral wealth and iron-bearing ores have been an important source of revenue for nearly a century. In the early days, any individual or company could bring a problem to the Mines Experiment Station and research could be done free. It was at MRRC that the taconite process was developed that made possible the profitable recovery of low grade magnetic ores from the Mesabi Range.
>
> In the 1970's, the Mines Experiment Station underwent reorganization and became the Mineral Resources Research Center. The Institute has a pilot plant which enables the researchers to separate theoretically possible processes from those that are technically feasible. The pilot plant is one of the few located at educational institutions in the United States.
>
> The minerals' industry is showing particular interest in mechanisms for better control over feeding ore into plants, in grinding processes, etc. The MRRC pilot plant is equipped with computer control devices to monitor such processes. Although industry has continually benefitted from the Institute and participated in Institute activities in the past companies have tended to regard it a service, a place where they can contract research aimed at solving a technical problem, rather than a center for basic mining research. This may be partly due to the structure of the mines and minerals industry (see Chapter VIII, pp. 61-62), and partly due to historical reasons concerning the origin and development of the institute. However, there are indications that the attitudes of the industry may be changing.

3. *Jointly Owned or Operated Facilities and Equipment*

Jointly owned or operated facilities are rare. The research team saw none that were jointly owned. However, there were a couple of instances where a facility was jointly operated, or at least jointly used. Usually such programs are based on a unique facility or expensive equipment. One such facility is the Laboratory for Laser Energetics at the University of Rochester. This was described in an earlier report (Brodsky *et al.*, 1979).

Another example is a shared research facility at a private midwestern university administered through their Chemistry Department.

> The university originally established the facility seven or eight years ago through funds obtained from industry for the purchase of the equipment. The equipment is housed at the university. The facility is open to industry on a fee basis. Companies pay a fee to join, and in addition, pay a fee each time the equipment is used. The fee for industry is higher than for departments at the university. An administrator at this university stated that this way

of funding the program is a double-edged sword. If the university raises the fees to be able to buy new equipment, or keep the equipment in top condition, they will close out some users who actually depend on the use of the facility. Furthermore, if they raise the rates, this might be considered by the Internal Revenue Service as creating unrelated income. However, since it is very expensive to maintain and operate this equipment, balance must be established. According to this administrator, this mode of industrial support is not really a long term solution, because if companies really want the equipment, they will buy it.

A unique example of university/industry collaboration in the use of big research facilities has developed at Brookhaven National Laboratories. (Teich, 1981.)

> A research facility known as the National Synchrotron Light Source (NSLS) which began operations in the fall of 1981 has been built at Brookhaven National Laboratories (BNL). In order to be able to equip fully the more than forty experimental sites at the facility, a unique organizational plan was developed.
>
> Two categories of users were established. A number of beam lines have been designed and instrumented by a class of users called "Participating Research Teams" (PRTs). These PRTs have paid for and set up their own instrumentation in return for exclusive usage of their beam line for up to three-quarters of its scheduled time over a period of three years. The remainder of the beam time and the equipment must be made available by the PRTs to general users, and the PRTs must assist the general users in setting up and conducting their experiments and, if mutually desirable, collaborate with them. These "general users," who make up the second category of users, also have access to the other beam lines and instruments built by NSLS staff and intended for general usage.
>
> In order to achieve a "critical mass" of scientific and technical skills, as well as usage needs, the NSLS management has encouraged potential users to join forces in setting up PRTs and shorter-term experiments. In several instances, these joint efforts involve both university and industry teams. One group on the ultraviolet ring, involves collaborators from Brookhaven, State University of New York, University of Pennsylvania, and Xerox Corporation. Another, an x-ray beam line, involves scientists from IBM Corporation and MIT. Since the facility is so new, it is still too soon to judge how well these arrangements are working.

D. Informal Cooperative Interaction: Co-authoring Papers, Equipment Sharing, Information Sharing, etc.

During our interviews, cooperative interaction without the exchange of money (informal cooperative research) was not alluded to frequently. Yet, we are aware that such interaction does occur, particularly with industrial scientists from companies that have large basic research efforts (*e.g.*, IBM, Bell Laboratories, Xerox, G.E. and United Technologies). At a few industrial laboratories, we witnessed university scientists using company laboratory equipment and cooperating with the industrial scientists. Such cooperative interactions are difficult to document systematically. The following anecdote is presented to illustrate what such an interaction can entail.

> A scientist, upon returning to a large high technology company after spending a few years teaching at a university, was introduced to the chairman of the physics department at a local university. They developed an immediate rapport. It turned out that they had been acquainted previously. They had similar research interests and began a dialogue on scientific matters. They continued to do so and this led to cooperation in research for seven years. Several co-authored papers have come out of this program. The company scientist helps supervise graduate students. He eventually received an appointment as a visiting professor. The academic scientist uses the company laboratory and he now has a consulting relationship with the company. The company scientist moved some of his own equipment to the university. He feels that this interaction has provided him with a mechanism for participating in new research with minimum commitment of his time. The interaction enhances his own company program. Although the company scientist is not in a position to give the academic scientist a grant, he can pay for services and issue work orders. The academic scientist uses this money to support graduate students. Furthermore, this interaction provides a base for obtaining government grants.

KNOWLEDGE TRANSFER

Knowledge transfer can occur through a variety of mechanisms, some of which have knowledge transfer as their main purpose, and some which do not. They are frequently an essential element to the development of cooperative research interaction. (See Chapter V, p. 18.)

A. Personal Interactions

Personal interactions between university and company scientists are particularly critical in helping to initiate large cooperative university/industry research programs. They involve both formal and informal programs that may or may not have scientific or technical knowledge transfer as their primary purpose. In a survey (Picard, 1981) of 128 MIT Industrial Liaison Program members, and former members, company contacts were asked to choose which services provided by the ILP Program were most useful. Choosing from a list of 26 specific services, company contacts ranked most highly the personal interactions with the faculty.

1. *Personnel Exchange*

Personnel exchange between universities and companies can be an important means for extending personal interactions. The practice of personnel exchange is implemented both through formal and informal programs that include: visiting professorships, post-doctorals, travel overseas, assignments at universities engaged in high priority research, consultants, company seminars by visiting scientists, participation in intensive workshops, and lectures by company scientists.

A majority of individuals contacted believe that personnel exchange, when it occurred was a fruitful interaction. However, there were no extensive or formal university/industry exchange programs at most institutions visited.

Investigators in over 50% of the schools visited mentioned they had participated in personnel exchange to a small extent, or knew of other individuals who had. All stated that this was not a large or significant university/industry research interaction. Most indicated that few scientists come from companies on a temporary basis to conduct research at universities, but when it occurred, it was a success. These cases are usually instances where a company sends a man for retraining and pays his salary and fees.

Several cases were reviewed where company scientists were paid by the company while spending time at a university research laboratory.

> For example, one drug company pays the salary of a scientist who works two days a week at a southern public university and three days a week at the company research laboratory.
>
> In another case, the chemistry department at Duke University provided space for personnel from a chemical company. The company paid rent for the space and in return a new and relatively inexperienced company employee was supervised by a faculty member. The university benefits from the rent and the interaction. This is a unusual interaction but other similar cases were documented.

The mobility of scientists at one information processing firm is a prime example of informal exchange.

> Each year, approximately 150 visiting scientists from IBM spend time in another research site. About half of these opportunities are within the United States, and half are abroad, primarily in Europe. The company employees who participate frequently spend time at other laboratories belonging to the company, or in universities. The non-employee participants are often post-doctoral students who come to a company laboratory for varying amounts of time. The areas of emphasis for these exchanges include: memory storage, input-output analysis, laser physics, computer architecture, software and computing services.

Universities occasionally establish informal exchange programs with local companies.

> In one program, a faculty member worked at a local company while two people from that company came to the university to conduct research in mechanical and metallurgical engineering. This program was a mixed success. Those who came to the university from industry brought an industrial research approach which served to broaden exposure of faculty and students. However, the professors who went to the company came back with a questionable new outlook. The university mostly sent young faculty to industry, whereas experienced engineers came to the university. This may have been the basis of some difficulties that arose. Despite the benefits of the program, according to one scientist, it was painful to operate. The experiment went on for three or four years, but stopped when the department head left. This underscores another aspect of the mixed success of the program. The program originated because the head of the university department put pressure on his friend, the company vice president. This sort of program, established purely on a personal basis, is quite subject to the mobility of the leader.

Sometimes personnel exchange emanates from an opportunity to participate in a consulting arrangement.

> In one interesting case, a genetic engineering firm moved to achieve close proximity to a large public university with excellence in biomedical and agricultural research. A molecular biologist at the school has worked out an agreement whereby half his time is spent at the commercial laboratory and half at his university laboratory and teaching. This arrangement required difficult negotiations about tenure and conflicts of interest, and these issues still have not been fully resolved.
>
> In another instance, four geneticists from a midwestern school of genetics arranged to spend one day per week at a local bioengineering firm. In this case, the university was concerned that there would be no faculty left to teach if they did not allow such an arrangement. Now, there are difficulties in arranging schedules and ensuring the absence of a conflict of interest.

A large number of scientists interviewed said they would favorably regard improving formal programs of personnel exchanges and would welcome new opportunities to participate in exchange programs. Industrial sabbatical programs are of increasing interest to both university and industry scientists.

> At one public university, the chemical engineering department, with a large industrial program, decided to stop teaching short courses, because they were too time-consuming, and instead, sponsor industrial sabbaticals at the university. This was well received and two chemical companies sent scientists for three to six months. The university would like to enlarge this program and feels that it has worked out well. One participating scientist from Ohio, after receiving a brief indoctrination in the formal part of the program, immediately started "hands-on research" and working with students. This experience helped him in his new position at the company. The company paid for the whole term of his university sabbatical. The university department chairman stated that the reverse has not taken place, *i.e.*, a university professor had not yet gone on sabbatical to industry.

The emerging interest in facilitating personnel exchange is indicated by its incorporation into several new university/industry research programs. Personnel exchange is an increasingly popular element of many university/industry cooperative research centers.

Industrial scientists coming to spend time and do research at the university is an integral part of the California Institute of Technology's Silicon Structure Program, the Computer Science Program of the University of Washington, the Catalysis Center of the University of Delaware, the Polymer Program of Case Western Reserve, and other similar programs (see Chapters VII, VIII and Section on Cooperative Research Centers in this chapter). A feature of several of the new university/industry partnership agreements (e.g., Celanese-Yale, Hoechst-Massachusetts General Hospital, Diamond Shamrock-University of Arizona, see Chapter VII) is a provision for a limited number of industrial scientists to spend time at the associated university laboratory. During the tenure (7 years) of the Harvard-Monsanto agreement there has been continual short term exchange of scientists.

Several company representatives interviewed stated that as a result of a professor's work at the company during the summer, cooperative research programs had been established with the professor's university.

Frequently, personnel exchange is accompanied by equipment gifts or loans and, in a few instances, personnel exchange depended on availability of unique equipment facilities. Such interaction is particularly viable when a large research company and research university are in close proximity to one another. Rarely are there institutionalized programs for sharing facilities. The basis for such interaction is normally personal contact. At a large public northwestern university, university scientists frequently use facilities at nearby aerospace and pulp and paper research laboratories. Industrial scientists use facilities at the university, such as the wind tunnel. This type of interaction is particularly dependent upon geography.

On a more formal basis, General Electric Company has several programs of interest.

> *Coolidge Fellowships.* Each year, up to three (but normally two) of the company's senior scientists/engineers are named by a council of peers as Fellows. This award conveys *inter alia* the right to spend up to one year working on a project of their own choosing, at any site worldwide. The company provides full financial support for travel, living and salary during this period. Upon completion, the award recipient returns to his previous position, without loss of seniority, salary growth, or other fringe benefits.

> *Visiting Research Fellows.* To facilitate the reverse exchange, the company has established this program to attract outstanding scientists and engineers to spend three months to one year at a Corporate R&D laboratory. These individuals are nominated by the Corporate R&D technical staff. Most often, they select people who can stimulate new research areas or bring needed fresh ideas into existing programs. Twenty-four such Fellows have been named to date, and five are currently in place. The company pays salaries, travel costs and certain benefits. Only a few other large corporations, including one aerospace firm, have similar formal visiting professor programs.

> *Visiting Research Scientists.* This is a relatively new program designed to bring young, promising faculty members to laboratories for intense discussions on problems of common interest. The stay is short-term, generally two weeks, and the company pays all the expenses.

Several investigators identified certain difficulties with personnel exchange. The primary problem is disruption of family life. Second, if a company is having economic problems, it is difficult to justify this type of program. Third, if the subject area is in the high technology field, or a fast-moving field of science, it may create a problem for the untenured university scientist to be out of contact with his department chairman, and it is also difficult for the industrial scientist to be out of contact with superiors. Each may be missing opportunities for advancement. Therefore, if such programs are institutionalized, a scientist must be assured of returning to a research program keyed to his research at the host institution, and he must be assured of a position equivalent to or better than what he left. A few university scientists expressed concern that the faculty member, after working in industry, would be tempted to remain there by a large salary offer.

Most agreed that any workable large formalized exchange program would have to be flexible in the length of exchange. Most felt that one to two months was a reasonable length for a good and fruitful interaction, but that one year was too long for those concerned about career development.

2. *Mechanisms for Stimulating Personal Interactions: Equipment Lending, Advisory Boards, Seminars, Speakers' Programs, Publication Exchange*

Other practices of fostering personal interactions, such as participation on advisory boards, seminars, speakers' programs, publication exchange and adjunct professorships, were pointed to as activities which could lead to greater cooperation between university and industry researchers, but their role in the actual development of such programs was difficult to evaluate. One mechanism, the cocktail party, was repeatedly mentioned as having established personal contacts which lead to research interactions.

Several universities said they held special conferences about half of them sponsored by industry, to attract more formal industrial support in a specific area. MIT recently organized a Chemical Sciences Industry Forum to promote increased communication between the parties. Ten companies are sponsoring this activity.

Many said the advisory councils typically associated with engineering and agricultural schools and institutes of technology are useful in providing information about current industrial concerns, and allowing industrial input on research directions and curriculum development. The councils can also help in the solicitation of funds from the legislatures and/or getting equipment for the university. However, most could not document large industrial grants or contracts arising out of industrial participation on these councils. Such things are difficult to document, but at least one instance can be cited where an advisory council improved university/industry research interaction.

> The chemistry department at the University of California, San Diego, established a formal industrial advisory committee in 1977, because the faculty recognized the isolation of the department from industry. In addition, the department hired a person to develop industrial relations. As a result of these activities, they increased their industrial funding by over 50%. Communications developed between the department and industry, and an industrial recruiting job placement program was established. The coordinated activities of the industrial liaison officer and advisory committee helped stimulate technology transfer. The department was able to forge ties with from 36 to 48 research-oriented companies. In three years, they established four graduate fellowships sponsored by industry, and attracted an industrially sponsored Faculty Development Award.
>
> In a case mentioned previously, the advisory committee of a public university's electrical engineering department anticipated a crisis situation in manpower for the 1980's. They were able to attract equipment gifts and research support for the department from industry (see Chapter IX, p. 69).

A recent development arising from the surge of new bioengineering firms is that university molecular biologists and geneticists are being asked to participate on the technical science advisory boards of these companies. We sensed that a majority of these scientists at major research universities in this field had already made a commitment to participate on such boards.

> One plant molecular biologist had recently been asked by 9 to 10 companies to be on their technical advisory boards. The investigator finally decided to sit on one board because the company was receptive to his advice to support activities of interest to him but beyond his own available time or funds. According to this investigator, a desirable outcome of his participation on the board would be unrestricted funds for the support of post-doctoral researchers and graduate students.

University biochemist and organic chemist participation on corporate boards has a long history at drug companies. Several other large research companies, especially in the electronics field, also said they had scientific advisory boards composed of university scientists. These boards help ensure that they do not lose sight of new directions, and that they keep up standards of excellence in their research programs.

> For example, one telecommunication company has a scientists advisory board of 12 top level academic principal investigators who visit two times a year. These professors are on a retainer (they are paid on a yearly basis). Twice a year, industrial scientists present their research results and new research directions. The object is to keep the company scientists on track, make them aware of pitfalls, and keep them apprised of new research developments which may affect their work.

Technical advisory boards composed of industrial scientists, formed to address specific university research programs, are less frequent, but a few large research projects were reported to have industrial steering groups. In some cases, the companies also fund the research, and in others, they serve mainly as advisors and critiquers of the faculty research.

3. *Adjunct Professorships*

Adjunct professorships can provide a solid base for continuing knowledge transfer between universities and companies. Many research departments said they had at least one or two adjunct professors in their departments. Drug companies supplied a large number of adjunct professors to many universities, and to a lesser extent, chemical companies provided personnel for professorships (see Chapter VIII). In the Research Triangle area, one drug company supplies over 27 adjunct professors, or part-time professors, to surrounding universities. In many cases, especially where the professional is an adjunct professor at a major research university and from a major company, the company pays his salary and donates his time to the university.

Within engineering schools, adjunct professorships are increasing because of the faculty shortage and influx of students. However, these professors usually just teach and do not participate in research. There are exceptions.

> In one case, half of the departmental faculty were adjunct professors, and most participated in research programs. This same university maintained a practice of hiring retired high level executives from local companies on a part-time basis. Both of these factors were important to developing the sensitivity of this school's scientists to industrial needs, and in fostering the establishment of several large and successful university/industry cooperative ventures.

Many company scientists expressed a desire to hold adjunct professorships. The opinion was expressed frequently that universities should be more open to appointing scientists from industry as adjunct professors. A university policy of severely limiting adjunct professorships could be a barrier to university/industry research cooperation. One private university having strict rules regarding adjunct professors had a history over the past decade of infrequent university/industry cooperative research interactions and lower than average industrially sponsored research programs based on percent of total research expenditures.

4. *Consulting*

The critical element in initiation of cooperative university industry research programs in over 34% of the cases where this question was asked directly was the consulting practice of those who developed the programs, usually the program director and active participants (Table 5 p. 19). Prior relationships which frequently involved some degree of consulting were important factors in 76% of these cases. Interviewees specifically mentioned consulting as being important in about 20% of the total number of interactions reviewed (Table 4, p. 19). The relationship between consulting and an awareness of industrial interests is further underscored in a recent study by Roberts and Peters (1981) at MIT. They found that professors reporting commercial ideas were much more likely to be involved in consulting with business or government than were those who did not report ideas.

Consulting policy utilized by the universities interviewed, present a wide variety of attitudes and objectives (See Table 25). Objectives in fostering consulting can vary from providing professors with a mechanism to supplement their income, to providing a conduit for bringing industry research projects to the university, to maintaining a communications network between the university and industry. Perhaps most critical is the aim of providing for increased ability to expose and guide students to career paths within industry. Thus consulting can relate to the fundamental objectives of the university for both education and research.

Some schools have special programs to promote consulting activity by the faculty and others have a hands-off attitude, and still others frown upon consulting as interfering with faculty teaching and research responsibilities, without crediting any positive relationship to these functions. Those not familiar with industrial needs and support seem not to recognize its real importance in establishing links necessary to developing large and stable industrially supported programs.

Many believe a degree of university guidance is necessary. This occurs both through encouraging university scientists to find 'proper projects,' as well as establishing a policy on the permitted frequency of consulting.

Several department chairmen were concerned about the types of projects a professor took on through his consulting activities. They did not believe that it was in the best interests of the university to have the professor's time taken up with problem-solving not related, or peripheral, to the professional development of the faculty member.

The most common policy on consulting frequency, found in 62% of the schools with available information, is to permit one day per week consulting. Two public universities had a policy of allowing two days per month, and one private university said that their policy was 13 days a quarter (Table 25.) In some universities, the policy varied on a school-by-school basis. Most scientists said professors rarely added more than $10,000 to their salaries through consulting activities. Most schools, especially the private schools, are quite informal about their requirements for reporting on faculty consulting. Typically, they are only interested in the frequency and not the monetary reward. Reporting consulting activity is usually voluntary, except at a few state universities. Of the schools providing this information, only 56% had formal reporting procedures. These were infrequently rigorously enforced.

Most of the schools interviewed did not discuss the fee structure for consulting. However, of those who did, the daily fee ranged from 0.6% to 2% of the academic year salary. The total annual compensation permitted ranged from $8-15,000. A formal reporting procedure was the only means of enforcing the guidelines.

Thus it is not surprising that concrete data on the level of consulting at universities is particularly difficult to obtain. No one interviewed felt that these privileges were being extensively abused, and most stated that only 10% or less of their faculty consulted at the maximal allowable rates. The results of our field study are consistent with a 1965 study of the University of California, indicating that only 30% of their faculty, primarily in medicine, engineering and social science, had some consulting activities during that year, and a 1973 report by the American Council on Education, which found 48% of university and college professors performed some sort of consulting service (Perry 1965; Baer, 1973).

The popularity of consulting can be associated with certain academic fields. It was frequently stated that consulting in business schools is at a much higher level than in either engineering or science schools or departments. In the technical units of a university, consulting activity is most prevalent in the engineering departments due to the applied nature of that discipline. In engineering schools, especially where ties with industry are already in place, consulting activities may even be taken into consideration at the time of promotion, all else being equal. In these schools, there is frequently a general feeling that one's excellence as an engineer is somewhat substantiated by his demand as a consultant. One engineering professor stated that if a professor did not have extensive consulting activities, he was suspect because he was not then cognizant of real-world problems.

All company representatives interviewed said they make use of university consultants. Most high technology companies, especially chemical and drug companies, have rosters (some are computerized) of university consultants they have used in the past or are using presently. During any one year, the larger companies (having sales of over $150 million) are not likely to use more than 125 university consultants. Representatives for several of the companies in our sample said that on the average they spent about one half million dollars annually on academic consultants to

Table 25

Consulting Policy and Activity as Reported in Interviews During NYU Field Study

University	Consulting: # of Days	Use/Abuse	Formal/Informal	Compensation
Carnegie Mellon	1 day/week	1 instance of abuse	informal	N.A.
Case Western	N.A.	encouraged as part of industrial liaison program	informal	N.A.
Clemson	2 days/month	average use 9-10 days/year, pressure for less	N.A.	N.A.
Colorado State	infrequent except for Business School	no abuse	formal	N.A.
Colorado School of Mines	infrequent	N.A.	reporting not pushed	N.A.
Johns Hopkins	1 day/week	through liaison programs	decentralized	N.A.
Lehigh	1 day/week	through liaison programs	formal	through liaison programs
Pennsylvania S te	1 day/week	spin-off companies	formal	N.A.
Purdue	variable	N.A.	informal	N.A.
Rensselaer	N.A.	N.A.	N.A.	N.A.
Rice	1 day/week	through REDDI	formal	through REDDI up to 1.5% of academic salary per day
University of Arizona	N.A.	Env. Res. Lab—no consulting in area of research otherwise institutional consulting	N.A.	N.A.
University of Chicago	variable	N.A.	informal	N.A.
University of Illinois	1 day/week 2 days/month Chemical School	N.A.	formal	N.A.
University of Maryland	N.A.	N.A.	N.A.	N.A.
University of North Carolina, Chapel Hill	variable	often initiated through recruiters	formal	N.A.
University of North Carolina, Raleigh	N.A.	university first allegiance	formal	N.A.
University of Utah	2 days/month	no abuse	N.A.	N.A.
University of Washington	1 day/week Dept. of Oceanography	heavy use by engineering, "abuses in one dept."	informal	N.A.
University of Wisconsin, Madison	N.A.	important in engineering	N.A.	N.A.
Washington University	most do less than 1 day/week	through Wash. U. Technology Association	informal	annually 10-15% of salary
University of Houston	1 day/month chemistry	abuse noted in one unit. Consulting in Public Policy led to research	formal	N.A.
University of Michigan	N.A.	Inst. Soc. Res. faculty not permitted to consult, permanent relationships have developed	decentralized	5% monthly salary/day
University of Delaware	N.A.	N.A.	formal	N.A.
Georgia Tech	permit 1 day/week 1 day/month average	institutional consulting 50% of engrg. fac. consult.	formal	N.A.
Duke	N.A.	some consult through Mercury Res. Fund	formal	allow $8-10K annually
University of Minnesota	1 day/week	encouraged by Hydraulic Lab. One instance of potential abuse.	informal	N.A.
Louisiana State	1 day/week average 1 day/2 weeks	Potential abuse in two units.	formal-Business Sch.-informal	N.A.
Stanford	13 days/quarter	seek awareness of real world problems	N.A.	N.A.
University of Texas, Austin	1 day/week	25% of faculty	formal	usually $2-3K/year
University of California, San Diego	1 day/week unwritten norm	small amount due to geography	no central reporting system but annual statements required	N.A.
University of Rochester	N.A.	N.A.	N.A.	N.A.
University of Southern California	N.A.	N.A.	N.A.	N.A.
Cal Tech	infrequent a few do 1 day/week. Contradictory information.	through Ind. Liaison Program	informal	none for faculty in Ind. Liaison Program

Table 25—Continued

Consulting Policy and Activity as Reported in Interviews During [illegible]d Study

University	Consulting			Compensation
	# of Days	Use/Abuse	Formal/Infor[illegible]	
Harvard	1 day/week	N.A.	N.A.	[illegible]
Princeton	1 day/week	about 80% of faculty involved-same 80% who do research.	N.A.	[illegible]
UCLA	1 day/week	N.A.	N.A.	[illegible]
MIT	1 day/week	Eng. Dept.-group incorp. themselves as consults. & hired someone to run the company.	must report consulting arrangements, days involved, client.	[illegible]where from $8 per hr. to $3000 per day
Yale	1 day/week	none	informal	N.A.

Note—N.A. = not available

their company. This suggests that on the average, by consulting for one company, a professor could add $5,000 to his annual salary.

Industrial scientists and administrators said they usually initiated interactions with consultants. The primary means leading them to consultants were perusal of the scientific literature, recommendations of their professional staff, which in many cases led them to former professors or employees, participation in workshops, seminars and conferences, and through company recruiters at universities.

Several universities have set up mechanisms to generate consulting opportunities efficiently for their faculty.

> At Rice University, an engineering design and development institute (REDDI) was established as an internal applied research institute. REDDI brought consulting onto the campus. It established the frequency of consulting permitted, fee standards and other reporting information. REDDI policy allows student involvement in all projects. Proprietary rights and publishing agreements are negotiated through this Institute. While projects may be undertaken on a confidential and proprietary basis, the publication of scholarly works, where appropriate, is encouraged.
>
> Companies come to the Institute with their problems and the Institute seeks opportunities for faculty participation. Faculty may charge a professional fee up to a maximum of 1.5% of their academic year salary per day. The Institute charges a 7% surcharge on the salary consulting agreements. Part of this surcharge is given to the University's general operating budget, and the rest is used to operate the Institute. This arrangement provides additional support money, support groups and equipment.
>
> At Washington University, St. Louis, a similar program is being established, Washington University Technology Association (WUTA). Its goals similar to the above-cited example, are to supplement the salaries of engineering faculty and to formalize faculty consulting research activities in applied engineering research. WUTA is somewhat different than the former Institute in that WUTA is a for-profit corporation.

University liaison programs often provide opportunities for consulting. At times, these programs direct industry to faculty, helping to establish consulting arrangements. At other times, consultancies provide the impetus for a company to establish an ongoing relationship with the university by joining the liaison program. Liaison programs which have, as a part of their services, trips of the faculty to company sites and also actively encourage company representatives coming to campus, are particularly good programs for fostering the initiation of consultancies. In most liaison programs, there is a consensus about what constitutes an informal discussion between a faculty member and company representative, and what constitutes a formal consulting arrangement. A first half-day visit between a company representative and industry scientist is usually regarded as a service of the program. When there is any longer degree of interaction, the company and the professor are encouraged to enter into a consulting arrangement or agreement.

A number of universities have established centralized listing of all research interests and activities by faculty. Thus industrial firms may come to the university with a particular problem and see immediately if the university has people with the required capabilities. This referencing system may be used for contract work as well.

An important issue related to consulting activities is to determine when do such activities create a conflict of interest (see Chapter X, p. 113). As mentioned earlier, faculty must maintain a balance between their outside consulting activity and their university obligation to teaching and/or research. Frequently, attempts are made to combine these activities by utilizing students to assist the consulting projects as at the engineering and design development institute.

A second issue involves the use of university facilities for outside consulting. Here again, the university policies vary widely. Allowing the use of facilities serves as a drawing card for many companies, and thereby increases university/industry interactions. On the other hand, this might bring the university into direct competition with small consulting and laboratory businesses. This is a special concern at state universities.

A third issue concerns the attempts by one company, in the view of a university administrator, to monopolize a university's faculty in a particular area. A striking example is the actions at one midwestern state university, of a company putting the university's top four molecular geneticists on retainer, which in the view of some has resulted in cutting off others from utilizing their knowledge and advances. Through proprietary restrictions, this could cut off not only other companies from these scientists' work, but also the students of the univer--ity.

B. Institutional Prcgrams

These mechanisms of knowledge transfer are defined as formal programs designed to contribute primarily to information exchange between universities and industry. Frequently, they serve as a broad-based information exchange providing a window on new scientific and technical developments.

1. *Institutional Consulting*

Institutional consulting was described as a mechanism of university/industry research interaction at only four universities of the 39 visited by the research team. Only in two instances was there a formal institutional consulting program. In each of these cases, the program involved a faculty member and a group of students who worked on an industrial problem. In both cases, the problem-solving was done at the company site. Both of these cases can be characterized as an educational program to acquaint students with real-world problems, rather than as a research program.

> An example is a program conducted at Yale University. In 1973-74, graduate students at that institution's chemistry department participated in a novel student consulting team approach to basic research problem-solving. Engineers at Texaco's Research Center at Beacon, New York, identified problems of interest to the corporation which the student team analyzed. Although the program was devised more as a training exercise for the young chemists, the interchange sparked more systematic contact than is ordinarily generated by many faculty consultations. Researchers at both ends of the university/industry spectrum gained knowledge of the other's research capabilities and expertise.
>
> Still another program which has generated a long-term consultative relationship is the MIT School of Chemical Engineering Practice, established in 1916, which operates two "Practice Schools"—one at General Electric's plastics and silicon production facilities at Albany, New York, and the other at Oak Ridge National Laboratory (operated under contract to the U.S. Department of Energy by Union Carbide's Nuclear Division). This school integrates classroom experience and practical work by providing MIT students with a four-month, intensive industrial research-oriented internship away from the university, but under the direct supervision of MIT faculty members. The curriculum is based on key industrial problems. The host company benefits from the frequent consultation efforts of visiting MIT faculty and its recruiting efforts are facilitated by the presence of students at the company. The Practice School operates much as a small consulting company, with student groups working intimately with host plant staff in solving problems. The resident faculty ensures that assignments are of significant educational benefit to each student and that assignments result in a major contribution to the plant operation and/or to the understanding of a phenomenon of professional significance.

2. *General Industrial Associates Programs*

There is a growing feeling that institutional general purpose industrial associates programs are not beneficial to either university or industry partners in research. At least five schools visited by the research team mentioned that they had initiated general industrial associates programs within the last ten years that had failed. Most company representatives were not enthusiastic about general industrial associates programs, although they usually belong to one or two programs of that nature.

The reason generally given for this dissatisfaction is that they are too broad and general, so they do not attract attention and commitment. General industrial associates programs are not designed to foster or to fund collaborative research. They offer loose support and links to several elements of industrial interests in the production of curricula, students and research. Universities usually organize these programs as a means of obtaining unrestricted funds from industry. Unrestricted funds, as stated previously, are extremely important to university scientists and administrators. Frequently, the money is used for the support of graduate students. At least one new large general industrial associates program is being initiated solely for this purpose.

At least 31 of the 71 industrial associates programs documented in this study can be characterized as general industrial associates programs. Eight of these were campus-wide programs. The largest campus-wide program had 265 member companies and generates over $4 million for the university.

Two private schools have had very successful general purpose industrial associates programs for over 30 years. However, the point was made several times that these schools are already focused and therefore the general purpose industrial liaison program works.

The membership fee for a general industrial associates program is usually about $20-30,000. However, there are some programs which cost considerably less, from $1,000-5,000. Consequently, the services provided to industry are also considerably less. However, one engineering industrial associates program at a public university charged only $5,000 in fees, and the school was still able to provide what several company representatives characterized as one of the best annual industrial associates symposia they had attended.

A dilemma expressed by many university administrators was whether or not to keep industrial associate membership fees sufficiently low so smaller companies could join, or to charge more and have fewer company members and a more elaborate program. Several schools are experimenting with fees based on a percent of sales, or at least with a differentiated fee structure for small and large companies.

Schools with successful industrial associates programs generate from one to four million dollars annually through these programs. Less successful schools generate approximately $100,000-200,000 in their liaison programs. Each of the successful schools has active and energetic liaison representatives (the smaller school has two to three, and the larger, fifteen) who run the program. The job of the liaison officer is to arrange programs and facilitate linking the professor and the company. A liaison officer is usually an industrially experienced graduate engineer. Each liaison officer is assigned a group of member companies for which he/she is responsible. Each officer is also assigned the responsibility for monitoring the activities of several departments, laboratories and centers at the university. The officers visit key company personnel to ascertain their interests and needs, alert the company to research patents and educational opportunities, and arrange host visits of company personnel to the campus.

If the program is to be successful, the officer also frequently visits with faculty to ascertain their research needs, alert them to industrial research needs and opportunities, and arranges faculty contacts with member companies on campus by telephone or by travel to company sites. In addition, the officer provides for discussions between company representatives and faculty. The service provided to industry also includes sending member companies a directory of current research, making available important university publications and reports, and giving short courses, symposia and seminars.

A general industrial liaison program is particularly useful to a company when it is interested in obtaining a technical overview of a new area. Schools with large and diversified research programs are usually the only institutions that can provide in-depth, broad spectrum overviews in a sufficient number of areas to make it worthwhile for the companies to pay high membership fees. Companies who regarded a particular industrial liaison program to be useful understood that they must make active use of the program and attend seminars and symposia on the campus. Many companies supporting such programs recognize that they are really giving support to general technical excellence. A company is usually dissatisfied with such a program if it expects to get something very specific for its membership fees.

C. University/Industry Research Cooperation and Education

Education is the central activity of universities and thus industry support for research is inextricably related in many ways to that educational mission. Some of the more central relationships of education to university/industry research cooperation involved the following:

1. *Universities Serve as the Source of New Science and Engineering Graduates for Industry: Fellowships, Internships, University/Industry Cooperative Training Programs.*

The most prevalent motivation for industry cooperation with university is based on the need for qualified science and engineering graduates. This need exists not only for Ph.D.s, but also at the baccalaureate level where the numbers required are much greater. In times of economic decline and at times when there is a personnel oversupply, these interactions become critical for the student as a guide to make contacts and to help direct their job-seeking.

Graduate students. The personal relationships established between industry researchers and university faculty help provide one path of access to graduate students as potential employees. The research relationship can provide industry researchers direct contact with graduate students, especially those at the doctoral level, since these students typically are involved in carrying out sponsored research. From the perspective of the university, industry support of graduate research assistants is most welcome. Graduate assistants generally become familiar with research problems of interest to the industrial sponsor, especially if they are working on contract research. The students, in turn, can be evaluated as potential employees of the sponsor. Therefore, it is not at all unusual for a graduate student working on an industry sponsored research project to work for the sponsor upon graduation. Hiring such graduates offers great advantage to industry, since costs of recruiting, and initial on-the-job learning are reduced, if not eliminated. Moreover, the employer has already had an opportunity to evaluate the performance and capabilities of the new graduate, thereby increasing the likelihood of hiring individuals who will pursue successful careers in the company. Thus, industry support of graduate research assistants is perceived as cost effective, not only for its own sake, but also for its recruiting potential.

Undergraduate students. Whereas the contact established with graduate students is often a direct outcome of research interaction, such is not generally the case with undergraduate students. However, industry has a continuing concern with the need for upgrading and updating university curricula so that the graduates are prepared to utilize the latest scientific and technical knowledge. Such upgrading and updating typically enhance the research capabilities of the university. This is accomplished through mechanisms such as equipment grants and personnel exchange. Upgrading the training and education of students can involve the loan of experts by industry to a university on a short-term basis to acquaint faculty and students with recent technical advances.

A case in point is the aerospace industry which perceived that new engineering graduates were not keeping up with CAD/CAM technology, and proceeded to develop a university program on the undergraduate and graduate level. This program was developed primarily through the initiative and cooperation of several aerospace firms who sent industry personnel to work at the university, donated appropriate hardware and software, organized the seminars, established fellowships and even endowed a university chair at the University of California, Los Angeles. This program also involves faculty and graduate students on research projects, thereby enhancing the research capability of the university in a new emerging technology.

In another case, a private university used its endowment funds and NSF seed money to rebuild their instructional laboratories and also build a research center which subsequently attracted a large amount of industrially supported research. Thus, from having an original purpose of developing their undergraduate curriculum, the university ended up at the leading edge of technology with a highly successful, industrially supported research program.

In a recent initiative, two new biotechnology companies and a public university are developing a certificate program (BS and MS degrees) in applied molecular biology. The companies involved will support a scholarship for a student in the program and/or help support seminar speakers connected with the program. They will also have company staff present occasional lectures or demonstrations. Some students may serve as interns at the company. In the long term, they hope that joint research projects will develop out of this program.

Minority students. Another reason for industry's support to a university is to increase the representation of minority graduates in science and engineering. Such industry programs have concentrated on selected universities with large minority student bodies. Some programs have extended to the graduate level and have transferred high technology capabilities from industry to those universities. This has resulted in enhancing the research capabilities of selected institutions. In some instances, federal government support has been instrumental in developing comprehensive plans of this type. However, industry initiative has typically preceded government support of such programs.

An example of such an initiative is given by the efforts of an aerospace company's corporate research laboratory in establishing solid state electronics research capabilities at two eastern minority institutions. For three-and-a-half years beginning in 1976, the company invested over $800,000 in capital equipment and research program sponsorships as well as approximately $400,000 of indirect support through services provided to the two universities by the company science center and university personnel from a highly respected engineering school. As a result of the advanced capabilities established at both universities, they were able to obtain over $1.5 million in solid state electronics research grants with almost a third of the funding from NASA. These research capabilities were inextricably related to the establishing of a Ph.D. program in electrical engineering at one university, and a strong masters degree curriculum at the other. One of the two universities is now a member of a consortium of universities and several companies which is developing the Micro-Electronics Center of North Carolina.

2. *Doctoral Graduates of Science and Engineering Curricula Initiate University/Industry Research Cooperation: Alumni Initiation of Research Interactions*

In some cases, doctoral graduates who are employed in industry may serve as key links in initiating cooperative research efforts with their former university. The familiarity of these graduates with the capabilities and interests of their former professors and with the needs of their employers makes them highly desirable as initiators of university/industry research collaboration. It is not uncommon for a former graduate student to call his major professor and propose a joint research effort.

One professor of chemical engineering attributed his large amount of industrial support directly to his former graduate students. These were his personal contacts.

In another instance, a former student was so intent on having the professor work on his company's problem that he wrote the proposal for the professor.

Many company representatives said they frequently identified their consultants through an employee's recommendation of his former professor.

3. *Continuing Education is Utilized to Initiate and Reinforce Research Collaboration: Short Courses, Personal Contacts*

The use of continuing education programs by universities has occasionally served to stimulate interest by industry in collaborative research participation. By means of short courses, seminars or workshops, industry participants are introduced to the university's capabilities and new areas of science and technology.

This approach has been utilized by one professor to obtain industry sponsorship for a highly successful research program focusing on new technology for the petroleum industry. Possible industry sponsors were invited to participate in short courses at the professor's initiative. Out of the short courses came wide industry support of his research program.

Moreover, continuing education can be utilized to maintain the interest of industry in supporting university research. Short courses, workshops and seminars can be utilized as knowledge transfer mechanisms to keep industry sponsors abreast of the latest developments in university programs. Such knowledge transfer mechanisms are included as a benefit to the contributors of some industrial associates programs and provide feedback for participants in industry sponsored research programs and centers.

4. *Industry Provides Funds for Graduate Fellowships*

Company foundations have long provided general fellowship support to certain schools and certain departments. Support for graduate fellowships was given by the 83 companies reporting such information in the Council for Financial Aid to Education (CFAE) Case Book (11th edition).

> For example, a fellow of an aerospace firm at a western private university joined the faculty at the school and became a consultant to the aerospace firm. As a result of the consulting relationship, he helped develop cooperative research contracts with DARPA and ONR funding in which the university subcontracted to the aerospace company.

Trade associations also provide general fellowships to specific technical units of a university.

> A case in point is a midwestern public university's 75-year program with a midwestern gas association. This association is subscribed to by all the power and gas companies in the state.

Cases of general fellowships designated to a specific technical department were numerous. While this is not support for a specific project, the intent is that research will be conducted in a certain area. Many investigators expressed the wish for a greater number of such fellowships.They do fit in with the primary motivations of industry, the production of well trained graduate students. These funds usually are not confining in the eyes of the professor.

An element lacking in general fellowship programs is an interplay in the planning of the research, but this does not necessarily have to be the case.

> In the new intern program at one private university, the target group is people in their late twenties or thirties. The intern student and the company enter into a formal contract agreement. The company agrees that:
>
> (1) their employee can have a one-year leave of absence to go to school;
>
> (2) the company will provide a person to serve on the Ph.D. committee· and
>
> (3) when the person comes back to the company, he/she will have an assignment within which to work on a thesis and be able to conduct that work as part of the company duties.
>
> Therefore, industry can share in the direction of the research project. These types of programs are rare. A unique aspect of this program is that it was initiated by a university. Such programs, unlike cooperative research programs, are most often initiated by industry.
>
> In another case, a Scholars program sponsored by a large aerospace and electronics firm at an eastern public university was initiated two years ago by the chairman of the board of the company in order to attract graduate students to systems engineering. It is a work/study program where the Scholars are, first of all, employees of the company. As such, they receive full salary and full employee benefits while in the program. There is a fifty-fifty mix between existing company employees and those newly recruited by the company and the university. Sixty percent of the Scholar's time is spent working at the company's research laboratories. The remaining 40% of the time is devoted to instruction and research. The MS degree is earned within two years. The goal of the program is for the student to conduct research and write a thesis related to the technology interests of the company sponsor.

The recognition of a shortage of graduate students and faculty in fields such as engineering and computer science, due largely to demand within the private sector, has resulted in an attempt by industry to increase sponsorship of university fellowship programs in these fields.

> One of the most significant of such attempts is that by the Exxon Foundation, which is providing a total of $15 million to support one hundred doctoral students at sixty-six colleges for three years, and a supplement of $20,000 annually to a hundred departments of engineering and allied programs for the support of junior faculty to keep them from being lured away by industry. Clearly, not all universities are being assisted, and even some of those receiving these awards need more funding to overcome the impending crisis in engineering education. It remains to be seen whether attempts such as those of this corporation will be effective in attracting graduate students and faculty to schools of engineering and science, and if they can be successful in fostering research programs more relevant to industrial interests.
>
> Also in an attempt to keep faculty at the universities, another petrochemical company is considering the establishment of a program which will provide a forgiveable loan to a junior faculty member who agrees to work for four years in an academic position. The loan is for $40,000. For each year up to four years, $10,000 will be taken off the loan while the professor stays in an academic position.

D. Collective Industrial Actions in Support of University Research Programs

The role of trade groups in fostering university/industry research interactions is largely an untouched subject. Shapero (1979) stated that before World War II, most industrial support of university research was via trade associations. Yet an NYU survey indicated that trade group support and interest in sponsoring technical university research is relatively recent. Currently, of the 30 trade associations studied, 12 (40%) funded no university research (Table 26). There are about 7,000 trade groups in the United States, each serving a target industry on matters of common concern (National Trade and Professional Associations of the United States and Canada and Labor Unions, 1981). We describe the total activity of these trade groups and/or industry-wide research activity as collective industry support of research. In order to discuss the ways in which these industry groups interact with universities in the area of technical research, it is convenient to divide them into four categories:

- Trade associations
- Affiliates of trade associations (mainly foundations)
- Independent research and R&D organizations affiliated with a university
- Industrial research consortia.

Of the 22 industrial sectors covered, 5 did not fund technical research on university campuses through one of the above means.

1. *Trade Associations*

A trade association is defined by the American Society of Association Executives as "a non-profit organization of business competitors in a single industry, formed to render a number of mutual aid services in expanding that industry's production, sales and employment."

The headquarters of a typical trade association functions as a secretariat for a wide range of committees and councils which will carry out the work of the primary operating units, these units are either permanent or formed on an *ad hoc* basis. Staff people responsible for their operation are permanent, while committee members, drawn from the supporting companies, volunteer to serve. The organization of a trade association is the key to tracing connections with university technical research. The most common arrangement consists of operating units created by function. These generally cover areas of governmental affairs, communications, finance, legal issues and technical needs to the industry. A few associations, such as the Rubber Manufacturers' Association, are organized along product lines, and there is no central research budget or committee. Therefore, their interactions with university technical research are dispersed and the overall level of such activity difficult to assess.

The technical unit of a trade association can cover a variety of areas. It can operate as a central agency for gathering, compiling and disseminating statistical data on industry-wide economic and market research; it can work for the improvement of product and industry classifications; it can deal with testing and standardization of the industry's products and processes; or carry out a combination of these functions.

Standardization often accounts for much of a technical unit's work, and as such, warrants some discussion. A standard is a definition of a product or procedure in terms of certain features, and standardization is the process of reaching agreement on the form and content of such a definition. Many associations work on the development of voluntary standards in their field, a practice challenged in 1980 by the Federal Trade Commission. Work in standardization typically includes literature searches and collection of broad-based industry input on the standard under review.

Another aspect involves testing to determine whether a product or process meets the standard. Testing equipment and procedures are continually being improved. Pertinent to the subject of university/industry research interactions, the testing facilities of several trade groups are located on university campuses. Although the level of technical research involved in testing may be low, students are trained in techniques, thus gaining practical, industrially-oriented expertise.

Only a few of those organizations surveyed are involved in technical research on any significant scale. Some exceptions are, the Motor Vehicle Manufacturers' Association, the American Petroleum Institute, and the

Table 26

Three Categories of Trade Groups Surveyed and their Current Funding of University Research[1]

Category	Fund University Research		
	Yes	No	No Response
Trade Association	13	12*	5
Research Affiliate	5	2	1
Independent Research or R&D Organizations	8	0	0

*Of these, five have no technical research

[1]The level of funding has not yet been ascertained in every case, but the fact that they do fund university research to some degree has been determined.

American Gas Association, all three of which supported well-regarded programs as testified to by interviewees in this field study.

2. *Affiliates of Trade Associations*

For those trade associations serving industries with heavy technical requirements, a common practice is to set up a separate foundation or corporation which acts in part as its research arm. These affiliates qualify for tax exemption under Section 501(c)(3) of the Internal Revenue Service Code. The requirements are that they be organized for scientific purposes, that no part of their net earnings go to the benefit of any individual, that no substantial part of their activity consists of propaganda, or attempts to influence legislation, and that they play no part in any political campaign.

An example of this type is the Bituminous Coal Research, Inc., formed in 1933, as the research arm of the National Coal Association (established in 1917). Its research center has laboratories for equipment development and chemicals research. In 1980, Bituminous Coal Research, Inc., allocated only a very small portion to universities of its substantial research budget. This was explained by the steadily declining campus effort in coal research over the past 20 years. Opportunities are provided to students to perform chemical research in its laboratory.

3. *Independent Research and R&D Organizations Affiliated with a University*

A few industries are served by independent R&D institutes which provide a pool of advanced science and technology for companies to draw upon. Within this group, some coordinate their research role with the responsibility to provide a professional and managerial base for their industry.

As a consequence of a dual focus on education and research, this type of organization has successfully integrated the traditional interests of industry with those of the university, often perceived as incompatible.

There are three prominent examples of such institutes in the United States: The Institute of Paper Chemistry, the Institute of Gas Technology, and the Textile Research Institute.

The Institute of Paper Chemistry (IPC) is an outstanding example of a unique partnership between industry and academia. Affiliated with Lawrence College in Wisconsin, the Institute of Paper Chemistry was established as an independent, privately supported educational institution, devoted to education and research in the natural sciences and engineering. Its academic programs lead to the MS and Ph.D. degrees. Each student receives a fellowship stipend and full tuition fees from the Institute. Upon graduating, the students usually take positions in the paper and pulp industry, often in R&D areas. Since its establishment fifty years ago, the Institute has matriculated 838 students.

A special feature of this program is the technical and research experience gained in industry during the summer term. This experience acquaints the student with industrial processes used in different regions of this country and abroad.

Support for the Institute is derived from four sources: annual dues from United States producers of pulp, paper and paperboard; contract research performed by the staff on a non-profit basis; scholarship and fellowship gifts; and miscellaneous sources. In 1980, the budget was $10 million.

The Institute provides the industry with a cooperative research facility dedicated to solutions of technical and scientific problems of the industry through fundamental and applied research of long-term interest, as well through developmental projects. Research directions are guided by a Research Advisory Committee, made up of nine senior committee executives who meet regularly with the Institute administration and staff.

The Textile Research Institute (TRI) in Princeton, New Jersey, had a 1980 budget of $1.3 million. It provides the textile industry with an independent research facility, focusing on fundamental scientific principles in the physical and engineering sciences concerned with polymers, fibers and textile systems. TRI's aim is to carry out basic research without losing sight of industrial relevance. Guidance for the core research program is provided primarily by the Research Advisory Committee, composed of 21 senior managers of textile companies.

The training aspect of TRI's program centers around a cooperative effort between TRI and the Department of Chemical Engineering at Princeton University. The students awarded TRI fellowships undertake thesis research on a fiber or textile-related topic. This program involves both students and faculty in the TRI effort to serve as a bridge between industry and academia, and to orient scientists and engineers to fiber and textile science and technology. In 1980, five research fellows and two undergraduate students at Princeton University were associated with the Textile Research Institute.

The sources of revenue come from general support and grants, industry supported research, government supported research, and publications.

The Institute of Gas Technology (IGT), affiliated with the Illinois Institute of Technology, was set up in 1941, modeled on the Institute of Paper Chemistry. It serves American companies involved in the production, distribution and utilization of gas and its by-products, and its budget was in excess of $30 million in 1980. Besides the laboratory, its research capability includes the Energy Development Center, which has three production plants. There are about 100 active projects per year, both in fundamental and applied areas. Contract research is routinely undertaken.

The educational programs offered provide graduate degrees in gas technology. There is also an undergraduate option in gas technology available to engineering students. Since 1941, IGT has produced 25 Ph.D.s, 113 masters degrees, and the undergraduate option has been taken by 204 students.

Those interviewed who had participated in a program at one of these Institutes (IPC, TRI, IGT) felt that their interactions had been professionally valuable.

However, in several instances, a question was raised concerning the impact upon the host university. One professor stated that there was absolutely no impact on the host university research program. The research capabilities of such institutes are constrained to some extent by their constituencies. As science moves in new directions, these institutes find it difficult to respond. One company representative stated that his firm had decided not to renew their institute membership because they had to invest their limited funds elsewhere to gain expertise and access to new developments in biotechnology. Presumably this is an issue currently challenging the major institutes mentioned.

4. *Industrial Research Consortia*

Several other independent industrial sector R&D organizations can be characterized as industrial research consortia funding university research. One example described below is the Council for Tobacco Research. Two others, the Gas Research Institute and the Electric Power Research Institue (EPRI) are described in Chapter VIII. Another example, and a new initiative, the Council for Chemical Research was described in this Chapter (pp. 81-82) under the heading cooperative research because it is established through the actions of both university and industrial scientists.

> *The Council for Tobacco Research* is an independent organization drawing its financial support from dues of its member companies, representing tobacco growers, manufacturers and warehousers. Although it does research of ultimate use to the industry, it does not contract work for the industry. No research involving tobacco itself is done, nor does it have any product testing capabilities.
>
> The 1980 budget was $6.5 million, of which $6 million was given to faculty at university medical schools. Its research emphasis is on etiology or pathogenesis of non-germ diseases such as cancer, emphysema and cardiovascular ailments. The work is carried out principally through universities. No work is supported on treatments or cures.
>
> There is a continuous planning process for determining its research program. This begins typically with contract from someone seeking to apply for support. A proposal for a three-year study is submitted and screened by a Council Executive Committee for relevance. If positive, a formal proposal is requested. These are assigned to the proper subcommittee for the Scientific Advisory Board. Proposals selected are reviewed over a four-day period at an annual meeting of the nine-member Scientific Advisory Board. The staff determines the appropriate level of budget allocations and proposals are awarded within these limits. A visiting committee from the Council follows the work in progress, and the results are published in the open literature. A researcher is typically awarded one or two renewals.
>
> The researchers used to be chosen from the ranks of those promising scientists without sufficient credentials to obtain support from large funding agencies. With the cutback in government research support, however, those applying are apt to be established researchers.

Several other industries (*e.g.*, the mining and minerals industry, the semiconductor industry) are reviewing the possibilities for collective industrial support of basic research. All view academic research as an integral part of any collective industrial action.

TECHNOLOGY TRANSFER

Programs structured with a view to capitalizing on university research or integrating technological results of university research into private sector programs or commercial products can be characterized as technology transfer mechanisms. (See Chapter V, p. 18.)

Such programs are designed to:

(1) address specific research problems of a company, or
(2) give technical assistance to companies in need of developing new product lines, or
(3) provide technical assistance in the development of a totally new business, or help entrepreneurs initiate their own high technology companies, or
(5) provide technology brokerage and licensing services.

A. Product Development and Modification Programs

1. *Extension Services*

The extension service programs point to the fact that the current interest in policies dealing with university/industry interactions is only the latest manifestation of a recurring theme in the United States. The Morrill Act of 1862 establishing land grant colleges was intended to develop and relate higher education to industrial economic performance. This act provided the mechanism for the establishment of agricultural extension and engineering extension at many state universities. The first engineering experiment station (EES) was established by the University of Illinois in 1903. The Illinois EES was to do for industry what the agricultural experiment stations did for farmers. There was a concerted drive to get federal support for university based engineering experiment stations that built to a peak in 1916 when it failed in Congress. By 1937, 38 engineering experiment stations had been established at land grant colleges using university and state funds.

Extension services are essentially used as a means of bringing technical assistance to small companies or helping industry develop in a rural area. They constitute a service rather than a mechanism to facilitate cooperative research. However, they do establish a network of industrial contacts and make the universities who participate more sensitive to industrial needs.

2. *Innovation Centers*

At innovation centers, emphasis is on the process by which innovation occurs and entrepreneurial activities are stimulated. Innovation centers are a means of helping entrepreneurs to develop their skills through prototypes to the point where they can start their own company. (See Chapter VII, p. 45.)

In 1973, the National Science Foundation undertook a five-year experiment designed to promote invention and entrepreneurship in American society. The Foundation established several innovation centers. The first three were at MIT, Carnegie Mellon University, and the University of Oregon. Table 27 lists examples of innovation centers in the United States.

The major goal of these centers is the initiation of an academic program to train and facilitate the work of young inventors and entrepreneurs. Enthusiasm for such centers seems to have waned in the last few years. However, the innovation centers have participated in the creation of over thirty new entrepreneurial ventures, a thousand new jobs, and have generated in excess of $6 million in tax revenues. (NSF, *Industrial Program Grantee Conference*, 1980.) Over 2,000 students have participated in the programs. Because of the long term nature of the innovation process, it is difficult for one to judge fully those centers in terms of any substantive contribution to innovation at this time. One innovation center reviewed in this study served primarily as an educational facility and catered to the needs of student's who wanted to develop an idea. At two other innovation centers, the focus was on the developed entrepreneur. It is clear that the most successful of these programs had an extremely active, energetic and knowledgeable director. Extension services and innovation centers are important ways the university can function in industrial development of its surrounding area.

B. University and/or Industry Associated Institutions and Activities Serving as Interface and/or Foundation for University/Industry Research Interactions

There are many institutions associated with a university that are not directly related to university/industry research interaction, but play a role in facilitating the integration of university research into the industrial innovation cycle. Likewise, many institutionalized activities such as technology brokerage and licensing affect the structure and functioning of this integration.

Table 27

Examples of Innovation Centers

American Center for the Quality of Work Life	Washington, DC
American Productivity Center, Inc.	Houston, Texas
Center for Entrepreneurial Development	Pittsburgh, PA
Center for Government and Public Affairs	Montgomery, AL
Center for Productive Public Management	New York, NY
Center for Productive Studies	Washington, DC
Center for the Quality of Working Life	Los Angeles, CA
Committee on Productivity (AIIE)	Norcross, GA
Experimental Center for the Advancement of Invention and Innovation	Eugene, OR
Georgia Productivity Center	Atlanta, GA
Harvard Project on Technology, Work, and Character	Washington, DC
Innovation Center	Cambridge, MA
Institute for Productivity	Hato Ray, Puerto Rico
Laboratory for Manufacturing and Productivity	Cambridge, MA
Management and Behavioral Science Center	Philadelphia, PA
MDC, Inc.	Chapel Hill, NC
Manufacturing Productivity Center	Chicago, IL
Maryland Center for Productivity and Quality of Working Life	College Park, MD
Massachusetts Quality of Working Life Center	Boston, MA
Oklahoma Productivity Institute	Stillwater, OK
PENNTAP	University Park, PA
Productivity Center, Chamber of Commerce of U.S.	Washington, DC
Productivity Center, Northwestern University	Evanston, IL
Productivity Council of the Southwest	Los Angeles, CA
Productivity Information Center (NTIS)	Washington, DC
Productivity Institute, Arizona State University	Tempe, AZ
Productivity Research and Extension Program	Raleigh, NC
Purdue Productivity Center	West Lafayette, IN
Quality of Work Life Center for Central Pennsylvania	Middletown, PA
Quality of Work Life Program, Wayne State University	Detroit, MI
Quality of Working Life Program, Ohio State University	Columbus, OH
Quality of Working Life Program, University of Illinois	Champaign, IL
RPI Center for Manufacturing and Technology Transfer	Troy, NY
South Florida Productivity Center	Miami, FL
Texas Center for Productivity and Quality of Work Life	Lubbock, TX
Utah State Center for Productivity and Quality of Working Life	Logan, UT
Work in America Institute, Inc.	Scarsdale, NY

1. *Technology Brokering and Licensing Activities*

Site visits during the course of this study yielded information on industrial and university viewpoints on patents issues. To further investigate the level of activity and interest in technology brokerage and licensing on campus, two surveys were conducted. The first dealt with university patent administration mechanisms and internal division of income derived from royalty bearing patents. Information from this survey is presented in Table 28.

The other survey sought information on total royalties received by certain universities in recent years and is discussed below (p. 105).

Increased interest in patent matters is apparent from the significant number (20) of those universities involved in the first survey (38) undergoing patent policy revision. Only six universities had current patent policies that were more than five years old. Most of these revisions are not only in response to the patent legislation (Uniform Patent Act) which went into effect July 1, 1981, but also reflect an effort at many universities to encourage invention by increasing the rewards to the inventor, and to modify their administrative procedures in handling patents. As federal funds for research have declined, initiatives have increased within the university system to generate their own research money, and many universities have pressed forward in capitalizing on their opportunities for patents.

a. *Patent rights.*

In general, inventions, innovations, discoveries and improvements made with the use of university facilities or services, or during the course of regularly assigned duties, are the property of the university, and can be used and controlled as to secure an equitable benefit to the public, the inventor and the university.

A notable exception to the obligatory assignment of rights by the employee to the university is the procedure followed by the University of Wisconsin. Their patent policy states that the university "does not claim any interest in employee inventions." Upon request, the Wisconsin Alumni Research Foundation (WARF), a separate not-for-profit corporation serving the university, will review any invention disclosures of any university employee or student to determine if it will accept assignment of the invention. If assignment is accepted the inventor will receive annually 15% of any net royalties deriving from licensing arrangements.

Universities, in general, claim no rights to those patents which are owned by third parties pursuant to sponsored research agreements, or those resulting from independent work or permissible consulting activities without the use of university facilities.

Government sponsored research terms of the Uniform Patent Act are as follows: A university or a small business has the right to elect to retain title to inventions made in the course of government sponsored research. Exceptions are made in three instances:

(1) operation of government-owned research or production facility;

(2) exceptional circumstances determined by the agency (stringent documentation is required from the agency and is submitted to the Controller General to curb abuse by the agency);

(3) when necessary to protect the security of the government intelligence or counter-intelligence activities.

If the university abandons the patent prosecution, all rights revert to the inventor. However, some

Table 28

Patent Administration and Royalty Income Distribution of Selected U.S. Universities

Year of Policy	Institution	Royalty Division	Deduction by Institution	Patent Management	Patent Matters Handled By	Univ. Income Goes Towards	Comments
1977	U. Arizona	Of net income: Inventor: 50% of 1st $10,000; 25% over $10,000		PMO	Individual responsible for discoveries and inventions	Fund for Promotion of Research - establ. in each unit.	
1980	U. California System	Of net income: Inventor: 50% UC System: 50%	15% for O/H plus deduc. for cost of patenting & protection of patent rights	Internal	System Board of Patents	1st consideration given to promotion of research	
1977	U. Chicago			PMO UPI	Office of VP for Bus. & Finance	Divisional research activities	When rights relinquished to inventor, "normal process of academic publication will be utilized for benefit of scholarly & gen. public"

Table 28—Continued

Patent Administration and Royalty Income Distribution of Selected U.S. Universities

Year	Institution	Royalty Division	Deduction by Institution	Patent Management	Patent Matters Handled By	Univ. Income Goes Towards	Comments
	U. Colorado	Of 60% of net which UPI allows: Inventor: 25% " lab 25% " dept. or admin. unit 25% University Patent Royalty Fund 25%		PMO Primarily UPI	Office of Patent Adm. sifts disclosures; Univ. Patent Comm. (10); Chairman-Dean of Studies, Reps from 4 campuses; Ex-officio member (incl. Patent Adm.)	See royalty div.; Patent Royalty Fund goes to res. & education	
Under Rev.	Cornell	Of net income: Inventor: 15% CRF: 85%	Direct expenses expenses CRF-$350 fee	Internal. PMO	Cornell Research Foundation	Research: Preference to orig. unit	
1979	U. Delaware	Inventors options: 1. Inventor 1/3 Approp. adm. unit 1/3 Res. Off. 1/3 2. Inventor-1st $5,000, then inventor 20% Adm. unit40% University40% This division holds until net income is $30k when terms in Option 1 take over	Direct expenses + 15% of direct expenses to cover overhead	Internal PMO	University Coordinator for Research		If univ. relinquishes rights & inventor develops it, any income must be shared with univ. (after inventor's expenses are deducted), on the basis that inventors's share be not less than royalty split under univ. funded inventions.
1979	Duke	Net: *1st $10k* Inventor 35% " lab 65% *$10-50k* Inventor 35% " lab 45% Univ. 20% *Above $200k* Inventor 15% " lab 15% Univ. 70%	Direct expenses	Internal PMO rarely used	Office of Patent Administration (estab. 1979)	General Fund	
1978	Georgia Tech	Inventor: 1st $1,000 + 50% of net income	Direct expenses	Internal: Office of Contract Adm/ Georgia Tech. Res. Institute	Institutional Patent Committee (incl. member from GTRI)		$250 to inventor for services rendered in providing technical documentation in filing
Under Rev. 1975	Harvard	Of net income: *1st $50k* Inventor 35% University 65% *2nd $50k* Inventor 25% University 75% *Over $100k* Inventor 15% University 85%	Direct expenses of processing patent	Internal	Committee on Patents and Copyrights	Faculty & academic dept. of inventor for research by inventor. Next $67,500-½ as above: ½ general use by inventor's dept. Remaining: divided between faculty & central university	
Under Rev. 1969	Johns Hopkins	Current: (net) Inventor 25% Proposed Inventor 30%	Direct expenses	Internal	Patent Administration		

Table 28—Continued

Patent Administration and Royalty Income Distribution of Selected U.S. Universities

Year	Institution	Royalty Division	Deduction by Institution	Patent Management	Patent Matters Handled By	Univ. Income Goes Towards	Comments
	U. Houston	Of net income: Inventor 50%					
Under Rev.	U. Illinois	Of net income: *1st $50k* Inventor 50% *2nd $50k* Inventor 35% *Over $100k* Inventor 20%		PMO			
	Lehigh	Of net income: Inventor 50% University 50%	Direct expenses	Internal			
Under Rev.	U. Maryland	Inventor 15%	Any litigation costs negotiated with Res. Corp.	PMO		Inventor's dept. for research	
Under Rev.	MIT	Of gross income: *1st $50,000* Inventor 35% *2nd $50,000* Inventor 25% *Over $100,000* Inventor 15%	No deduction	Internal	Office of Patents & Copyrights		
	U. Michigan	Of net income: Inventor 20% Orig. Unit 40% VP for Res. Eqpt. Fund 40%	Direct expenses	Internal PMO			
1971	Michigan State U.	Inventor: 1st $1,000 gross; 15% total royalties thereafter		PMO			
Current	U. North Carolina	Inventor: not less than 15% gross. Exact proportion specified in agreements with PMOs.		PMO	Faculty Patent Committee	Trust fund for research on each campus. Inventor's school or dept. will have preferential treatment.	
1976	North Carolina State	Inventor: 15%		PMO			
1979	Penn State University	Of gross income: *1st $3,000* Inventor 50% *Next $10,000* Inventor 25% *Over $13,000* Inventor 15%		PMO	Univ. Patent Counsel (in office of VP for Research & Grad Studies). He is also Pat. Counsel for Penn. Res. Corp.	Royalty income minus inventor's share equally divided between Res. Corp. & Penn. Res. Corp.	Penn. Res. Corp. is a non-profit organization which acts as transmittal agent to Res. Corp.
1977	Princeton	Of net income: *1st $50,000* Inventor 50% *Next $50,000* Inventor 40% *Over $100,000* Inventor 30%	Direct costs	Internal PMO	University Research Board	100% to research fund. Inventor's field of activity given preferential treatment	
1973	Purdue	Of net income: Inventor 1/3 University 2/3	Direct plus indirect costs	Internal	Committee on Patents & Copyrights, Purdue Research Found.		

Table 28—Continued

Patent Administration and Royalty Income Distribution of Selected U.S. Universities

Year	Institution	Royalty Division	Deduction by Institution	Patent Management	Patent Matters Handled By	Univ. Income Goes Towards	Comments
Under Rev.	Rensselaer Polytechnic Institute	Of gross income: Inventor 15%		Internal PMO	Patent Review Committee	General Fund	
Current	Rice University	Inventor share negotiated case by case		PMO	Office of Advanced Studies & Research		Not active re: patents
1980	University of Rochester	Of net income: Inventor 50% University 50%	Direct expenses	Internal PMO	NONED Corp. (wholly owned sub. of Roch. for patent mgmt.)	2/3: Inventor's Dept. 1/3: Inventor's college for educ. or res.	
1978	S.U.N.Y.	Of gross income: Inventor 40%		Internal	Technology Transfer Office	SUNY Research Programs	
1980	Stanford University	Of net income: Inventor 1/3 Dept. 1/3 University Royalty Income Fund 1/3	15% of gross + direct expenses	Internal	Office of Tech. Licensing		
Current	Texas A&M	Of net income: Inventor 50% Unit responsible for inven. 50%	15% for administrative costs + legal fees for patent processing		Office of Patent Administration		
1981	U. of Texas	Of net income: *0-$5,000* Inventor 75% System 25%	Costs of patenting & licensing	Internal PMO	Patent Office	1st to defray expenses of Patent Office, then for research by unit where invention was made	
Late 60's Current	U. Utah	Of net income: Inventor 40% of first $20,000; 35% of next $20,000; 30% thereafter	Direct	Internal Utah Res. Foundation	U.R.F. purchases services of director of University Patent Office to manage patents	Support of research & education (1st priority-operation of Patent Office	University Patent Office may award up to $1,000 to inventors for their aid in developing info. to help patent prosecution.
1972	Washington University	Of net income: Inventor 50% (max.) Univ. Balance	No more than 50%	Internal	Vice Chancellor for Research & Patent Coord. Patent Advisory Committee	Educational & Research programs	Rights rest with inventor, subject to "shop rights" if done with university funds &/or facilities.
Current as of 1981 (1969)	University of Washington	Of net income: *1st $5,000* Inventor 100% *Next $15,000* Inventor 50% *Over $20,000* Inventor 30%	15% service	Internal PMO	Patent Office	Account for Research	
1975	U. Wisconsin	Of net income: Inventor 15% Wisc. Alumni Res. Found. 85%		Internal	Vice President & Chancellor, Wisc. Alumni Research Found.	WARF returns 15% of income from inventions and investments for research	
Under Rev.	Yale U.	Split what PMO allows 50/50 with inventor		Internal PMO	Patent Review Committee		

institutions put up barriers, such as requiring a share of the royalties or publication of findings. Many, however, put no conditions on the release.

b. *Patent administration.*

In informal discussions with university patent and research administrators, it was found that many of the patent policies were under study or revision. Questions such as the following were being addressed by school officials.

(1) Is the patent policy up to date, or should it be revised?

(2) Is the division of royalties between the university and inventor equitable, and sufficiently encouraging to the inventor?

(3) Who should retain the rights to the patent? Should the university relinquish the rights to the invention and under what circumstances?

(4) At what stage and from what funds should the patent office overhead and other expenses be taken?

(5) Under what office of the university should the patent administration lie, and what administrative officials in particular should have final say on a decision involving patents?

(6) Does the university have an adequate internal capability to manage patent development? If not, should it be improved or should the university use the services of an external patent management organization?

In general, patent royalties to universities from inventions of their faculty members are an increasing potential source of income. To date there has been some lack of consistency of handling this source of revenue and disposition of the revenue itself. Furthermore, with increased fees for domestic patents as well as the high costs of obtaining foreign patents, the issues and expenses must be considered with care. In most universities examined, such detailed debate among administration and faculty is being pursued.

Many universities have agreements with external patent management organizations (PMOs). These were generally viewed with dissatisfaction by many university administrators and scientists. It was often stated that these organizations are not sufficiently aggressive is seeking out patent and licensing opportunities. Several administrators also stated that they did not believe these organizations were receptive to their needs. These views can be interpreted as expressions of the belief that opportunities have been missed. We note that we did not conduct a separate survey of patent management organizations and their interactions with university scientists.

Increasing numbers of universities are developing their own internal capabilities for patent management. In our aforementioned survey of 38 universities, 17 use internal means exclusively for managing patents, and 7 use both internal means and PMOs (Table 28). Although having internal management capability is a very expensive proposition, it does allow the university to own patents which would formerly have been assigned to a PMO. It is hoped that internal management will provide an opportunity to get a return on investment sufficient to have a significant impact on university research programs.

c. *Division of royalty income.*

In general, there are two situations in which an inventor who is a university employee can earn royalties. The first case is that in which an invention arises from externally funded research, where the overhead is adequate to cover university expenses. Royalty income divisions are negotiated as part of each contract or grant, and the sponsor's terms are controlling in the matter of limitations on the inventor's share. Some universities reported that they make every effort to have the sponsor follow that division of royalties specified in that university's patent policy. Some contracts with companies were found to allow for no payment to the inventor. Under the Uniform Patent Act, a patentable idea arising from government funding, partial or total, must include a percentage for the inventor. The terms for division varies with government agencies.

The second case is that in which the invention arises from research supported by university funds on university time, or using university facilities, and when the patent has been executed internally. Here, the division specified in each university's patent policy is controlling. Although there is wide variation among universities in relation to royalty income schedule, our survey showed that 15 (7 private and 8 public) out of 38 universities surveyed offer (in varying increments) at least 50% of net royalties to the inventors.

Data on the division of royalties by individual universities is also given in Table 28.

d. *Patent income management.*

State and private universities have established independent research foundations for the purpose, in part, of facilitating the patenting and licensing of university developed products and processes (*e.g.*, the Wisconsin Alumni Research Foundation of the University of Wisconsin, the Cornell Research Foundation, Inc., and the California Institute Research Foundation of the California Institute of Technology).

The Wisconsin Alumni Research Foundation is the most well known example of this type of arrangement. It manages income generated from inventions and investments on behalf of the University of Wisconsin, and returns 15% of the total income annually to the University of Wisconsin for support and administration of research. (Note that the generation of funds from inventions comes from a few very highly successful patents.) These funds are primarily used to aid young investigators, support teaching assistants, and provide seed money for new research projects and programs.

e. *Levels of total income received from patents.*

In order to collect data on the level of total patent income received by universities during FY-1979 and FY-1980, a list of schools thought to receive the largest amounts of royalty income was developed. No prior tabulation of such data exists, and therefore, personal judgments were used as a first guide to this neglected area. Candidates were suggested by patent and research administrators, as well as by officials at the National Association of College and University Business Officers and the Society of Patent Administrators.

Information concerning the annual amount of income from royalty bearing inventions was requested from 36 universities, both public and private. Responses to date number 25, a 69% response rate. These initial results for 1980 and 1981 are shown in Table 29.

Of the 25 respondents, 3 had not yet tallied their 1981 amounts. Two of these may account for the decrease in the lowest class from 10 in 1980 to 7 in 1981, as their income was well down toward the lower end of the range, and is not expected to distort the aggregate sums.

Indicative of a trend is the aggregate amount in each year: $7,316,915 in FY-1980, and $9,178,276 in FY-1981, which represents a 25% increase even without completed tallies.

f. *Attitudes towards prepublication review and patent ownership.*

Most companies view the interest of universities in patents and licensing as healthy. They would rather negotiate these matters than leave them undecided. Many regard faculty awareness of the importance of patenting before publishing a prerequisite to a joint collaborative research effort. All the aspects of this issue, however, are not resolved. Every university visited was concerned with the issue of prepublication review rights of the industrial sponsor. Companies believe that they should have the right to review publications coming out of their sponsored research for inadvertent disclosures of company proprietary information and for potentially patentable ideas. Most scientists do not object to this review for patent potential. The debate centers around the appropriate length of time for such a review.

Generally, a company feels comfortable with the university owning a patent, particularly if the university is willing to provide an exclusive license for a certain time period. Many (7 out of 8) of the new university/industry partnership agreements in biotechnology grant exclusive licenses to the sponsoring company (see Chapter VII, pp. 43-44). However, companies do not always require an exclusive license as a condition for significant commitment to research cooperation with a university (*e.g.*, Exxon-MIT, see p. 43). The company participants in most of the cooperative research centers reviewed (90%) did not require exclusive licenses in return for their participation. A large number of these centers may be characterized as focusing on research related to process technology (*e.g.*, combustion processes, polymer processing). In these areas of research the exclusive license may not be as important as in areas of research where the outcome may be a new drug or agricultural product. While university policies and the mechanism of university/industry interaction will affect negotiations concerning patents and licensing, a company's willingness to accept the university stance may be related to the technology base and structure of the industry to which the company belongs. (See Chapter VIII.)

A few company representatives regarded this new interest in patents and licensing as a threat to their own interests. One company reprepentative stated he would not want his company to enter into a cooperative research activity with a university that was actively pursuing patents. He regarded such universities as among his competitors.

Table 29

Frequency Table
Total Patent Royalties Received by Sample of Universities—1980 and 1981[1]

Gross Income	Frequency 1980	Frequency 1981
0—$ 99,999	10	7
$100,000—$199,999	3	4
$200,000—$299,999	3	2
$300,000—$399,999	3	0
$400,000—$499,999	0	1
Over $500,000	6	8
TOTALS	25	22[2]

[1] One major university reports an aggregate total of income from inventions and investments. The part of this attributable to inventions has not been separated, and therefore cannot be reflected in this table.
[2] The 1981 tallies of 3 universities were not yet available.

2. *University Connected Research Institutes*

The body of organizations under discussion may best be described as separately incorporated units that serve as legal entities for administering sponsored research and related programs for their parent universities (Table 30). Although the articles of incorporation confer independent status on them, they are in fact interdependent with, and under varying degrees of control by, their host universities.

Ambiguity of name and purpose makes university connected research organizations difficult to identify. Variously called institute, foundation or corporation, each candidate must be examined carefully to see if it fits the operational definition one has in mind. (In this discussion, institute will serve as the generic term.) Each university prescribes for its institute a special mix of activities which typically changes as it evolves.

The university-connected research institute is most commonly associated with publicly supported schools (Daniels, *et al.*, 1977). These universities must operate under the restrictions placed upon them by their charters and further constraints imposed by their state legislatures. This situation does not provide a flexibility of operations attractive to industry sponsorship of research. Yet, a strong program of sponsored research is critical to carrying out the aim of educational and scientific excellence at the graduate level. Thus, major research universities must often devise means for flexible operations.

The mechanism of the university-connected research institute has been used by a number of public universities for the administration and/or the development of industry sponsored research programs and the concept is under active consideration by other universities, spurred in part by the current government encouragement of university/industry research interaction. A general statement of the purposes served by separation between a public university and a not-for-profit corporation in its service is that the state is responsible for the basic support of the university, while the institute's funds directly or indirectly help the tax dollar accomplish more by allowing for the provision of services which public monies cannot fund or are insufficient to fund.

The institute provides a way of minimizing many of the constraints imposed by state government control mechanisms, and thereby allows the university to respond to sponsor requirements for efficient performance of research. For example, within the university, the research process can be impacted adversely by requirements for competitive bidding for research equipment, by policies relating to the hiring of research personnel, by limitations on travel funds, faculty consulting time and faculty salaries, and by possible discontinuity of funding.

There are also controls within the university on the content of research projects and development of research results. For example, the institute may take on programs outside the areas of standard academic programs, such as those involving security clearance, and enterprises of a commercial nature. Currently, the institute is being recognized as a means of facilitating patent commercialization through licensing.

Besides minimizing state government impediments to research, there is another role that the institute can perform. As the size and volume of research projects increase, specialized attention over and above the university's regular academic and administrative procedures is required. The institute can develop the capacity to handle large, sometimes long-term programs. It can also organize multi-disciplinary research teams when necessary, and can control which projects graduate students work on.

Beyond these functional reasons for an institute is the potential psychological benefit. The traditional issues which divide university from industry can better be negotiated one step removed from their traditional bases and, perhaps most important, removed also from the public arena in which a public university functions. One public university in this survey is reviewing the possibilities of funneling most or all of its industrial contracts through a university associated research institute. This university hopes that this will facilitate the administration of large industrially funded projects.

A university-connected research institute can function somewhat like a private contract research institute with these added benefits:

(1) The institute is backed by an educational program and a fundamental research program reflecting awareness of scientific frontiers.

Table 30

Examples of University-Connected Research Foundations

	Established
• Purdue Research Foundation	1930
• Ohio State University Research Foundation	1936
• Indiana University Foundation	1936
• Texas A&M Research Foundation	1944
• University of Kentucky Research Foundation	1945
• Research Foundation of the State University of New York	1951
• Research Foundation of the City University of New York	1963

(2) It has university faculty available as consultants on its projects, and it can also contract with the university to perform basic research of particular interest.

(3) The institute can draw on the pool of graduate students enrolled at the university, and often the cost of doing research in this environment is less than at a private contract research institute.

(4) An intangible, but important factor in commanding sponsor interest, is the reputation and credibility that a great U.S. research university has worldwide.

In summary, it appears that universities with a separate research and development institute can be particularly attractive to outside sponsors and may develop into being an important buffer mechanism in university/industry research interactions.

In 1980, the National Commission on Research published a report on industry and the university, *Developing Cooperative Research Mechanisms in the National Interest*. A key recommendation states:

> "The commission recommends that universities examine their administrative structures and policies relevant to cooperative research arrangements with industry. Such research arrangements should facilitate cooperation while protecting the academic research environment. Universities should also examine their patent policies and be sure that they have the staff capable of identifying and pursuing patent opportunities."

This can be interpreted as support for the concept of the university-connected research institute which acts as a buffer in university/industry research interactions.

3. *Industrial Parks*

The industrial park model has been developed at several major campuses to improve relationships between research-intensive companies and sponsoring universities who rent space for corporate activities. According to one prior study which described the highly successful Stanford University Industrial Park:

> "The results in terms of encouraging faculty consulting and entrepreneurship, industrial staff enrollments in university courses, and the use of industrial scientists as university lecturers are generally considered to be significant stimuli to technology transfer." (Baer, 1977).

Interviews at companies in the Stanford University Industrial Park, and with Stanford University professors, substantiated the results of that study. However, most industrial parks are generally not significant stimuli to technology transfer.

Appendix III presents several examples of university associated industrial research parks.

Of the 39 universities visited in our field survey, 14 universities had owned or associated themselves with industrial parks. Of these parks, only 4 can be characterized as successful in terms of stimulating technology transfer. However, even in these cases, the presence of the park, in and of itself, did not necessarily strengthen university/industry research programs. The presence of the park in successful cases did facilitate technology transfer through providing space for companies arising out of university research programs. In at least three of the more successful parks, the presence of the park in close proximity to the university may have helped provide a climate for the general acceptance of university/industry research programs. Those universities associated with parks tended to have stronger programs of university/industry cooperative research. For further discussion of industrial parks, see Chapter X, pp. 109-110.

4. *Spin-off Companies and University/Industry Research*

Companies that spin off from university research programs tend to have an initial formal research association with the university which includes sharing of facilities and hiring of graduate students. As the companies become more directed towards producing a product, they become more isolated from university programs, and at this point have little money to fund them. Only in the cases where these companies are highly successful do they return their attention to the university and contribute substantial funds to university research. In order to ensure that the university derives an optimum return in these instances, many are considering the possibility of the university taking equity in the spin-off company in lieu of royalties. (See Chapter X, pp. 110-112). Universities are trying to calculate which would bring in more to their research programs, an original 5% royalty from university patents licensed to a spin-off company, equity in the company, or reliance on the company's philanthropy and gifts.

Excluding engineering consulting firms, most university administrators could only recall one to three spin-off companies coming from university research programs. However, three universities said that they could point to over 100 spin-off companies, and another three could point to 25 to 30 such companies. Appendix III presents a few examples of spin-off companies reviewed in our field study.

There is certainly an untapped potential in providing mechanisms which would facilitate the collaboration between the research programs of these new companies and university research programs. Several universities are currently looking into a variety of possibilities, including programs of technical assistance, providing "incubator space" for the new companies, and mechanisms by which a university can integrate its research into programs of economic development.

CHAPTER X

THE SIGNIFICANCE OF CURRENT ACTIVITIES AND EFFORTS TO COORDINATE UNIVERSITY AND INDUSTRY RESEARCH

This chapter summarizes several recurring themes and debates regarding university/industry coupling. The material presented is based on our observations and interpretations after our wide range of interviews and a review of the current literature.

A. *Opportunities for Growth*

Current discussions of university/industry research interactions might imply that this idea was discovered *de novo* in 1978. Our studies document that there is a history of continuing and fruitful interactions. The present emphasis, however, is somewhat different, for reasons indicated in Chapters IV and V.

The enthusiasm with which this subject was treated by all who were interviewed, however, indicates that focused interest in university/industry coupling is long overdue. One university president stated his belief that industry support of university research is an unexplored margin for the university in general. Many agree. But recently there has been a rising chorus of caution from both university and industry representatives stating that although interest in this subject is long overdue, it can be vastly overestimated in importance. It is necessary to maintain a sense of perspective about university/industry research interactions. Edward E. David, Jr., President of Exxon Research and Engineering Company, a strong supporter of university and industry scientists interacting together in research, has in many recent speeches said that it is impossible to expect industry to fill any large funding drop by the federal government (David, 1981).

Companies do intend to draw more direct ties to universities, but resources are limited, and they already support the university research endeavor through taxes. It is important to remember that industry has to pursue a direction which strengthens its own long term interests, and the university must pursue a direction based on its function in society. These directions can intersect but to a limited extent. Only the government has the resources and network capabilities to monitor the complex U.S. research system and ensure that we have a broad technical base. Industry's approach to research is strategic. For example, there are relatively few technical fields, e.g., computer science, electrical engineering, polymer science, molecular biology, genetics, chemical engineering, receiving major industrial support at universities. Industry's technical effort is targeted, similar to the approach of government mission-oriented agencies. However, the government must support research in the national interest and maintain a technical base that will provide for national security. Thus, the government has a mandate to support broadly based research. While there is room for growth in university/industry coupling generally, and particularly in fundamental areas, broad based research support will undoubtedly continue to flow primarily from federal sources.

There are conditions today that may indicate some degree of change (see Chapter IV and V). One new factor is that the number of science-based, technologically-oriented industries has grown. This provides greater opportunity for university/industry cooperation. As the older, more mature industries see this occur, two options can arise:

(1) Actions can be taken to adapt the new technology to the existing business.

(2) Business plans can be based on the potential of high technology for stimulating new business directions and the role of university/industry interactions in stimulating and producing technical change.

While most agree that increased university/industry coupling will be beneficial, there is active discussion of the effects of this on both institutions. Some of these considerations and concerns are discussed in this chapter. (See Section D.)

Despite concerns, many groups (public and private), in recognition of the economic potential of science based industries, are actively seeking to forge new bridges and linkages between academia and the private sector. Many of these activities are regional.

B. Regional Variations and Activities in Cooperative University/Industry Ventures

Regional and state activities continue to feature research programs related to their economies and natural resources. Thus at state universities in the northwest (Washington, Oregon) and middle Atlantic (North Carolina) there are excellent forestry products institutes. There are significant textile programs in Georgia and North Carolina. Petroleum engineering is well supported at the University of Texas, Austin. The Great Plains states (*e.g.*, Wisconsin, Minnesota) have well supported state programs in food and agriculture and so on.

Currently, an increase can be noted in the tempo of state and regionally supported development activities involving academic and industrial cooperation. States significantly involved in such activities include Arizona, California, Colorado, Georgia, New Jersey, New York, Michigan. They are seeking to take advantage of recent advances in the fields of microelectronics, genetic engineering and robotics. These activities are also, to a great extent, in response to concern about lagging U.S. innovation and productivity, as these apply to local industrial activity. States in economically depressed regions, regions where the predominant industrial base is mature (*e.g.*, the steel, heavy machinery, and automotive industries) are particularly interested in the creation of new jobs through fostering the development of new high technology start-up companies. In most of these activities, university administrators and researchers, as well as private sector representatives, are playing active roles.

> North Carolina has provided exceptionally dynamic leadership over the last decade in fostering economic development through university/industry coupling. The Science and Technology Board, under the direction of Governor Hunt, has been responsible for mapping the state's strategy in these matters, developing the Research Triangle Park, and lately the development of a microelectronics and biotechnology center. The State appropriated over $27 million in 1981 to the microelectronics activities.

Several other states have also established special groups to foster regional university/industry cooperation and economic development.

> One such institution is the Pennsylvania Science and Engineering Foundation (PSEF) founded in 1968 with appropriations of $8.2 million to use as seed funds in nurturing Pennsylvania's economic position through technological innovation. The PSEF is located at Penn State University. During its existence, it has attracted $68.3 million from industry, local governments, and the federal government in support of applied science and engineering projects (PSEF, undated). PSEF has been responsible for, among other things, the development of a new capacitor material.
>
> Recently, New York State established a new charter for the state's Science and Technology Foundation, giving that organization a key role as promoter of technologically oriented activity. As part of this initiative, the state and foundation have recently been active in exploring new forms of university/industry cooperation.
>
> New Jersey is taking substantial initiatives in this area. They are proposing a program of $8.7 million to foster university/industry cooperation in technological innovation.
>
> In Wisconsin, Michigan and Minnesota, special organizations (Appendix III) have been established to foster regional economic development through high technology development and university/industry cooperation.
>
> In Pittsburgh, Pennsylvania, U.S. Steel, Carnegie Mellon and the University of Pittsburgh formed a committee, the *Ad-hoc Committee on Cooperative Research*, with objective of establishing cooperative research projects between the participating universities and local industry. The idea for a regional approach came from the president at Carnegie Mellon. The universities are represented by the deans of the respective schools of engineering.
>
> The deans put together an inventory of research capabilities and current projects. From this, prospective industrial sponsors can determine possible areas for research cooperation. To date the companies participating in the program include U.S. Steel, Westinghouse, Alcoa, Gulf and PPG, with current projects in combustion and coal utilization research. The interactions have developed as individual contract research programs despite the initial goal of developing an umbrella grant. Although the initial goal has not been realized, the committee still holds this to be a possibility for the future.
>
> In Michigan the technology-based industry committee, in cooperation with the University of Michigan, sponsored the Michigan Technology Fair in April 1981. One of the fair's objectives was to create a climate that encourages the pursuit of high technology. The event showcased advanced industrial technology and state-of-the-art scientific research being carried out in Michigan.

Many of the above mentioned activities have the long term goal of starting or expanding university research parks.

For example, in Madison, Wisconsin for Research (WFR) Inc., a private, not-for-profit joint venture was created for the purpose of assuring a permanent basis for cooperation between academic and economic interests for the long range benefit of the state, university and WFR members. Charter members (including 16 companies) contributed $2,000 each. The organizational approach is to establish a formal channel or clearing house for information and ideas that will lead to more activity and more contracts between the university and private industry. It is their hope that the long range net effect of this activity will be the establishment of a research park designed to draw high technology companies to Wisconsin.

Many other universities (Yale, RPI, Princeton, University of Texas, Austin) are currently interested in expanding existing parks or developing new parks (see Chapter IX, p. 107).

Universities have many reasons for wishing to participate in the development of these parks. They include:

(1) An investment that will generate new funds for the university.

(2) Providing incubator space for spin-off companies emerging from university research.

(3) A mechanism for preventing "brain drain" and underemployment by providing jobs which will require skills appropriate to a university graduate.

(4) A mechanism by which the university can maintain the "campus environment" in the surrounding area.

(5) A mechanism for fostering joint university/industry cooperative research programs.

University participation in the development of these parks continues to rise as universities become increasingly interested in capitalizing on their research.

C. The Role of University Research in New Business Development

There were numerous reports in 1980-81 of new ventures emerging from research conducted in university laboratories, or of new high technology enterprises enlisting outstanding university professors for their staff or their board, or of large corporations giving a major grant to a university for the conduct of a broad research program. These developments have been compared to the development of Route 128 around Boston with ties to the MIT-Harvard complex; the growth of electronics in Silicon Valley that began with some distinguished graduates of Stanford University; and the seemingly unlimited flood of venture capital into high-technology companies in the 1960's.

There are many points in common between today's new business developments and those of the past 25 years, but there are also important differences. The differences are fundamental to the relations between universities and industry that will evolve in the years ahead.

They are as follows:

(1) The technical base for new business has shifted in emphasis. Many of the earlier developments were in semiconductors. Today's emphasis is on biotechnology and data processing. Obviously, new businesses are emerging from a range of technologies, but the technical pattern today is different from yesterday.

(2) The geographical pattern is more diffuse. There is widespread sensitivity to the commercial potential of new technology and an availability of venture capital for exploitation. When the Route 128 phenomenon was reviewed in the Charpie Report of 20 years ago, it noted the receptiveness of the financial community in such key centers as Boston and San Francisco, as compared to other cities. These differences seem to have lessened considerably.

(3) There is far greater maturity in industry today regarding the processes of industrial research, *i.e.*, for the integration of R&D into the business planning and operations of the corporation. The possibility of developing major new business interests from technical advances within the corporation or via a small start-up company outside the corporation is now considered a standard business mechanism, not an unrelated speculation.

(4) The technologically-based new business developments of 15 to 25 years ago were often geared to markets deriving from the needs of military and space programs. Or at least, the technical developments were related to those programs. Thus, some R&D support and, perhaps, some procurement might have come from federal sources during the initial phase of a new venture. Today, this is not as frequently the case, and the new developments must survive under traditional private-sector ground rules almost from the start, in contrast to the public-sector involvement of the past.

(5) Prior to 1970, the university research system was in a high-growth period, relatively well-financed from the increasing federal budgets for R&D, and fairly stable with regard to overall student enrollment and cost structure. This has changed drastically in the past 10 years. While federal R&D support has not declined in absolute amounts, the cost structure of universities has deteriorated generally and thus weakened their ability to offer growth opportunities for research scientists based on the traditional income from, and needs of, the student body. In brief, the university system requires additional and stable sources of income.

Thus, there is a new set of ingredients for university-industry relations in new business development. There is a consciousness on the part of corporations as to the potential for integrating university research advances into current business planning, there is an availability of funds from many sources, and the financing activities are geared to the private sector economy. Further, the universities are relatively more sophisticated, demonstrably more aggressive, and looking for new sources of funding.

The traditional mechanism by which universities have received income from the commercialization of their research output is through patent licensing. There is great variation among universities as to their practices regarding the ownership of these patents or the assignment of rights to the research professor (Table 28).

As long as the numbers of patentable ideas were limited, the royalty income often insufficient to cover patent costs, and the university financial affairs in reasonable balance, there was insufficient reason for universities to reorganize their patent management procedures. Scattered examples of significant returns existed, such as the royalties received by Rutgers from the Waksman patents on streptomycin. But even this was a gift from Waksman, since the policy of Rutgers was to allow patent ownership to stay with the faculty.

There was a chicken-and-egg quality about the system at the time. The income was too modest to justify the investment in the sales and market development that might serve to increase the income. This stimulated the activities of third-party brokers, such as the Research Corporation and, more recently, University Patents. These groups could provide commercial expertise and cover the patent costs.

During the 1970's, universities began to turn their attention more sharply to the potential of income from patent licensing. Their financial situation became worse, and the increasing activity of patent brokers may have aroused the interest of universities in the opportunities for greater income. Thus, more universities began to assign active patent development responsibility to their own employees. What might start as a part-time assignment often became a full-time position for one or more people in the larger research universities.

The growth of these activities led to a more intense interaction between university and industry on the subject of commercial exploitation of university research. An important feature was the increasing presence of individuals at universities concerned with obtaining income from research, and who served as a buffer between the traditional faculty values and those of the industrial world.

The increased attention to patents and licensing activity, and the increasing importance of royalty income, led to university considerations to share in the resulting business. Furthermore, the publicity that accompanied commercial ventures in biotechnology by companies such as Cetus and Genentech, with the dramatic evidence that sizable investments were available from private parties, the stock market, and major corporations, guaranteed the attention of universities. The commercial potential of recent advances in biology are considered to be so substantial that corporate structures and financing have been established while much of the science and technology is still in the development stage. This necessitates close relations between the new companies and the researchers responsible for the advances, who are often members of university faculty. These same faculty members are also establishing more formal relations with the new companies as consultants, as officers, or as directors. And in many cases, the individuals have left the universities to work for the new ventures.

This ferment of activity involving university research and faculty, plus the presence of investment and the potential of future income, has caused the university to consider new mechanisms by which the university system itself can become involved directly in the growth of new business ventures.

University ownership of business is not new. Any major university fund or endowment may have stocks in its portfolio. This, of course, is simple investment without involvement. At one period, New York University owned the Mueller Spaghetti and Macaroni Company, a rather extreme form of investment, and unrelated to university functions except as a source of income.

Presently, we are in a period of exploration with regard to the role of universities in new business development. There is a very considerable effort going into the expansion of traditional mechanisms for university/industry research cooperation, and the growth of new institutional devices that might lead to even more satisfactory relations for the generation and transfer of research. There is additionally a new look by universities at the possibility of deriving continuing and substantial income from the ultimate commercial values related to these arrangements.

One approach is the use of third-party mechanisms. This is analogous to the patent broker for licensing, but now the university would have a participation in this third-party structure. The functions performed by the new organizational structure are:

(1) To create a neutral buffer between the continuing faculty activities necessary for the operations of a university and the business dealings with the private sector for commercial development of research,

(2) To provide professional expertise required for these activities,

(3) To provide continuing income for the university, and

(4) To offer an effective structure with which industry can communicate and negotiate.

This third-party structure can take many forms. A recent announcement from California (*Time Magazine*, September 28, 1981, p. 63), describes the establishment of a non-profit Center for Biotechnology Research, with participation by faculty of Stanford and the University of California. Commercial development arising from this research will be pursued by a new company called Engenics. Funding of the Center will be from private corporations, and the Center itself will own 30% of Engenics. The companies will own the remainder.

One can easily conceive of similar structures being established by a group of universities, by a single major university in conjunction with an investment bank, and any number of public-private combinations. Several universities indicated they were considering a number of such possibilities, especially those which would cause minimum disruption to the educational and research structure of the United States. This situation should stabilize during the 1980's, and the result may be more effective conversion mechanisms from research to commercialization to the advantage of both university and industry.

Another approach is the investment in or the establishment of university based research parks as discussed in the previous section. A few universities are establishing or assisting in the development of programs to provide entrepreneurs (including entrepreneurial faculty) with technical assistance and with help in business planning.

It is unclear at this moment exactly what are the optimum mechanisms for university participation as an equity owner in new business development, and if this could be a major new phase of university growth. Other effective approaches may be more suited to the university structure and its role in society.

D. Emerging Concerns

Table 31 lists 15 issues that were brought up at various times during our interviews. Although most were not mentioned more than 25% of the time by either company or university representatives, some have significant implications for present research systems. Interviewees varied extensively in the way they characterized what they considered to be legitimate concerns regarding university/industry research interaction. However, several themes were identified.

In discussing the development of university/industry research interactions, concerns related to matters of academic freedom and research quality were continually articulated. Those conversant with the status of university/industry connection, or those who had an intimate involvement with a specific issue suggest several additional concerns. They include: credibility, continuity, and commingling of funds.

Still other concerns were identified after interviews with those involved in joint programs, study of the evolution of many case histories, and discussions with key individuals. They include: conflict of commitment, preservation of the academy, and the importance of exploratory research. The following is a short sypnosis of particular aspects of concern flowing from each of these issues.

1. *Academic Freedom*

Freedom and flexibility are the rubric of U.S. academe. They are viewed as the cornerstones of the success of our university system. Those who consider themselves protectors of academic institutions have suggested that any changes in the status quo could destroy the delicate balance developed to preserve these institutional qualities. Such discourse occurred when there was a vast increase in federal funding of university research in the 1950's, as it does now when a significant increase in industrial sponsorship is expected.

Indeed, flexibility and the climate of freedom to enquire is essential to the development of new fields and new knowledge; they are critical to the vitality of university research. The concept of academic freedom includes freedom to explore new subjects, to publish without delay or political constraint, and to allocate one's resources and time to what the principal investigator sees as most productive for his research.

The National Commission on Research, in its report on industry and the universities, suggested that the university might face certain constraints in these areas through participation in cooperative research

Table 31

Issues Concerning University/Industry Research Interactions Derived from Interviews with Scientists and Administrators at Institutions Surveyed in NYU Field Study

Issues Identified	Percent of Institutions Surveyed Where Representatives Identified These Issues: Universities (n=39)	Companies (n=56)
1. Basic vs. applied research	26%	16%
2. Academic freedom: Conflict of interest and/or commitments	23%	0%
3. Should university take equity in a company?	23%	0%
4. Importance of key individual (project director, dean, department manager or chairman, etc.	23%	14%
5. Industry vs. university pay scales	21%	2%
6. Government role as intermediary	18%	11%
7. Tax policy/incentives	18%	23%
8. Industry grants smaller than government grants	15%	0%
9. Ability of small firms to compete with large firms for access to university resources	15%	4%
10. Multi-disciplinary nature of cooperative efforts	15%	5%
11. Restrictions on public universities	13%	11%
12. Peer review	8%	9%
13. Commingling of industry and government funds in support of university research	5%	0%
14. Credibility of the university	3%	2%
15. Collective industrial support and anti-trust regulations	0%	4%

relationships with industry. They suggested that universities could be influenced on research direction and publication rights from these relationships, which serve as inducement for universities to become involved in more applied and development-oriented programs. This debate deals with potential outcomes, which have not been evident to date in the expanded activity for university/industry cooperation.

Such issues are being recognized and discussed by many universities around the country as expectations rise that a greater proportion of their research will be supported by industry. Rather than suggesting that concerns for academic freedom and flexibility be obstacles to changes in the status quo, universities diligently are attempting to develop new guidelines for faculty involvement with industry that will not compromise their flexibility or academic freedom.

2. *Conflict of Commitment*

Resolving issues related to academic freedom can be fairly straightforward, but there are also cases where there is no clear answer. Situations involving conflict of commitment are examples. Such issues are embodied in the following situations:

> A principal investigator has a new graduate student who is particularly good in a field he knows will be of interest to a company with which the professor has a consulting relationship. The professor obtains fellowship support for this student from the company. The professor and the company devise a program for the student's thesis research, following which the company gives research support to the professor for this program. Other research conducted by the professor in a related field is supported by the federal government. The professor maintains his consulting contract with the company and it is through this arrangement that company proprietary information is handled. Yet some of this information is relevant to the student's thesis.
>
> In another situation, several researchers at the same university in the same academic department are advisors to different companies, while their research support is from the federal government.

These types of arrangements are not new and have certainly been handled adequately in the past. But, as the diversity of research support increases, such situations may become exceedingly complex and more prevalent than in the past. It may not be possible to ignore the complications of such activities. At the same time, it does not seem fruitful to simply prevent them.

Several universities have formed *ad hoc* committees to discuss these activities and in some instances monitor them. A few universities have set up guidelines for dealing with such situations. For many universities, such guidelines are new and therefore not proven. Harvard University's policy divides situations that may present conflicts of interest into three categories:

(1) Activities that are clearly permissible. These include consulting arrangements that do not detract unduly from university objectives.

(2) Activities that should be discussed with chairman or vice chairman on extramural activities. These include situations in which a professor directs students into a research area from which he expects to derive financial gain.

(3) Activities which present serious problems. These include:

a. Situations where a faculty member assumes executive responsibilities for an outside organization which would create conflicts of loyalty, and

b. Situations where a substantial body of research that could, and ordinarily would, be carried on within a university is conducted elsewhere to the disadvantage of the university.

In our opinion, the dialogue preceding establishment of useful guidelines may be strengthened by opening up discussions to all parties involved, including industrial research scientists and managers.

3. *Openness of the University*

It is our observation that industrial grants or contracts, even the very large ones, generally do not cause a conflict of commitment or interest, nor do they necessarily foster an air of secrecy. Some scientists have always been secretive about their research. This may stem from a desire to be absolutely correct or a desire to be the first to discover a breakthrough. We found no evidence that industry sponsored research within the university system increased this secretive behavior. When the situation is otherwise, *e.g.* where there are strong incentives for a professor to begin his own company, or become involved in the operations of a start-up company with potential high returns, secrecy may be a problem. However, the majority of professors involved in such activities stated they were very careful about separating their commercial activities from their university research.

4. *Commingling of Funds*

Maintenance of diversified funding sources is critical to the health of university research. But this can lead to complex situations as presented in the above section.

Commingling of funds can become a particularly thorny issue when a company has negotiated an exclusive licensing arrangement with a university for patents deriving from the company-supported program. Companies can make a good and justified case for an exclusive license when they give significant amounts in support of a research program. Without an option for an exclusive license there is little incentive for a company to take the steps necessary to commercialize a product.

Difficulties may arise when the research equipment used in an industrially sponsored program has been bought under federal contracts, as is often the case, or if the federal government is still providing partial support for a university scientist's research program which also receives industrial support. To further complicate matters, another company may be supporting the research program of a colleague with whom this scientist has collaborated in the past and with whom he presently shares research equipment.

Sorting out who owns what could also arise in a simpler case where several companies are supporting a generic research center at a university, while they have separate agreements with professors at the center. This can lead to complex questions of proprietary rights if a patentable discovery results from this work.

5. *Objectivity and Credibility*

University researchers and administrators are aggressively looking for new ways to fund university research. Among these options being actively considered are programs for commercialization of university research and programs to foster university/industry cooperative research. Both these new thrusts require that universities review present policies regarding patents, licensing, publication, and outside activities of faculty. As the universities alter or modify policies to meet the needs of new programs for research funding, the academic reputation for impartial analyses may be eroded in the university's quest for funds. Indeed, this can present a problem to the university itself for the credibility that is established by the university's objective stance is a major asset universities have to offer as a third party.

The importance of university objectivity to those interested in the credibility of the outcomes of sponsored research and the potential for such interactions to evolve into large programs is suggested in the following example:

> The University of North Carolina, Chapel Hill (UNC) operates the occupational Health Sciences Group, which is a unique effort of union, company and university institutions to conduct research aimed at protecting the health of workers. It originated as a partial condition for settlement of a labor management dispute. The labor unions required that the rubber companies sponsor research on worker health outside of their own companies. They specifically required that the research must be credible. Of the six companies involved, four sponsored research at UNC and two at Harvard. The program was initiated in 1970.
>
> Prior to this program, UNC had little university/industry interaction which was important to the unions. Because UNC is a public university, it engages in no proprietary research.
>
> The initial step taken under the program was the collection of worker health data. It is from this data that the research program developed. The companies gave advice, but the university designed the program. Proposals for research projects were submitted to the union occupational Health Committee for approval. Then contract agreements were signed with the university. The average funding for the program was $1 million per year including overhead.
>
> The university conducted two-to-three-day scientific critiques to discuss the research progress. In addition to the Department of Environmental Science and Engineering, the business school was involved in the data gathering aspect of the program.
>
> A new program as a follow-on to the rubber company sponsored program is developing with 18 phosphate companies located in Florida. This comes at an opportune time for UNC, since the rubber companies are phasing out their involvement.

A university must consider several aspects of this question of credibility:

(1) The capability of university scientists to be objective must be preserved through enabling researchers to diversify their funding sources. This is important for industry and government when they need data and interpretations in response to law and liability suits;

(2) In an effort to generate their own funds, universities may create situations where their efforts are directed toward a tangible end rather than maintenance or creation of a body of knowledge and toward training those who can transfer it to users.

The question is how to devise the appropriate rules and policies for attracting or creating these new sources of income without endangering the university asset of credibility. Once again, the answer lies in an estimate of balance. There is a certain level of directed research, industry or government oriented, in which universities can engage. Each university must evaluate that level for its own circumstances.

6. *Choice of Research Topics and Types of Research Activity*

Much has been made in the literature of the possibility of industry "buying" university scientists. In their report on university/industry cooperative research relationships, the National Commission on Research suggested that increased industrial support of university research would be an inducement for universities to become involved in more applied and development oriented programs. They thought that this possibility could lead to some neglect of university basic research and teaching programs. We also suggest that this is a possibility, but point out that mission-oriented government research which has increased at universities in proportion to government sponsored basic research over the last few years poses the same difficulties. Industry-sponsored research differs philosophically from mission-oriented government sponsored research in that the general rhetoric and economic criteria are different. Commercial utility is the issue, rather than national security or national interest. However, in each case, the university scientist must relate his research interests to the missions of the sources of support.

This issue is really part of a much larger issue, namely, the future of the research university (OECD, 1981). How a scientist chooses his topics of enquiry and seeks support for them must be put within the context of the obligations of the research university to society. There are different views on what these obligations are and how to proceed once they are established. The changing role of science and technology in society will most likely affect university research subjects and the proportion of basic to applied research conducted at universities and sources of funding for university research. This may have future implications for university structure.

Most researchers when asked were uncertain or unable to state what they believed the ideal mix of government/federal/state/industry/university support of research should be. In our discussions with company scientists and administrators, they stressed their belief that neither the university nor government should be involved in development. Practically all stated that university scientists should concentrate on basic research. This is a clear contradiction of the belief of many university scientists that industry desires more applied activities at the university.

At this time, we point out once again that there is a continuous spectrum from basic to applied research, and what is one organization's applied research can be another's basic research. This was very evident to us in our field study. It is true among universities and industries, as well as between the two sectors. A vice president at a leading eastern university said that at one point he was trying to characterize applied research at his university. He went to what he thought would be the most likely place to find it, the dermatology department. Scientists there were very upset because, in their view, they were conducting research on extremely fundamental problems. This situation is even more evident in references to engineering research versus the physical sciences.

Government funds for non-mission oriented research areas are limited. In the past, the Department of Defense provided funding for very general research areas. After the Mansfield Amendment, which required the Department of Defense to restrict support of research to those areas directly related to defense, these general funds were no longer readily available.

We have observed that industry is in fact more likely than government to contribute unrestricted funds for research. These are basic research funds which can be used for exploratory research (see p. 67), or as seed money to develop new program areas (see p. 73). Furthermore, in the several cases investigated of large, long-term contractual arrangements between a company and a university the programs were primarily mission-oriented, but, according to the principal investigators of the programs, there was considerable leeway to explore new research areas, and frequently unrestricted funds are incorporated into the grant. Thus industrially-sponsored research is not necessarily more directed or applied than government sponsored research.

However, the bulk of direct industrial support of university research is in the form of smaller, short-term contracts ($50,000-100,000) for directed research. This type of interaction does restrict the choice of research topics, just as do most government research contracts. Once again we note a significant portion of government sponsored academic research is contracted and mission-oriented. Yet several government agencies fund unsolicited proposals, while companies generally do not.

7. *Exploratory Research and Seed Money*

The complexity of today's science often precludes the randomness with which scientific questioning was often identified in the past. Serious researchers today may not be able to afford to ask many wide-ranging questions. Yet, there is still a need for exploratory research.

Many industry scientists, as well as university scientists, are concerned about present opportunities for exploratory research. At least two large research-based firms have initiated significant programs to foster exploratory research at universities. Industry's interest in giving seed money to support new ideas is not necessarily new. The significance of these two programs is that the companies sought exploratory research in areas they deemed to be important (see Chapter IX, pp. 73-74).

8. *Gaps in Communication*

A number of professors were interviewed who received little or no industrial support. While they were not specifically negative towards industrial support, they held the opinion that industry had no interest in what they were doing, or that what they were doing was of no immediate value to industry. Therefore, they had not considered seeking industrial support. Furthermore, they were unsure how to approach industry. To some extent, this perception of the lack of immediate relevance of their research to industry is correct. Many science-based companies are quite comprehensive in their attempts to keep themselves apprised of research related to their interests. Through technology scanning activities, industry discovers those in the university community doing research of interest to them. They develop contacts with these individuals and may even ask them to be consultants. Industry will send recruiters to those campuses they believe are training graduates of interest to the company. These recruiters will talk with professors and determine who might be doing research of interest to the company, then bring the information gathered back to the company scientists.

Despite the extensive networks developed between university and industry, both parties still express a belief that opportunities are being missed. Many stated that new collective industrial actions to support university research, such as the Council for Chemical Research, are a major step to facilitate communication (see Chapter IX, pp. 81-82). University scientists in particular were concerned about establishing a permanent mechanism to match academic research interests with companies. Some suggested that there should be an information clearinghouse. Several thought that the trade associations or professional societies could play a more active role in facilitating communication between the two sectors.

Company scientists were not as concerned with being unaware of research opportunities as they were with being misunderstood. They expressed more frequently a concern with a gap in understanding with regard to the attitudes of the professors, rather than a gap in communication *per se*.

9. *Equity*

The increasing awareness on the part of universities, that conscious efforts to derive income from university research may be worth the efforts, has caused several universities to consider seriously active ownership of some portion of a new business development arising from university research.

Equity participation by a university in a new business development arising from university research could in fact provide a source of income that is related to university functions. But this raises very serious questions concerning the status, treatment and recruitment of faculty whose work might lead to such commercial exploitation. The efforts required for a typical university faculty to act effectively along these lines are considerable. Equally disturbing is the possibility that universities would act to inhibit research publications pending evaluation of commercial potential. There is a further basis for disruption if the desire for commercial exploitation ever became a factor in accepting graduate students. There could conceivably be limitations on foreign students who could return to other highly industrialized countries with the latest state-of-the-art in biology or microelectronics, and there could be barriers to students sponsored by corporations which are competitors of a major sponsor funding particular areas of research. There could be a temptation for universities to take this so seriously that they become involved actively in the commercial development process itself, and participate in decisions concerning markets, financing, and business planning.

Considering our discussions with university representatives, this is very unlikely at the present time. But the above concerns have been voiced by both company and university representatives.

E. The Significance of Current University/Industry Coupling

Despite the vitality of the university/industry system, we have no evidence contrary to previous figures indicating that industry in total provides a very small percent of direct funds in support of university activities. Even if you add corporate philanthropic funds designated for research to those given in direct support of research, most universities (80%) receive less than 10% of total university R&D expenditures from industry (Table 32). There is room for general improvement in cooperative research and some industrial sectors may have underutilized the university as a resource (Tables 17 and 15, pp. 50,48).

Dialogue between academia and industry has increased and there seems to be greater discussion of their common interests and problems as well as their respective individual goals. This has apparently led to a greater frequency of professional contacts between the two sectors. Because of the importance of prior contacts in the initiation of cooperative research programs, (Tables 4 & 5, p. 19) this opening up of communication channels may be extremely important for ensuring stable growth of cooperative activity between university and industry scientists in the future.

In fact, there are extensive connections between industry and academia. But this is not true for all industries (See Chapter VIII.) Furthermore, although there is a wide spectrum of companies that interact with universities, there are very few who do so on a significant scale and a continuing basis (Table 16). Currently, as well as historically, the most active industrial group in all forms of university research support, and particularly in cooperative research interaction, is the chemical industry (Table 17, p. 50. See also Chapter VIII, pp. 54-57.) In order to increase university interactions with some industry sectors, programs which address the structure and/or science base of the industry must be developed.

It is not clear whether external stimulus is necessary for current activity in university/industry coupling to continue or expand. We have seen that some degree of federal support can be helpful, and has been critical in many instances. However, the partners themselves have been the key elements in successful program development. Government, as a facilitator, can ensure that there is an appropriate climate for cross-sector networking, and may provide circumstances for increasing contacts between the two sectors. The significance of the many new university/industry programs may be that new channels of communication have been opened not that they are helping overcome tight federal fiscal policies.

Decline in federal funding for basic research cannot be fully compensated for by industry. The U.S. research system would be strengthened if university and industry could mutually agree to cooperate in

Table 32

An Estimate of Industrial Support of University Research Expenditures 1980*

University	Corporate Voluntary Aid to Educ.	Est. of Corporate Voluntary Aid to Educ. going to Research	Industrial R&D Support Primarily Grants & Contracts	Est. Total Corp. Res. Support Incl. Gifts & Contracts (Col's 2+3)	Total University R&D Expenditures	Total Estimated Corp. Res. Support Expressed as a Percent of Total University R&D Expenditures
	(Number in Thousands of Dollars)					
Carnegie Mellon University	5,124	382	5,010	5,392	29,306	18.4
University of Arizona	19,796	6,755	5,923	12,678	69,095	18.3
University of Maryland	5,409	3,936	2,263	6,199	39,917	15.5
Colorado School of Mines	2,573	200	497	697	4,510	15.5
Pennsylvania State University	4,056	2,658	7,842	10,500	71,840	14.6
University of Rochester	3,670	192	7,869	8,061	65,845	12.2
University of Southern California	7,178	1,522	7,462	8,984	74,304	12.1
Lehigh University	1,999	8	1,076	1,084	9,413	11.5
University of Illinois	5,246	5,924	3,404	9,328	83,274	11.2
University of Houston	3,493	802	602	1,404	12,628	11.1
Georgia Institute of Technology	3,044	55	6,243	6,298	56,653	11.1
University of Michigan	10,409	5,854	6,145	11,999	111,316	10.8
Massachusetts Institute of Technology	16,191	6,102	11,402	17,504	163,566	10.7
Louisiana State University	7,015	4,324	1,267	5,591	53,058	10.5
University of Delaware	1,855	976	702	1,678	16,746	10.0
California Institute of Technology	4,992	2,144	1,993	4,137	43,259	9.6
Rensselaer Polytechnic Institute	4,765	0	1,394	1,394	14,824	9.4
Purdue University	3,651	933	4,756	5,689	61,765	9.2
Case Western Reserve University	4,774	1,822	1,790	3,612	40,688	8.9
Harvard University	16,137	3,192	3,995E	7,187	100,901E	7.1
University of North Carolina, Chapel Hill	2,771	1,028	1,370	2,398	38,924	6.2
Colorado State University	3,604	23	2,505	2,528	40,678	6.2
Clemson University	980	0	1,126	1,126	18,366	6.1
Rice	2,497	20	467	487	8,029	6.1
University of Minnesota	7,083	2,472	4,352	6,824	119,065	5.7
Stanford University		3,034	3,215	6,249	113,120	5.5
University of Texas, Austin	6,355	2,416	1,237	3,653	78,621	4.6
University of Wisconsin	6,080	3,658	2,615	6,273	138,227	4.5
Duke University	5,222	856	779	1,635	39,066	4.2
Princeton	3,051	669	423	1,092	27,821	3.9
University of California, Los Angeles (UCLA)	6,461	3,119	NA	3,119	88,934	3.5
Yale	4,600	1,160	582	1,742	71,446	2.4
University of Chicago	5,653	579	402	981	58,436	1.7
University of California, San Diego	4,765	NA	NA	—	14,824	—
John Hopkins University	3,657	NA	NA	—	253,204	—
University of Washington	NA	NA	3,830	—	111,858	—

Table 32—Continued

An Estimate of Industrial Support of University Research Expenditures 1980*

University	Corporate Voluntary Aid to Educ.	Est. of Corporate Voluntary Aid to Educ. going to Research	Industrial R&D Support Primarily Grants & Contracts	Est. Total Corp. Res. Support Incl. Gifts & Contracts (Col's 2+3)	Total University R&D Expenditures	Total Estimated Corp. Res. Support Expressed as a Percent of Total University R&D Expenditures
	——————— (Number in Thousands of Dollars) ———————					
Washington University	NA	NA	1,029	—	59,379	—
North Carolina State University	NA	NA	1,800	—	42,725	—
University of Utah	NA	NA	851	—	31,175	—

SOURCES OF INFORMATION:

NSF: Academic Science R&D Funds FY 1980. Table B-16
CFAE 1980-1981. Voluntary Support of Education
CFAE data tapes and discussions with CFAE representatives

*Excluding capital gifts

the feasibility and developmental potential of basic concepts.

Academic science and engineering, in fact, is not a productive force (see Chapter II), it is a pursuit for understanding, and as such calls for exploration of a wide variety of alternatives. The productive force relates to the mechanisms of screening these alternatives after their characteristics have been better revealed. Industry, in some sense cannot be expected to fund broadly-based exploration, but it is of great value to industry to be able to tap into this exploration. Industry can and should be able to fund the screening and testing of alternatives.

It is our judgment that there are no insurmountable barriers to university/industry cooperation. But the issues must be addressed carefully and non-negotiable items (freedom to publish for universities and proprietary information for industry) must be fully understood. The interests of each party must be placed on the table immediately. Understanding the useful boundaries of these interactions is critical to successful outcomes.

CHAPTER XI

THE FUTURE OF UNIVERSITY/INDUSTRY RESEARCH COOPERATION

This study was intended to provide information rather than recommendations. Nevertheless, our survey led us to identify a number of subjects which appear to form the principal areas for discussion, action and change in the years ahead. The emergence of these topics—some we would call call opportunities, others concerns or issues—does indeed constitute a major development in the broadening research relationships between university and industry.

In this section, we attempt to set down the nature of these subjects from the collective perspective of the informed observer with knowledge of both university and industry objectives and needs. Our primary concern is with the optimum role of university/industry cooperation in our society and the factors which affect this.

A. Changes in Government Funding

There are a number of key relationships between government funding of university research and/or training, and research cooperation between university and industry. The simplest, of course, is that a decline in government funding for a particular area, or even a perceived decline, can be a powerful stimulus for initiating university actions to attract industry attention.

Lower government funding across the board will reinforce the pressures for university/industry cooperation, and will increase the role of the private sector in attracting research efforts to particular areas and in guiding career patterns for graduates. Such responses will presumably extend the role of the university in its contributions to society and to economic growth.

These contributions, however, require a minimum stable base of university research capabilities—faculty, facilities and graduate students. To a large degree, the government has provided support for this base and the broad spectrum of science, basic and applied, that is necessary for the long term national interest; indeed, no realistic expectation exists (David, 1981) that industry can support that base by replacing government funds.

Even in areas of science where the private sector can reasonably be expected to support a larger proportion of the research cost, the government will most probably continue to provide for the underlying technical infrastructure of university research capabilities. Industry's willingness to strengthen university research cannot be interpreted as being a commitment to provide for the basic university structure. In fact, if government funding drops too drastically, the present system for university/industry cooperation itself would very likely be jeopardized.

What must be the minimum research base at universities, and what is the appropriate mix of funding sources? The approximate current level of $6 billion annually in total R&D conducted at universities, with about $300 million funded by industry, may not be sacrosanct in either absolute amounts or as a proportion of the national R&D expenditures. Nevertheless, even if industry funding were to rise to, say, $600 million annually, the effectiveness of that support to achieve scientific progress and graduate training would still require a substantial base of university research. But there must be some level below which there would be serious damage to the long-range stability and productivity of the research enterprise.

In summary, industry funding itself is based upon the existence of a stable university research community, and this in turn depends today on a substantial level of support from the federal government. The precise level of that support is arguable, but a consensus as to an approximate range of this support, and the mechanisms by which it is provided, appears essential to the strength of university research in general, and to the encouragement of university/industry cooperation.

There is a second issue. Even if research funding is not cut, it is likely that there will be substantial shifts in government funding so that a larger proportion of these funds will come from mission-oriented agencies, for example, the Department of Defense. Such shifts can be large enough to affect the direction of university research for many years to come. These changes can affect future university/industry research cooperation both directly,and indirectly by influencing the career choices of graduate students.

Finally, as a third issue, there is the effect of decreased government support upon other programs, specifically student aid and fellowships. Although largely beyond the scope of this study, it can be observed that, just as industry support is based upon a stable university research community, there is an obvious dependence of that research community upon a financially sound total university system. Furthermore, cooperative research arrangements are often attractive because the university has a highly talented, relatively inexpensive graduate student work force upon which to draw (Chapter VII, pp. 34-36). The stability of the total system is clearly a fundamental concern for future industry/university relations.

B. Commercialization of University Research

There is an increasing sensitivity on the part of universities—faculty and administration—to the opportunity for obtaining income from the commercialization of university research. Universities have evolved a moderate source of income over the years from licensing of patents based upon this research (see Chapter IX, pp. 104-105). Expansion of these activities at many research oriented universities has taken place in recent years and may be leading to increased income (Table 29, p. 105).

A significant development lies in considerations related to some form of university equity participation in new ventures derived from university research. Such demands are producing debate within the university system itself concerning its structure, objectives, and value systems (see Chapter X, pp. 110-112).

Concern about finances creates a steady pressure for universities to move towards activities providing new sources of income through commercialization of university research. The changes in government funding increase this pressure. Additional stimulus comes from the concern for attracting and holding faculty in financially lucrative fields such as biotechnology and computer sciences, and in the search for new mechanisms to permit this. Further impetus comes from the several dramatic examples of new ventures in the field of molecular biotechnology, which have attracted large amounts of financing from corporations and investors.

The debate within the university centers on how the university can obtain added income from participation in commercial ventures while maintaining its integrity and basic values. Serious questions arise concerning research priorities, criteria for selection of faculty, selection of graduate students based upon criteria related to ultimate commercial interests, effect of secrecy in research on community interaction and information dissemination, and the possibly damaging effect on university/industry relations of university equity participation in new ventures.

There is presently a sense of experimentation concerning mechanisms for a university role in new business development from licensing through equity. An integral aspect of this experimentation is the growth in research institutes or other structural entities in which commercial linkages can be pursued without disrupting the university structure (see Chapters IX and X, pp. 106-107 and 110-113). Whatever the outcome of this experimental period, the future university approach to commercializing its research will set an important boundary condition for cooperation with industry.

C. Instrumentation and Research Facilities

The condition of the physical infrastructure of university research is both a cause and effect of rising research costs. Modern research depends upon advanced instrumentation, so that the capital cost per researcher is increasing. Yet the budget limitations of the university research system has led many research administrators to hold back on modernization in order to maintain their research staff.

The strengthening of this physical infrastructure is a critical issue today, and will remain so. It affects both the training and research objectives which are sought by industry in its relationship with universities. The adequacy of university research facilities can serve to stimulate or discourage industry cooperation.

These circumstances give rise to the complex issue of how a university should allocate a fixed amount of research resources. The steady increase in full-time equivalent professional personnel engaged in R&D activities at universities since the mid-1970's (*cf, Science Indicators*, 1978) has been coupled with the growing concerns about the obsolescence of research facilities and equipment valued at over $10,000. A case can be made that research "productivity" at universities could have been increased by spending more money on instrumentation and using fewer research personnel. Yet, if actions had been taken along these lines, they would then conflict with two other factors:

(1) The principal research personnel at universities are generally teaching faculty members. Therefore, changes in research personnel will affect the university educational structure as well,

(2) Administrative constraints and regulations on the allocation of funds may not leave the university free to apportion them in order to obtain the optimum distribution between research personnel and facilities.

- These issues suggest several topics for consideration.

(1) Identifying means to earmark funds for research facilities and instrumentation.

(2) Determining ways to provide funds to selected research institutions for the maintenance and operation of instrumentation. Constraints on the allocation of the resources for instrumentation and facilities highlights the need for the creation of rational priorities of investment among the many research areas, and adequate assessment of the desired level of university research capabilities relative to specific industrial sectors.

(3) Identifying the appropriate mechanisms for encouraging shared instrumentation.

An example of the difficulty of finding up-to-date instrumentation in universities is in the field of microelectronics. Research facilities in the private sector are far superior to the general level of those at most universities. Implicit in this situation is that the universities cannot be full partners to industry in this rapidly developing industry where the U.S. must fight to keep its competitive edge. Furthermore, students will not be trained on state-of-the-art instrumentation, nor will the university be able to maintain appropriate cadres of faculty willing to forego lucrative industrial positions.

Two mechanisms to improve the university's ability to function in microelectronic technology involving industry are operating, and may serve as examples for other fields. One is a more conscious effort by both university and industry to identify equipment within industrial laboratories that can be given to universities. There are difficulties with this approach, however, and this will still not equal the most advanced industrial facilities, but can be a marked improvement over existing university capabilities (see Chapter IX, pp. 68-69). A second mechanism is the effort to concentrate activities requiring specialized research instruments and facilities at research centers connected with universities (see Chapter VIII, pp. 58-60).

D. Changing Requirements for Technical Personnel

We are in a period of extreme personnel shortages in particular areas, and anticipate continuing and emerging shortages in others. Simultaneously, there is poor demand and underemployment in some technical disciplines. This situation defines several issues related to the nature and extent of university/industry cooperation.

The work of this study has already emphasized that the primary objective of industry in its interactions with the university system is the production of new graduates (Chapter VII, p. 34). Current and anticipated shortages may serve to focus this objective more sharply.

The demand for technical personnel has been cyclical in the past, with peaks in World War II and from the late 1950's to 1970, followed by sharp drops after the Korean War and in the early 1970's. And individual fields of science and technology have had their own ups-and-downs relative to other fields, appearing almost as short-term perturbations within the general cycle of supply and demand. Some fields of biology, *e.g.*, dentistry, are in little demand today while geneticists are in critically short supply. Particle physicists do not have the employment opportunities open to solid state physicists.

It is necessary to determine which aspects of the technical personnel situation are transient and which, if any, represent a long-term problem. The solutions to the problem depend on this analysis.

Industrial demand for technical personnel appears to be affecting the traditional university structure in two ways:

(1) Fewer doctoral candidates: graduates in computer sciences with bachelor's or master's degrees are going directly to industrial careers, with a smaller proportion than expected going on to a doctorate. This diminishes the pool of those pursuing advanced research and/or those available as future faculty.

(2) Drain of advanced university personnel: in both computer sciences and genetics (as well as some engineering disciplines), both faculty and new doctoral graduates are turning to industrial positions. This drain to industry raises critical questions about the resources available for training needed future graduates and maintaining the desired research base at universities.

The problems are well-identified today, which is a first step towards solution. It is a healthy sign that they are being raised in as many articles and talks by industrial representatives as by university presidents. Such concerns will be a principal focus for university/industry relations for the foreseeable future. They will call for constructive experimentation, some of which is already taking place.

Concern for graduates has already influenced the rules for funding distribution of the new Council for Chemical Research, a university/industry collaboration being formed by the chemical industry. The original intent was for industry to commit annual funds on the order of $30 million for support of basic research in an NSF style, that is, in response to research proposals from universities. The most recent proposal for distribution calls for the allocation of funds to major research-oriented universities in proportion to the number of masters and doctoral level graduates produced (Chapter IX, p. 82). One cause for this shift is the concern that the organization should not unduly influence the direction of university-based research, but the shift is also a recognition of the growing problem of turning out needed graduates.

Another approach is the recently announced program of the Exxon Corporation to provide $15 million towards augmenting the salaries of junior faculty and providing student fellowships in particular departments of selected universities. The objective is presumably to decrease the gap between university and industry salaries to a more acceptable level, not to eliminate it, in order to encourage faculty careers in critical areas.

We have noted in this study a desire for increasing use of such mechanisms as the loan of industry personnel to universities (Chapter IX, pp. 85-87). Use of junior faculty in summer programs within industry, or in consulting, are other methods being pursued as much to provide additional income as for fostering the specific research involved.

Direct approaches, such as industry providing supplemental money and manpower to universities, may be expected to expand in the near future. If the problem continues, however, different structural approaches will be necessary. For example, Dr. Omenn (1981) has suggested that the creation of university associated centers may allow engineering schools to hire "clinical" faculty similar to the medical schools who are allowed to continue their "practice" (e.g.contract work). Presumably, this could provide an opportunity for professionals to sustain high salaries while also teaching, and for students to have access to the latest industrial knowledge.

E. Control of the Export of Technology

This is a sensitive issue with broad ramifications, most of them well beyond the scope of this study. Yet the issues touch at the heart of university/industry interactions, namely, graduate education and research.

There is a continuing concern with the overt transfer, as well as the inadvertent leakage, of advanced technology having military significance to potential adversaries. The issues are:

(1) How to separate technology of military importance from technology of commercial importance, particularly when there is considerable overlap, and

(2) How to decide when a strategic military advantage can be maintained and/or improved by secrecy and compartmentalization as against free access that will expedite advances by the entire research establishment of the U.S. and friendly nations, as well as unfriendly ones.

Some of the most advanced research in microelectronics is being pursued at university research centers such as Cornell's submicron facility, MIT, and Stanford. There are significant percentages of foreign graduate students in these centers and in other advanced research programs. Any attempts to control, and hence to restrict, these graduate students would obviously impede such research. Further, foreign graduate students constitute an important percentage of the hirings by the microelectronics industry, which has been complaining of acute shortages.

It is clear that extension of export controls to graduate schools would have adverse impact on research and on the production of graduate students. A broad definition of military concern would impair the ability of many industries to hire qualified graduates. There would be far more serious consequences if student access were limited based upon concern over the U.S. international competitive status, not only in electronic products but in biotechnology or any other technically-based industry.

This is not the place to analyze the basis for any restraints on graduate students, or to demonstrate cause-and-effect relationships leading to technical superiority in either military or commercial fields. There is much emotion and insufficient understanding. It does, however, appear obvious that much of our advance in university research today is dependent on foreign graduate students,and that these students are in turn providing a necessary resource for U.S. industry. Any serious disruption of this process will be an equally serious obstacle to university/industry cooperation.

F. Collective Industrial Activities

We have referred to the concerns faced by universities, and hence by industry, with regard to shifts and/or declines in government funding, inadequacy of research instrumentation, and loss of faculty in critical areas. Among the possible approaches to easing these difficulties, although not a complete solution, is steadily increasing collective industrial activity in support of research.

This collective activity is peculiarly American, quite different from the activity of European trade associations. While almost every U.S. industry has a trade association, only a modest number support research (Chapter IX, pp. 95-98). They operate typically through small grants to universities and other research institutions out of a total budget on the order of several millions of dollars. Only a very few industries collectively support research laboratories, such as the Textile Research Institute at Princeton. Of course, clusters of individual companies have combined to support research institutes or centers (see Chapter IX, p. 82).

In recent years, there have been a number of initiatives by different industries to act collectively for the support of research on a much greater scale. The largest of these is the Electric Power Research Institute (EPRI), started in 1973 with a 1980 operating budget of $217 million. Next largest is the Gas Research Institute (GRI), initiated in 1976. Its 1980 budget of $84 million is planned to increase to $140 million by 1983, primarily to complete particular development programs being cancelled by the Department of Energy. These two organizations represent the electric and gas utility industries respectively. (See Chapter VIII, p. 52).

In the earlier discussion of changing requirements for technical personnel, we mentioned the current effort within the chemical industry to establish a Council for Chemical Research.

Another recent initiative has been taken by the Semiconductor Industry Association (SIA). A committee of the SIA is coordinating an industry-wide commitment to provide about $25 million annually for support of university-based R&D. The money is intended to cover a spectrum from scientific studies to process research. Most, perhaps all, of its funds will go to support a few of the university research centers emphasizing some aspect of microelectronics, a substantial number of which are now in existence, with others apparently being planned over the next few years.

A different version of these collective efforts initiated by industry is the industry-oriented institute initiated by the university which is supported by several companies from different industries (see Chapter IX, p. 82).

There are several issues related to these collective industry actions. First, the clear intent is to use collective action to supplement, not replace, support of university research by the individual companies. How best to do this, and how to maintain ties between the individual companies and the appropriate university personnel are subjects for continuing attention. In any event, it could provide an increase of total industry funding of university research of perhaps 30-50% of the funds now provided by individual corporations.

The second issue is what role the government might play as different industries collectively increase their own support of the science and engineering relevant to their needs. If the trend continues for collective industry action to identify and support relevant needs in a mission-oriented field, much of the justification for support of the mission-oriented research by the federal government would seem to diminish. The government might then intensify its support of the strong general infrastructure of basic science and technology. (Fusfeld, Langlois and Nelson, 1981).

The third issue centers on the fact that collective industry actions will inevitably strengthen particular areas of basic science and engineering, and very probably particular departments and universities. Industry is free to concentrate its spending on the most appropriate institutions in its fields of interest without political pressures. If sufficiently concentrated, such funding will have the same impact as the defense-related research of the 1960's when, for example, the very specific development of Materials Research Centers supported by the Advanced Research Projects Agency (ARPA) of the Department of Defense helped to produce the strong university centers of that science today. The several centers that the Semiconductor Industry Association may choose to support in microelectronics will very likely be the leading centers in this field. Further, the programs they pursue may well advance more rapidly than others in the field of microelectronics.

The overriding issue, as we consider these new mechanisms which increase industry support of university research, is how to insure that these added new efforts provide balance and new inputs into our technical base. The total level of industry support for the foreseeable future will be such that increased university/industry cooperation will certainly bring about technical change in selected areas. The federal government through its convening and information gathering capabilities may furnish avenues for sustaining an appropriate balance.

G. Non-University Training

There appears to be increasing activity in initiating or expanding programs intended to provide some form of organized advanced education that do not involve the participation of a university. We are not considering a routine program for new industrial employees to become adept with a particular facility, or a general internship to become acquainted with company or research operations. Neither are we considering courses given under university control at an industrial site.

We refer in this section to those courses organized within industry, trade associations, or professional societies which are intended to advance the technical background of individuals. These can fall into a number of categories, including the following:

(1) A particular subject that would add specific knowledge in a new field for current employees, *e.g.* fiber optics.

(2) A formal set of courses that would permit existing technical employees to keep abreast of new advances in their own field, or provide the basis for converting to a new field.

(3) A formal set of courses for new employees that would bring them current with the theoretical and experimental state of the art in industry, assuming this was more advanced than their previous university training as, perhaps, in computer sciences.

(4) A formal degree-granting program run by a company or industry for either current employees who wish to advance themselves, or potential new employees required by the company or industry. For example, the General Motors Institute is certified by the State of Michigan to grant bachelor degrees. More recently, the Wang Computer Company established the Wang Institute, with the intention of granting advanced degrees.

The first two categories have been common over the years. They address questions about obsolescence of individuals or the decline in relevance of technical fields. While these problems are often solved with the cooperation of nearby universities, they may indeed be organized by a company or industrial organization in order to tailor the material to the knowledge available within that company or organization.

G. The second two categories, however may take on more significance in terms of the ability of universities to deliver services in rapidly advancing high technology industry fields. To some extent, they address the questions of personnel shortages in these fields, of loss of faculty that could teach these subjects in a university, and of the university lagging behind industry in the use of the most advanced research facilities in actual knowledge. If the problems engendering the apparent growth in industrial training programs (see Chapter IX, pp. 93-95), are short-term, the issue and the mechanisms will disappear or at least level off to find a modest place in our technical structure. If the problems remain, or even if the mechanisms remain at a high level as a continuing feature of technical training, then a new set of questions arise for the university, and for the university/industry cooperation.

There are clearly opportunities for training outside the university structure that can complement the university's role. Occasionally, industry is at the vanguard in developing exploratory or innovative teaching programs that can point the way to new initiatives for the university. The growth of such external programs should at least stimulate both analysis and introspection by universities in examining their optimum role in society generally, and with regard to industry in particular.

H. Internal Structure of Universities

The primary and unique function of the university is to provide students with a broad range of degree-granting disciplines and curricula. A principal additional function, particularly within the graduate schools, is the pursuit of research. In the graduate schools, the interdependence of these two university objectives, education and research is critical.

Although industry interacts with universities for the same objectives and with the same order of priorities, its own structure and organizational approach to research is different than that of a university (see Chapter VI, pp. 26-31). One can reasonably expect that some organizational structure within the university is optimum for the objective of encouraging and improving the effectiveness of such interactions. It seems equally reasonable to expect that this would not be the same structure which is optimum for the traditional internal operations of the university. The issue raised as a factor in future university/industry cooperation is whether and how to modify the university structure to maintain the strength and integrity of its basic functions while attempting to meet changing external conditions and internal pressures.

There are many structural aspects to a university. Among the more important are:

(1) Grouping of scholars by disciplines, with academic administrators responsible for traditional discrete schools.

(2) Appointments bestowed by departments.

(3) Tenure granted by faculty within a department, generally tied to teaching obligations and tuition income.

These elements have evolved with the growth of the modern university. They are at the heart of the freedom and objectivity of scholarly research, they encourage and strengthen individual research and they should tend to produce a conservative financial base and create barriers to fads in either training or research.

Unfortunately, they also form disincentives to interdisciplinary research, which focuses on a mission or objective that may call for coordination of contributions by many disciplines. Yet that is precisely the essence of industrial research. Industry relates its technical needs to business planning in terms of products and processes, and sets technical priorities in terms of properties and specifications, not scientific disciplines.

This is hardly a fatal defect. But it is a factor, an "impedance mismatch," that detracts from maximizing university/industry cooperation. This constraint works in two ways. First, the university scientist does not see the overall problem facing industry. The industrial research manager must decompose the broad objective or problem into its scientific components, so that the component matches the research interest of the academic researcher. Thus, the university researcher may miss the opportunity to contribute to a broader issue than that within his immediate specialty. The whole may in fact be greater than the sum of its parts, and the university researcher may not be exposed to this broader picture.

Second, from a highly pragmatic viewpoint, industry can assign value more easily to a mission or objective than to a research component. Increased funding might be available more readily if the university system could approach industry on this basis. This would not have to take the form of shifting from basic to applied research. It would, however, change the emphasis from the independent scientist doing undirected basic research to greater emphasis on scientists cooperating in what we would term directed basic research.

This brings us back to our initial remarks opening this section as to how far the university structure can or should be modified. Obviously, the university system is not in existence to provide the best possible match for industry needs. If it does not maintain its strength and freedom for independent scholarly research, then it has lost its uniqueness. The issue before the university is to be aware of the interdisciplinary approach inherent in industrial research and explore its own flexibility to meet this.

This exploration is evident in the creation of research centers and institutes to form a type of matrix structure at some universities. Where these institutes are within a well-defined department or school, they tend to lack the broadest attributes of a mission-oriented structure. Where they are free of this constraint, there tend to be strains between those personnel on research appointments to the institute and the traditional department appointments. These are, in short, problems to be resolved.

This last item relates to the question of tenure appointments and criteria. While there has been steady growth in university personnel engaged in R&D since the early 1970's, these do not normally represent career opportunities unless tied to teaching programs. This is a critical structural question for the universities, particularly in areas of shortages of teaching personnel. If industry were to make substantial funds available for research in particular areas, but the universities could not make tenure-track appointments, there would probably be little change in the research capabilities of the universities.

I. Conduct of Large R&D Programs

One mechanism for university/industry cooperation is their mutual participation in large R&D programs. In the past, these have arisen in the public sector, with such examples as the Manhattan Project or the Apollo Program. It is conceivable that other large programs can arise more closely related to private sector plans, but possessing substantial public interest. These might include activities in the energy field, *e.g.*, synthetic fuels, or a major cooperative effort in robotics.

Whatever the subject matter, opportunities can arise where many institutions must work together toward a planned set of objectives. These programs will very likely require that some efforts be devoted to basic research, although these will, by definition, be in the realm of "directed basic research." Thus, in the early developments in ato ic energy, it became essential to know more about the effects of radiation on solids, about the theory of diffusion processes, about metal flow processes at high rates of deformation, and so on. The common element was that these advances in basic knowledge were important to the funding agency and to a wide spectrum of the technical community, not simply to the researcher.

The urgency of war, or the broad acceptance of society's commitment to land a man on the moon, were sufficient to overcome the disincentives of the university departmental system with regard to two operational characteristics:

(1) The university accepted, through an administrative officer or senior faculty member, responsibility for program management for a "package" that encompassed different units within the university, and in some instances units external to the university.

(2) University research programs were geared to objectives that meshed with those of a broader system.

There is presumably no reason why such involvement by universities in future large-scale research programs directed toward industrial interests could not occur. However, it is very likely that new programs would be initiated and managed by industry. The mix of government funds and private funds would depend on the program.

Such programs would fall in between a public sector program such as Apollo and a major effort by a single large corporation. There would be some form of consortium or cooperative effort, and there could be an important role for university research. The new initiatives in collective industry programs (*e.g.*, SIA, CCR) could be the forerunners of such programs.

The issues here relate partly to the structure of the university, partly to the philosophical approach. The university research participants would be part of a "team," and objectives would be worked out cooperatively in the best sense of a broad attack on a scientific problem.

The willingness and the ability of a university to participate in large research programs could be an important factor for future university/industry cooperation. Even more, it could be a mechanism for the university to contribute substantially to major systems for technical change in our economy. But it will surely require the type of adaptations within universities called for in the Manhattan Project. Finding a realistic niche for that approach in the university structure can be an important challenge.

J. Sources of Technical Change

A fundamental issue to consider is the role of university research in bringing about technical change in our society, and the related question of the contribution of university basic research to the flow of basic research from all sources. A realistic appraisal of future university/industry cooperation must be based upon an understanding of the importance of university research to current industry operations, near term plans, and longer range interests.

Technical change takes place over a broad and relatively continuous spectrum. We normally describe this "from left to right" in terms of basic research, applied research, development, design, testing, and on through the manufacture of products, installation of processes, or delivery of services. This is convenient for the purposes of description, but should not be taken as the necessary, or even the most common, chronological order or cause-and-effect relationship. The stimulus for basic research and for new scientific concepts often arises from problems encountered in practical uses of technology (Fusfeld, 1976). Further, development of advanced instrumentation may be a necessary stimulus to such research.

One general truism, however, is that technical activities at universities focus on basic research, while those in industry focus on applied research and development. Nevertheless, there is actually a distribution of activities in each sector, though obviously skewed. And this skewed distribution becomes an interesting factor in university/industry relations. Specifically, the fact that universities engage in many applied research activities, and that industry does pursue some basic research programs, must be understood to avoid an over-simplified view of the functions pursued by each sector, and hence of the factors underlying future university/industry interactions.

The university uniqueness and internal reward system derive from its basic research activities. Yet there are necessary peripheral efforts that involve instrument development, preparation of computer software and, in the engineering schools, process design and pilot plant operations. Thus, the university can indeed present a broader interface for cooperation with industry if it so desires. We expect and hope that the present spectrum of university objectives will be evident in a multitude of approaches. Universities can package more interdisciplinary programs should that decision be made compatible with their internal structure, and some may choose to present a wider array of services, provided this would not distort the university function. Industry would respond positively to the increased points of contact according to individual company objectives, provided these were presented in addition to, not in place of, university status in basic research.

Perhaps a more significant feature resides in the conduct of some basic research activities by industry. This must be viewed in the context that major industrial firms conduct those technical activities necessary to support present business interests and provide a basis for planned growth. Where such activities call for some allocation of resources to basic research, this is done. The point is that industry tends toward a self-sufficient balance, allocating *all* resources in some appropriate proportion to each other, including technical activity, and including within that basic research, where appropriate.

Thus, to carry out any current business plan, a corporation does not *need* outside basic research, such as might be performed at a university, although it does need well-trained, capable university graduates. If it *needed* such research activity, if the corporation's current business plan *depended* on it, then such activity would be pursued internally or, when economic, externally at the initiation of the company. Our studies show that the latter case accounts for a very small proportion of industry-funded research at universities.

However, corporations will normally *want* to have basic research pursued at universities, and are more and more willing to support this activity. But it is absolutely critical in the evolution of university/industry interactions for universities to appreciate this distinction.

Technical change is introduced into economic use by industry. For the most part, this is accomplished through a purposeful industrial research structure. This research structure is immersed in a sea of science and technology with which it maintains close contact, and from which it extracts new concepts and necessary technical data. A very important contribution to this "sea" is the university. But the total input comes from all universities, U.S. and foreign; all unclassified outputs of government laboratories, U.S. and foreign; and all published or publicly available science and technology from private corporations, public and foreign.

Given this complex and dynamic system, the university is in the position of contributing basic research that is both essential yet diffuse. It maintains the advance and quality of the scientific base, and possesses collectively the highest probability for stimulating wholly new directions. But these values raise the level of our technical "sea" to the potential benefit of all who draw upon it, hence minimizing its competitive value to a single corporation.

The future paths for university/industry cooperation will depend on the way that each university and corporation perceives the essential role of the university. Hence, it can be expected that many varieties of interaction will persist and develop. The preceding discussion, perhaps more philosophical than called for in this study, was intended to prepare the background for a somewhat obvious, but often misunderstood, conclusion.

There is considerable opportunity for universities to work more closely with industry in research, to move from a position where the university satisfies *wants* to where it satisfies *needs*. We speak in the short term sense, since a long term *need* may be considered only a short term *want*. In brief, the university can develop more of a partnership relation, adding greater immediate value to its technical activities. The compromise, of course, is fairly evident. As the university moves closer to a partnership with industry, more resources can become available, but the university inevitably relinquishes some of its unique capabilities for unrestricted exploratory research and freedom of action.

There are no absolutes, and the issues become one of degree and common sense. There is little freedom in the absence of resources. Thus, each university must work out the degree of partnership to achieve adequate linkages and resources. Too close a partnership with industry can be bad for long term growth, but too little can prevent the university from providing its optimum contribution.

The primary requirement, therefore, is not so much increased partnership, but increased understanding of each other's role. That is the ultimate basis for a healthy strengthening of university/industry cooperation.

Allen, Thomas J., *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information Within the R&D Organization*, MIT Press, 1977.

Baer, Walter S., "University Relationships with Other R&D Performers," P 5780, Santa Monica, California: Rand Corporation, January 1977.

Berlowitz, Laurence, Zdanis, Richard A., Vaughn, John C., "Instrumentation Needs of Research Universities," *Science*, 211 (1981), pp. 1013-1018.

Brandt, Norman J., *Financial Statistics of Institutions of Higher Education: Fiscal Year 1978, State Data*, Washington, D.C.: National Center for Education Statistics.

Brodsky, N., Kaufman, H. G., and Tooker, J. D., *University Industry Cooperation: A Preliminary Analysis of Existing Mechanisms and their Relationship to the Innovation Process*. New York: NYU Center for Science & Technology Policy, July 1979. (Under National Bureau of Standards Order Number NB79 NAA/A8898).

Bromley, Allan D., "The Other Frontiers of Science," *Science*, 215 (1982), pp. 1035-1044.

Brown, Alfred E., "The Industry/University Interface in America Today." Paper presented at The American Society for Metals, Materials and Processes Congress, Cleveland, Ohio, October 28-30, 1980.

Business Week, "R&D Scoreboard," July 6, 1981, pp. 60-75; July 7, 1980, pp. 47-70; July 7, 1979, pp. 47-70; and July 3, 1978, pp. 58-77.

Cantwell, Katherine M., "University-Industry Research Relationships at the Stanford Synchrotron Radiaion Laboratory." A report submitted to the National Science Board, July 1980.

Chemical and Engineering News, "Facts and Figures for Chemical R&D," July 27, 1981, pp. 47-71.

Cooperative Automotive Research program, "Technical Framework: Research Area Working Groups," in *Congressional Record*, Senate, November 18, 1980, pp. S12813-S12834.

Council for Financial Aid to Education, Inc., *The Casebook*, New York: C.F.A.E., 1970, 1972, 1974, 1978, 1980.

Council for Financial Aid to Education, Inc., *The Survey of Voluntary Support of Education, 1974-75, 1976-77, 1977-78, 1979-80*, C.F.A.E., 1975, 1977, 1978, 1980.

Daniels, Raymond D., Martin, Ralph C., Eisenberg, Lawrence, Lewallen, Jay M., Wright, Ronald A., *University Connected Research Foundations: Characterization and Analysis*, Norman, Oklahoma: University of Oklahoma, 1977.

David, Edward E., Jr., "Science Futures: The Industrial Connection," *Science*, March 2, 1979.

David Edward E., Jr., "Industrial Research in America: Challenge of New Synthesis," *Science*, Vol. 209 (July 4, 1980), pp. 133-139.

David, Edward E., Jr., "A New Splice of Life: The Re-engineering of Industry-University Relationships in Research," Keynote Address at the Annual Meeting of the Council for Chemical Research, Rochester, New York, November 2, 1981.

Declercq, Guido V., "Technology Transfer from Campus to Industry," *International Journal of Institutional Management in Higher Education*, 3 (October, 1979), pp. 237-252.

Engineering Education, "Engineering College Research and Graduate Study," issues of March 1980 and March 1981.

Evenson, Robert, "Agriculture," in: R. R. Nelson, ed., *Government and Technical Progress, A Cross Industry Analysis*. New York: Pergamon Press, 1982.

Fusfeld, H. I., "New Approaches to Support and Working Relationships." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

Fusfeld, Herbert I., Langlois, Richard N., and Nelson, Richard R., *The Changing Tide*, New York: NYU Center for Science and Technology Policy, Graduate School of Business Administration, November 1981.

Grabowski, Henry, and Vernon, John, "The Pharmaceutical Industry," in: R. R. Nelson, ed., *Government and Technical Progress, A Cross Industry Analysis*. New York, Pergamon Press, 1982.

Hazewindus, Nico, *The U.S. Microelectronics Industry*, New York: Pergamon Press, 1982.

Hippel, Eric von, *The Role of the Initial User in the Industrial Goods Innovation Process*, NSF, July 1978.

Johnson, P. S., *Cooperation Research in Industry*, New York: John Wiley & Sons, 1973. 232 pp.

Industrial Research Institute/Research Corporation, "Cooperative Technology Program: Evaluation of Nine Candidate Areas for Industry Participation and Support," Revised Version, December 16, 1979.

Large, Arlen J., "A 'Monument' Industry Innovation Law Crumbles," *The Wall Street Journal*, July 15, 1981, p. 34.

Libsch, J. F., "The Role of the Small, High Technology University." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

Mansfield, Edwin, "Basic Research and Productivity Increase in Manufacturing." *American Economic Review*, 70 (December 1980), pp. 863-873.

Mansfield, Edwin, *et al.*, *Research and Innovation in the Modern Corporation*. New York: W. W. Norton, 1971.

Mogee, Mary Ellen, "The Relationship of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity." Washington, D.C.: Library of Congress, Congressional Research Service, August 24, 1979.

Nason, Howard K., and Steger, Joseph A., *Support of Basic Research by Industry*. Washington, D.C.: National Science Foundation, 1978. (Prepared for NSF/STIA/SRS under Grant NSF C-76-21517.)

National Commission on Research, *Industry and the Universities: Developing Cooperative Research Relationships in the National Interest*, August, 1980.

National Trade and Professional Associations of the United States and Canada, and Labor Unions, Washington, D.C.: Columbia Books, Inc., 1981.

Nelson, Richard R., ed., *Government and Technical Progress, A Cross-Industry Analysis*, New York: Pergamon Press, 1982.

Omenn, Gilbert S., "University/Industry Research Linkages: Arrangements between Faculty Members and their Universities," Presentation to AAAS Symposium on Impact of Commercial Genetic Engineering on Universities and Non-Profit Institutions, Washington, D.C., January 6, 1982.

Organization for Economic Cooperation and Development (OECD), *The Future of University Research*, OECD, Paris, 1981.

Pavitt, K., and Walker, W., "Government Policies Toward Industrial Innovation: A Review," *Research Policy*, vol. 5, no. 1, January, 1976.

Pennsylvania Science and Engineering Foundation (PSEF), "Putting Technology to Work," undated pamphlet, Harrisburg, Pennsylvania.

Picardi, Shirley Mae, "Survey of MIT Industrial Liaison Program Member Companies Located in the U.S. and Canada," MIT, MS Thesis, 1981.

Prager, D. J., and Omenn, G. S., "Research, Innovation, and University-Industry Linkages," *Science*, vol. 207, January 25, 1980, pp. 379-384.

Quigley, John, "Residential Construction," in: R. R. Nelson, ed., *Government and Technical Progress, A Cross Industry Analysis* New York: Pergamon-Press, 1982.

Rabkin, Y. M., and Lafitte-Houssat, J. J., "Cooperative Research in the Petroleum Industry," *Scientometrics*, 1 (Nov. 4, 1979), pp. 327-338.

Research Management, "Perspectives," March, 1981, p. 2.

Roberts, Edward B., and Peters, Donald H., "Commercial Innovations from University Faculty," *Research Management* May 1982, pp. 24-30.

Rogers, Everett M., Eveland, J. D., and Bean, Alden S., "Extending the Agricultural Extension Model," Stanford University, Institute for Communication Research, September, 1976. (U.S. Department of Commerce, NTIS PB-285119.)

Shapero, Albert, *University-Industry Interactions: Recurring Expectations, Unwarranted Assumptions and Feasible Policies*. Columbus, Ohio: Ohio State University, July 31, 1979. (Prepared for NSF/STIA/PRA under PO-SP-79-0991.)

Shapley, Willis H., Teich, Albert H., Breslow, Gail J., and Kidd, Charles V., *Research and Development*, AAAS Report, Washington, 1980.

Smith, Bruce L. R., and Karlesky, Joseph, J., *The State of Academic Science: The Universities in the Nation's Research Effort*, New York: Change Magazine Press, 1977.

Thackray, Arnold, "University-Industry Connections and Chemical Research: an Historical Perspective." A report submitted to the National Science Board, 1982.

Teich, Albert H., Lambright, W. Henry, and Shelanski, Vivien B. "The Role of National Laboratories in University-Industry Relationships", a report to the National Science Board, September 1981.

Teich, Judith L., "Inventory of University-Industry Research Support Agreements in Biomedical Science and Technology," A report prepared for the National Institutes of Health, 1982.

U.S. Department of Commerce, "Cooperative Generic Technology Program Procedures," *Federal Register*, vol. 45, no. 159, August 14, 1980, pp. 54028-54031.

U.S. Department of Commerce, Office of Cooperative Technology, "Cooperative Technology Program: Key to Industrial Innovation," Revised Draft, January 24, 1980.

U.S. Department of Commerce, "1981 U.S. Industrial Outlook for 200 Industries with Projections for 1985," Washington, D.C.: U.S. Government Printing Office, 1981.

U.S. Department of Energy, Office of Conservation and Solar Applications, *The DOE Industrial Conservation Program: A Partnership in Saving Energy*, Washington, D.C., undated.

United States. National Science Foundation, *Five-year Outlook on Science and Technology-1981*, Washington, D.C.: U.S. Government Printing Office, 1982.

United States. National Science Foundation, *1980 Industrial Program Grantee Conference Proceedings*, edited by David E. Douglas, Industrial Research and Extension Center, University of Arkansas, Little Rock, Arkansas, 72203.

United States. National Science Foundation, *National Patterns of R&D Resources: Funds and Personnel in the United States, 1953-1979*, Washington, D.C.: U.S. Government Printing Office, 1979.

United States. National Science Foundation. *Proceedings of a Conference on Academic and Industrial Basic Research*, Princeton University, November 1960. (NSF 61-39.)

United States. National Science Board, *Science Indicators—1980*, Washington, D.C.: U.S. Government Printing Office, 1981.

United States. National Science Foundation, *Scientists, Engineers, and Technicians in Private Industry: 1978-80*. (Special report, NSF 80-320.)

U.S. Senate, "National Technology Innovation Act of 1979," 96th Congress, Second Session, Report No. 96-781, May 15, 1980.

Vetter, B. M., "Supply and Demand for Scientists and Engineers," Washington, D.C.: Scientific Manpower Commission, 1977.

Zerkel, Fred H., "White House Shapes Strategic Approach to R&D," *Chemical and Engineering News*, March 20, 1972, p. 24.

APPENDIX I

List of the ninety-six institutions visited in this study (universities, companies and others).

University Sample

Public	Private
Great Lakes Area	
Purdue University	Case Western Reserve
University of Illinois	University of Chicago
University of Michigan	
University of Wisconsin	
Southeastern	
Georgia Institute of Technology	
Southwest & South Central	
Louisiana State University	Washington University (St. Louis)
University of Texas (Austin)	Rice University
University of Houston	
Colorado State University	
Colorado School of Mines	
Middle Atlantic	
University of Delaware	Johns Hopkins University
University of Maryland	Lehigh University
Pennsylvania State University	Carnegie Mellon University
Clemson University	Duke University
North Carolina State U.(Raleigh)	Princeton University
University of North Carolina (Chapel Hill)	
Northeastern	
	University of Rochester
	Rensselaer Polytechnic Institute
	Harvard University
	MIT
	Yale University
Northwest & Great Plains	
University of Minnesota	
University of Washington	
California & the West	
University of Arizona	Stanford University
University of California (San Diego)	University of Southern California
UCLA	California Institute of Technology
University of Utah	

Industrial Sample

Aerospace

United Technologies
Lockheed
Boeing
Fairchild Industries

Appliances

Singer

Automotive (cars, trucks)

General Motors

Automotive (parts, equipment)

TRW

Building Materials

Johns Manville
Ideal Basic Industries

Chemicals

Monsanto
E. I. Dupont de Nemours & Co.
UOP Inc.
Dow Chemical
Diamond Shamrock Corp.
Allied Chemicals

Conglomerates

Rockwell International

Containers

American Can

Drugs

Burroughs Wellcome
Alza Corp.
Merck Sharpe & Dohme
Upjohn

Electrical

General Electric
Westinghouse Electric

Electronics

Tracor, Inc.
Ampex
Varian Associates

Food, Beverages

General Mills, Inc.

Fuel

Exxon
Shell
SOHIO
AMOCO

Information Processing: (computers, peripherals)

Hewlett-Packard
Honeywell
Control Data Corporation
IBM

Information Processing: (office equipment)

Xerox
Bell Laboratories
Fisher Scientific

Instruments (measuring devices, controls)

Foxboro
Perkin Elmer

Leisure Time Products

Eastman Kodak Co.

Machinery (farm construction)

American Hoist & Derrick

Machinery (machine tools, industrial, mining)

Cincinnati Milacron

Metals, Mining

Aluminum Co. of America

Miscellaneous Manufacturing

Borg Warner Corp.
3M Company
Ceramatec

Oil Service Supply

Dresser Industries
Hughes

Paper

Crown Zellerbach

Personal & Home Care Products

Procter & Gamble

Semiconductors

National Advanced Systems
Intel
Signetics (Philips North America)

Steel

U. S. Steel

Telecommunications

Communications Satellite
General Telephone & Electronic Corporation

Textiles

J. P. Stevens

Tires, Rubber

General Tire and Rubber Co.

Tobacco

American Brands

Additional Site Visits

Research Contract Business

Mathematical Sciences Northwest

Genetic Engineering Co.

Genex

Software & Computer Graphics

Evans and Sutherland

Technical Services

Terratek

Research Institutes

Electric Power Research Institute
Scripps Clinic and Research Foundation
Carnegie Mellon Research Institute

Government Agencies

Office of Naval Research
National Science Foundation
National Institutes of Health

APPENDIX II

PROTOCOLS FOR SITE VISITS

The following are examples of the types of questions asked during our interviews of administrators and scientists at companies and universities surveyed in this study.

NSF Study: University/Industry Research Interactions

Protocol for University Site Visit

Our objective is talk to key individuals involved in university/industry research interactions. We are interested in talking to those people responsible for initiating such interactions and those conducting research in the programs generated. Therefore, our visits should include discussions with appropriate administrators and heads as well as directors of and participants in joint university/industry programs.

General Questions

1. a. What do you perceive to be the problems and/or benefits that would result from university/industry research programs?

   b. Which of these barriers is the most difficult to overcome and which of the benefits is the most important in encouraging university/industry research interaction?

2. Do you prefer to participate in a federally sponsored program, an industry sponsored program, or an industry and government sponsored program?

3. a. Would you like to see an increase in joint university/industry programs?
   b. What is the ideal mix of industry and government support of university research?

4. Do you compute overhead in an industry sponsored program in the same manner as you compute it for a government sponsored program?

5. Describe the most outstanding type of interaction your institution (or you) has had with industry. (Consider the following in describing the program: initiation, structure, goods and outcomes)

Questions for directors of university/industry research programs and participants in such programs

1. Describe the sequence of events which lead to the establishment of the program.

   a. Did the program begin because of industry or university initiatives?

   b. Did the government play any role in the initiation of the program?

   c. Who specifically was responsible for starting the program?

   d. What was his/her (their) position in the participating institution(s) and how much time did it take to establish the program?

   e. To what extent did previous cooperative activities (e.g., consulting, personnel exchanges) affect the initiation of this program?

   f. How were participants (both individual and institutional) selected?
   g. What effect did the proximity of the companies involved have on the establishment of the program?

   h. What processes were involved in establishing the program? Consider the following in describing the evolution of the program: formation of advisory committee, delineating patent rights, new facility construction, geography, travel time and cost, prior relationships, needs and benefits, barriers and constraints.

   i. What were the most important factors and critical incidents in bringing about this cooperation and in providing for its continuation?

   j. How long has the program been in existence?

2. What were the specific objectives/goals when the program was established; were they achieved?

3. How is the program structured and administered?
   a. What are the specific arrangements for staffing and administration?
   b. What is the program's relationship to the university administrative system?
   c. What is the research management structure?
   d. What is the number of decision-making levels?
   e. What are the roles of each partner in decision-making relevant to the determination of the project's budget, staffing, changes in goals, etc.?

4. What were the resource commitments arranged between partners?
   a. What are the funding commitments?
   b. Who is involved in the program and what is the mix of faculty, students, research scientists, and administrators?

5. What were the problems/barriers and benefits/needs which governed the establishment of this program?

6. What policies served as incentives or disincentives for your participation in this program?

7. How much time do you spend on the program?

8. What rewards did you expect to receive as a result of your participation on this program? What rewards did you actually receive?

9. What do you see as the outcome(s) of these joint ventures?

Questions directed toward administrators

1. a. In what type of university/industry research interactions does your university (department) engage?
   b. What is your reason for participating in this type of interaction?

2. a. In what types of university/industry research programs do you prefer to participate?
   b. What is the reason for your preference?

3. Which types of interactions do you think are most beneficial to the university, to the company, to the department, to the individual participants involved?

4. What are the policies and practices of the university (your department) that serve as incentives or disincentives to establishing joint university/industry research programs?

5. a. What are the formal and informal channels of communication between your university (department) and industry in the vicinity of the university (and U.S. industry in general)?
   b. What effect does location have on your establishing or maintaining channels of communication?
   c. Does the character of industry in the vicinity of your university affect the research that goes on at the university.?

NSF Study: University/Industry Research Interactions

Protocol for Industry Site Visit

Our objective is to talk to key individuals involved in university/industry research interactions. We are interested in talking to those people responsible for initiating such interactions and those conducting research in the programs generated. Therefore, our visits should include discussions with appropriate administrators and division heads as well as directors of and participants in joint university/industry programs.

General Questions

1. a. What do you perceive to be the problems and/or benefits that would result from university/industry research programs?

   b. Which of these barriers is the most difficult to overcome and which of the benefits is the most important in encouraging university/industry research interaction.

2. Do you prefer to give money to a university research program sponsored solely by your company, sponsored by several companies, or sponsored by industry and government?

3. a. Would you like to see an increase in joint university/industry programs?

   b. What is the ideal mix of industry and government support of university research?

4. Describe an outstanding research interaction your company has had with a university. (Consider the following in describing the program: initiation, structure, goods, and outcomes.)

Questions directed toward administrators

1. a. In what type of university/industry research interactions does your industry engage?

   b. What is your reason for participating in this type of interaction?

2. a. In what types of university/industry research programs do you prefer to participate?

   b. What is the reason for your preference?

3. Which types of interactions do you think are most beneficial to your company, to the individual participants involved.?

4. What are the policies and practices of your company that serve as incentives or disincentives to establishing joint university/industry research programs?

5. a. What are the formal and informal channels of communication between your company and universities in the vicinity of your company (and U. S. universities in general)?

   b. What effect does location have on your establishing or maintaining channels of communication?

Questions for directors of university/industry research programs and participants in such programs

1. Describe the sequence of events to the establishment of the program.

   a. Did the program begin because of industry or university initiatives?

   b. Did the government play any role in the initiation of the program?

   c. Who specifically was responsible for starting the program?

   d. What was his/her (their) position in the participating institution(s) and how much time did it take to establish the program?

   e. To what extent did previous cooperative activities (e.g., consulting, personnel exchanges) affect the initiation of this program?

   f. How were participants (both individual and institutional) selected.?

g. What effect did the proximity of the universities involved have on the establishment of the program?

h. What processes were involved in establishing the program? Consider the following in describing the evolution of the program: formation of advisory committee, delineating patent rights, new facility construction, geography, travel time and cost, prior relationships needs and benefits, barriers and constraints.

i. What were the most important factors and critical incidents in bringing about this cooperation and in providing for its continuation?

j. How long has the program been in existence?

2. What were the specific objectives/goals when the program was established; were they achieved?

3. How is the program structured and administered?

   a. What are the specific arrangements for staffing and administration?

   b. What is the program's relationship to the company's management structure?

   c. What is the research management structure?

   d. What is the number of decision-making levels?

   e. What are the roles of each partner in decision-making relevant to the determination of the project's budget, staffing changes in goals, etc?

4. What were the resource commitments arranged between partners?

   a. What are the funding commitments?

   b. Who is involved in the program and what is the mix of faculty, students, research scientists, and administrators?

5. What were the problems/barriers and benefits/needs which governed the establishment of this program?

6. What policies served as incentives or disincentives for your participation in this program?

7. How much time do you spend on the program?

8. What rewards did you expect to receive as a result of your participation on this program? What rewards did you actually receive?

9. What do you see as the outcome(s) of these joint ventures?

APPENDIX III

SAMPLE MATRIX

The following matrix is a sampling of university/industry research interactions documented at the institutions visited in this study. It is not meant to be an exhaustive list of university/industry research interactions, but does contain most of the significant research interactions of these institutions with companies. (See end of Appendix for footnotes)

NORTHEASTERN

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction**	No. of Years In Existence*
23	Private	University of Rochester	Exxon, SOHIO, GE, Northeast Utilities	Laboratory for Laser Energetics	Physics, Aerospace, Electrical & Chemical Engineering	Government-industry funded cooperative research laboratory (jointly used facility)	11 years
			Xerox, Gleason Ward, GM, Boeing, Kodak (& others)	PADL Program	Mechanical & Electrical Engineering (CAD)	Ind/Gov't funded U/I cooperative research (grants)	8 years
			Abbott, Allied Chemical, Owens-Illinois, Xerox, TRW (20 companies)	Institute of Optics	Optical Engineering	Industrial funded cooperative research center, contract research & industrial affiliates (focused)	53 years
			General Ionex Corporation	Additions to Tandem Accelerator Facility at U. of Rochester for Ultra Sensitive Particle Ident.	Physics	Gov't funded U/I cooperative research (grant)	Time Limited 2 years*
			Xerox	Computer Science	Computer Science	Equipment discount	7 years
				Industrial Park	Multidisciplinary	Industrial park	New
			Miles, Cullers, Bayer, Dow	Bacillus Subtilus Fermentation	Medicine	Industry funded U/I cooperative research (contract-grants)	9 years
			Drug Co., Chemical Co., Consumer Product Co., Conglomerates	Optics Industrial Associates Program	Optical Engineering	Industrial affiliates (focused)	5 years
126	Private	Rensselaer Polytechnic Institute	United Technologies, GE, GM, Boeing, Norton, Kodak, Cincinnati Milacron, Fairchild Republic	Center for Manufacturing Productivity	Engineering	Industry funded U/I cooperative research center	2 years
			IBM, Evans & Sutherland, Hewlett-Packard, Prime Computer (& 20 cos.)	Center for Interactive graphics	Computer Science, Engineering	Government/ Industry funded U/I cooperative research center	3 years
			IBM (& 8 cos.)	Center for Microelectronics	Engineering Science (VLSI)	Industry funded cooperative research center	New
			Raster Tech., Inc. Testamatic Corp. & others	Industrial Park	Multidisciplinary	Industrial Park	New
8	Private	Harvard	Monsanto	Harvard Monsanto	Life Sciences	Partnership (contract)	6 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Seagram & Sons	Alcoholism Program	Medicine	Grant	1 year
				Biogen	Molecular Biology	Spin-off co.	3 years
			Mutual Research Corporation	Diffusion Flame Energy Transfers	Chemistry	Government funded cooperative research	Time limited 1 year*
			Hoechst	Molecular Biology Laboratory	Medicine	Partnership (contract)	New-time limited (10 years)
				Harvard School of Public Health—Industrial Associates Program	Environmental Health	Industrial affiliates (focused)	1 year
			DuPont	DuPont-Harvard Agreement	Molecular Genetics	Partnership (contract)	New
1	Private	MIT		MIT Industrial Visiting Committees.	Multidisciplinary	Membership on Advisory or Governing Boards	Ongoing
			Bayer	Bayer Professorships	Chemical engineering	Endowed chair	5 years
				Laboratory for Manufacturing Productivity	Multidisciplinary	Research consortia	4 years
			10 Companies	MIT Chemical Sciences/Industrial Forum	Chemistry	Seminars—Informal discussion	Recent
			30 Companies	Engineering internship program	Engineering	Education-training internship	3 years
			50 outside organizations	Undergraduate research opport. program	Multidisciplinary	U/I Cooperative training program	12 years
				Cooperative program	Electrical engineering, Computer science	research internship (Summer employment)	Ongoing
				Center for the Health Effects of Fossil Fuel Utilization	Environmental science & Toxicology	Gov't/Industry funded cooperative U/I research center (grants-contracts)	2 years
				National Magnet Laboratory	Physics & Engineering	University based institute serving industrial needs (contract/ subcontract)	20 years
			25 Companies	Center for Energy Policy Research	Social Science	Industrial Affiliates (focused)	5 years
			19 Companies (users & vendors)	Center for Information Systems Research	Computer Science	Industrial Affiliates (focused)	7 years
			Allied Chemical Corp.	Theoretical Studies of Polydiacetylenes & Polyacetylenes	Materials science	Gov't funded U/I cooperative research (grant)	Time Limited 2 years*
			IBM	Instrumentation of an X-ray Beam Line at Nat'l. Synchrotron Light Source, Brookhaven	Materials Science	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*
			Perkin-Elmer Corp.	Laser-Generated Etching of Semiconductor Surfaces	Chemistry	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*

Northeastern—Cont.

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Exxon Corporation	Effect of Bulk Lqd. vs. Gas Phase on Selectivity in the Fischer-Tropsch Syn.	Chemical engineering	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*
			Pratt & Whitney	Powder Metallurgy	Materials science	Gov't funded U/I cooperative research (grant)	4 years
			General Electric	Ceramic Transparencies	Materials science	Gov't funded U/I coop. res. (contract)	4 years
			Electronics Industries	Microelectronics	Engineering	Industry-government funded cooperative research center	New
			Rolls Royce	Energy	Engineering	Government-industry funded cooperative research (contract)	4 years
			Bolt, Beranek & Newman. Inc.	Military science	Math, Engineering	Gov't funded coop. res. (contract)	2 years
			Exxon	Exxon-MIT	Combustion Energy	Partnership (contract)	1 year Time limited (10 years)
			ITT, GM, Xerox (12 cos.)	MIT Polymer Processing Program	Engineering, Chemistry, Matls. Sci.	Government & industry funded cooperative research center	8 years
			Computer Control Corp., Hertra Inc.	Innovation Center—MIT	Engineering	Innovation Center	8 years
			265 companies	MIT Industrial Liaison Program	Multidisciplinary	Industrial associates (general)	34 years
			EPRI, GRI	Energy Laboratory	Engineering, Science Policy	University based laboratory serving industrial needs, trade assoc. support, (contracts)	10 years
			A.D. Little, GE, Union Carbide	MIT School of Chemical Engineering Practices	Chemical Engineering	Industrial extension	64 years
			Texaco	Career Development Term Chair	Chemical Engineering	Endowed Chair (partial)	1½ years
			Flow General	Biotechnology	Biology	Ind. funded coop. res. (contract)	New 5 years
			Many Companies	MIT Technology Square	Multidisciplinary	Industrial Park	19 years
			Whitehead Foundation	MIT-Whitehead Institute	Developmental Molecular Biology	Industry/Foundation funded research institute	New
24	Private	Yale University	Miles Laboratory	Institute of Preclinical Pharmacology	Medicine	University based institute serving industrial needs (facility sharing)	1 year
			Texaco	Yale/Texaco	Chemical Engineering	Institutional consulting	Time Ltd. 2 yrs. (ended)
			AVCO Everett Research Laboratory	Theoretical Investigation of Electron Impact Excitation Processes	Physics	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*

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Northeastern—Cont.

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Celanese	Composition and Synthesis of Enzymes	Biochemistry, Molecular Biology	Partnership (contract)	3 years
				Yale Associates	Multidisciplinary	Industrial associates (campus-wide program)	New
			Olin Corporation, City of New Haven	Science	Multidisciplinary	Industrial Park	New

MIDDLE ATLANTIC

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
105	Public	University of Delaware	Oil & Chemical Cos. (Approx. 20-23 cos.)	Center for Catalytic Science & Technology	Chemical Engineering	U/I cooperative research center Industrial affiliates	3½ years
			GE, DuPont, Hercules, Ford, Corning (Approx. 13 cos.)	Center for Composite Materials	Mechanical Engineering	U/I cooperative research center Industrial affiliates	7 years
			Chevron & Other Cos. (Approx. 7)	Institute for Energy Conversion	Photovoltaics	University based institute serving industrial needs (contract)	9 years
			Information Ser ·ce Co.	Computer Aided Design Laboratory	Computer Science and Engineering	Equipment gift	New Program
			IBM	Distributed Computing	Electrical Engineering	Industrial funded cooperative research (contract)	Time limited 2-3 years (ending)
			DuPont	UNIDEI Foundation	Multidisciplinary	Endowment Foundation	32 years
			13 Cos.	Symposia	Chemistry	Symposia Conference	Time limited Recent
				Ocean Engineering Liaison Program	Oceanography & Engineering	Industrial Affiliates (focused)	New
			Intel	Fellowships	Computer Science, Micro processes	Undergraduate fellowships	New
			Wyeth Labs du Pont	Chemistry	Chemistry	Equipment gift (mass spectrophotometer	2 years
			Sohio, DuPont, Stauffer	Chemistry	Chemical Engineering	Personnel Exchange	1 year
15	Private	Johns Hopkins	Biospherics	Venture Program	Env. Science, Biology, Eng.	NonProfit Organization	2 years
			Bristol Myers	Center for Oncology	Basic medical sciences	Unrestricted gift	5 years Time limited
			Siemens, GE, Picker, Pfizer, Phillips	Radiology Program	Radiology-Computer Sciences	Equipment donation	3-5 years
			Institute of Scrap Iron & Steel	Center for Materials Research	Multidisciplinary	University based institute serving industrial needs (contract)	1 year

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Exxon Research and Engineering	Systematic Develop. of New Organic Conductors	Chemistry	Government funded U/I cooperative research (grant)	Time Limited 1 year*
			Applied Research Laboratory	Defense	Mathematics, Fl. Mechanics	Government funded cooperative research (contract)	4 years
			Chemical Sys. Lab.	Education	Biochemistry	Government funded cooperative research (contract)	3 years
			Oil & Chemical Co. Exxon, Union Carbide	Biotechnology Institute	Biology, Eng. Medicine (cross-discp.)	Technology transfer center	New
			Fairchild	Fairchild Projects	Grants		Time limited New
			Burroughs-Wellcome	Burroughs-Wellcome Prof. of Oncology	Oncology	Endowed Chair	30 years
			A. Benzone	Interferon	Basic Med. Science	Contract	Time limited (5 years)
46	Public	University of Maryland	Fairchild Industries	Fairchild Scholars Program	Elec. & Communications, Engineering	Industry funded cooperative training program	3 years
			Genex Bethesda Research Labs (BRL)	Certificate Program in Appl. Molecular Biology	Molec. Bio., Biochemistry, Bioengrg.	Industry/University cooperative training program	New
			Many	SciComplex	Biotechnology & Electronics	Industry Park	1 year
			Koppers Co.	Chemicals, Wood Preservatives	Microbiology, Biology, Chemistry	Government funded cooperative research (contract)	5 years
			Physical Sciences Inc.	Collision-Induced Emission and Light Scattering in High Pressure, High Temperature Gases	Chemical Engineering	Government funded U/I cooperative research (grant)	Time limited 1 year*
			du Pont	Manufacture of Interferon	Biochemistry-genetics	Industry funded cooperative research (contract)	Time limited (2 years)
			CDC	Computer System Design & Manufacture	Computer Science	Industry/university cooperative training program—equipment transfer	New
16	Public	Pennsylvania State U.	Various small companies	Penn. Tech. Asst. Program (PENNTAP)	All	Extension services technology transfer	16 years
			AICHE	Data Book Project	Chemical Engineering	Personal Interaction-publication	10 years
			Bechtel, other cos.	Fellowships	Engineering	Fellowship	New
			GE, Bethlehem Steel	Material Research Laboratory	Materials Science	Industry/university cooperative research center	20 years
			Many	Office for Indus. Research and Innovation	All	Innovation center	1 year
				Ceramics Liaison Program	Materials Science, Engineering	Industrial Affiliates (focused)	New
				Geology Liaison Program	Geology	Industrial Affiliates (focused)	New

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			GE	Electrical Eng. Industrial Affiliate	Electrical Engineering	Industrial Affiliates (focused)	New
			U.S. Steel (& 15-20 Co.)	Metallurgy Ind. Coop. Program	Metallurgy in College of Earth & Min. Science	Industrial Affiliates (focused)	10 years
				Coal Cooperative Program	Several Depts in College of Earth & Min. Science	Industrial Affiliates (focused)	2 years
130	Private	Lehigh	4-5 companies	Center for Surface & Coatings Research	Chemical Eng. Chemistry, Metallurgy	Industry funded cooperative research center	10 years
				Energy Research Center	Engineering, Science	Industry funded cooperative research center	3 years
			Air Products, Bethlehem Steel, Leeds, DuPont, AFCO, Northrop, American Standard, Instrument & Control (approx. 20 cos.)	Materials Science Research Center	Metallurgy, Materials Engineering	Industry funded cooperative research center	19 years
				Biotechnology Center	Chem. & Civil Engineering, Chemistry, Biology	Industry funded cooperative research center	1 year
				Institute of Metal Forming (IMF)	Metallurgy Materials Engineering	Industrial affiliates (focused)	11 years
			National Printing Ink Trade assoc.	Color Associates	Chemistry Chemical Engineering	Collective industrial support (grants)	35 years
			General Electric	Heat Transfer in Rotating & Curved Ducts	Civil & Mechanical Engineering	Government funded cooperative research (grant)	Time limited 1 year*
			Bethlehem Steel (& approx. 20 cos.)	Materials Science	Materials Science	Industrial affiliates (focused)	18 years
			20 companies	Computer Associates Program (CAP)	Computer	Industrial affiliates (focused)	6-7 years
			Energy Product & Equip. Manufacturers, Energy Users (Approx. 20 cos.)	Energy Liaison Program (ELP)	Multidisciplinary	Industrial affiliates (focused)	3-4 years
			20 Companies	Emulsion Polymer Institute Liaison Program	Metallurgy, Mat. Science, Chem. Eng., Chemistry	Industrial affiliates (focused)	5 years
				Thermo-Fluid Liaison Program	Mech & Chem Engineering	Industrial affiliates (focused)	3 years
			4-5 Companies	Center for Surface and Coatings Liaison Program	Metallurgy, Chemistry, Chem. Eng.	University/industry cooperative research center	10 years
				Biochem Liaison Program	Biochemistry	Industrial affiliates (focused)	2-3 years
			5 companies	Freezing Coal Program	Multidisciplinary	Government-Industry-University Contract (Res. Consortium)	New

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Fairchild Foundation	Engineering Fellowship Program	Solid State Phys. & Engrg	Fellowsh/Endowed Chairs/Equipment/ Facility	5 years
64	Private	Carnegie Mellon	Exxon, Xerox, Alcoa, Ford, Westinghouse	Processing Research Institute	Process Engineering	Govt. funded U/I coop. res. (grant)	10 years
			Westinghouse	Robotics Institute	Computer Science	Industry/university cooperative research center	2 years
			Mobay Chemical	Mobay Professor	Chemistry	Endowed Chair	5 years*
			Alcoa	CMU-Alcoa Exchange	Chem. Engrg.	Personnel exchange	Time limited 3-5 yrs. (ended)
			Oil Co	Catalysis Lab	Chem. Eng.	Equipment	Time Limited (5 years)
			EIA (small synfuel co.)	Environmental Engrg.	Env. Eng.	Contract	Time limited recent
			Gulf Research	Civil Engineering	Civ. Eng.	Grant Personnel Exchange	Time limited recent
		(Also the U. of Pittsburgh)	U.S. Steel, Alcoa, PP&G, Westinghouse, Gulf	Ad Hoc Committee on Coop. Research	Combustion & Coal Utilization	Contract Research	1 year
			Many	Carnegie Mellon Institute	Multidisciplinary	Contract Research Institute	68 years
			Westinghouse	Investigation of Electrical Breakdown in Vacuum	Electrical Engineering	Government funded U/I cooperative research (grant)	Time Limited 1 year*
			IBM	Statistical Design of Integrated Circuits	Electrical computer & systems eng.	Government funded U/I cooperative research (grant)	Time Limited 1 year*
			Digital Equipment Corp.	Facility Development & artificial Intel. Knowledge Representation	Computer Science	Equipment discounts	Time Limited 5 years*
			Xerox	Personal Computing Program	Computer Science	Personnel exchange & equipment donation	Time Limited 5 years*
			Many	Center for Entrepreneurial Development	Multidisciplinary	Innovation center	8 years
			Koppers (& 3 Cons. Eng. firms)	Cooperative Masters Degree Prog.	Civil Engineering	Personnel Exchange	New
91	Public	Clemson University	Poultry Assoc., Tobacco Co., Food & Food Pkg., Grain Co.	Agriculture Extension	Agriculture	Extension Services	67 years*
			Westvaco	Nitrogen Fixation Program	Forestry	Industry funded U/I cooperative research (contract)	Time Limited 1 year
			American Hoechst, Caterpillar, Alcoa Fdn., Duke Power, John Deere Co.	Mechanical and Manufacturing Systems Design	Mechanical Engineering	Institutional consulting	3 years
			J.P. Stevens	Textile Science	Engineering	Gifts and Industry funded cooperative research	29 years
			Diamond Shamrock	Biologically active factors	Microbiology	Industry funded coop. res.-contract	Time Limited New

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			DuPont	Chemical Waste Contamination	Forestry	Gov't.-Industry funded coop. res	Time Limited 1 year
			Trade Assoc.	Woven Fabric Center	Textiles	University based institutes serving industrial needs	New
			Hooker Chemicals, USDA, Textile Mills	Flame Retardant Program, ETIP Progr.	Textiles	Research consortia	Time limited 8 years* (ended)
			Renky Co.	Irrigation Program	Agricul. Eng. (irrigation)	Equipment loan	Time Limited (3 years)
			DEC	Computer Graphics Research Program	Elec. & Comp. Engineering	Equipment grant	1 year
			6 Companies	Clemson Park	Multidisciplinary	Industrial park	16 years
			American Soybean Assoc., Sparry & New Holland	Computer controlled grain combine	Computer Science	Equipment loan	Recent (1-2 years)
45	Public	North Carolina State U. (Raleigh)	Several	Research Triangle Park	Multidisciplinary	Industrial park	22 years
			Furniture Mfg. (6)	Furniture R&D Applications Inst.	Engineering	Govt. funded U/I coop. res. center	8 years
			Neuman Machine Co.	Acoustic Laboratory	Mechanical & Aerospace Engineering	Government-industry funded research (contracts)	11 years
			Sun Oil, Texas Gulf, Owens Corning, Moisture Controls Systems (& others)	Minerals Research Laboratory	Engineering	Government-industry funded research Center	10 years
			Pullman-Woodex, IBM, Handcore, MidState Tile	ERSD	Engineering	Industrial extension	25 years
			Many	Research Triangle Institute	Multidisciplinary	Research institute (contract)	21 years
			Many	TUCC	Computer Science	Research institute	16 years
			Many	Triangle U. Recombinant DNA Co.	Multidisciplinary	Development Co.	New
			GE	Microelectronics Center of N.C.	Engineering & Comp. Science	State-govt. funded U/I coop. research	1 year
			B.F. Goodrich	Transport and Relaxation in Glassy Polymers	Chemical Engineering	Govt. funded U/I cooperative research (grant)	Time Limited 1 year*
			DEC, IBM, Lockheed, Daniel Fluor	Graphics	Computer Science	Industry funded cooperative research	Time limited New
52	Public	University of North Carolina (Chapel Hill)	GE	Microelectronics Center of North Carolina	Engineering & Computer Science	State-govt. funded U/I cooperative research	1 year
			DuPont	Chemistry	Chemistry	Gift	Several years
			Lithium Corp. of America	Lithium Iron Conductor	Chemistry	State-govt. funded U/I coop. research	Time limited 1 year
			Diamond Shamrock, GTE Labs	Summer Research Fellowships	Chemistry	Fellowship	Recent

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Rubber Co., Phosphate Co. Wkers. Unions	Occupational Health Sciences Group	Environmental Health Sciences	Industry funded cooperative research	11 years
			IBM	Computer Graphics	Computer Sciences	Unrestricted gift	Time limited new
			Many	Research Triangle Park	Multidisciplinary	Industrial park	22 years
			Many	Research Triangle Institute	Multidisciplinary	Research institute (contract)	21 years
				TUCC	Computer Science	Research institute	16 years
			Many	Triangle U. Recombinant DNA Co.	Multidisciplinary	Development Co.	New
44	Private	Duke	GE	Microelectronics Center of North Carolina	Engineering & Computer Science	State-govt. funded cooperative research	1 year
			Many	Industrial Associates	Engineering	Industrial associates	1 year
			A.D. Little	DUMAT	All	Private Non-Profit Licensing Co. (PMO)	1 year
			FMC	Post-doctoral Chemistry Program	Chemistry	Personnel exchange	Time limited 2-3 years
			Many	Research Triangle Park	Multidisciplinary	Industrial park	22 years
			Many	Research Triangle Institute	Multidisciplinary	Research institute (contract)	21 years
				TUCC	Computer Science	Research institute	16 years
			Many	Triangle U. Recombinant DNA Co.	Multidisciplinary	Development Co.	New
			FMC, Mobil Chemistry, Dow, Bayer	Chemical Screening Program	Chemistry	Industry funded coop. res. (contr.)	1 year
			Shell International, Oceaneering Int'l.	Man under sea activities	Biomedical sciences	Govt.-industry funded U/I coop. res. (contract)	2 years
			Data General	Computer science, engineering	Electrical Engineering	Unrestricted gift	Time limited recent
			Weyerhauser (& others)	Mercury Fund	Medicine, Public Health	Unrestricted funds	Ongoing 5 years
			GE, Burroughs-Wellcome	Power Electronics Program	Electrical Engineering	Equipment gift & Fellowship	New
			Local Companies	Health Care Systems	Medicine	For Profit Corp.	10 years
			Monsanto	Physico-Chemical Studies of Rodlike & Semi-flexible Chain Polymers	Materials Science	Government funded cooperative research (grant)	Time Limited 2 years
65	Private	Princeton U.	Burlington, J.P. Stevens (& other textile companies)	Textile Research Institute	Chemical Engineering	Industry funded cooperative research center-cooperative U/I training program	40 years
			Bell Labs	Fiber Optics	Electrical Engineering	Industry funded U/I cooperative research (grant)	Time Limited 11 years (ended)

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			United Tech. Research Center	Energy	Engineering combustion	Government funded U/I cooperative research (grant)	3 years
			Prudential Insurance Co.	Solar Energy	Energy & Environmental Science	Grant	2½ years
			Dow, Amoco	Engineering research	Engineering	Grants	Time limited
			Amoco, Tenneco, Conoco, GM, Ford, others	Center for Energy	Engineering	Gifts	Time limited
			Mobil	Several line items	Engineering	Industry funded coop. res. (grant)	Time Limited (5 yrs), 1 yr
			Prudential Insurance & others	Princeton Forrestal Center	Multidisciplinary	Industrial park	6 years
			Grumman Aircraft, other aerospace Cos.	Aerospace Program	Mechanical & Aerospace Engineering	Facility sharing; contracts	3 years

SOUTHEASTERN

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
38	Public	Georgia Tech.	Small Companies	Engineering Experiment Station	Engineering	Industrial Extension Service	50 years
			Many	Fracture & Fatigue in Metals	Chemical Engineering	Industrial Affiliates (focused)	New
			J.P. Stevens (& Approx. 60 other Cos.) Georgia Textile Mfg. Association	Textile Engineering	Engineering (Textile)	Industry funded (U/I cooperative research (equipment donation)	Time Limited but Eng. Dept. in Existence 40 years
			Many	Corporate Liaison Programs	Multidisciplinary	Industrial Associates (general)	New
			Prime, IBM, HP, DEC, Ungerman, Bass, Network, Loftec	Partnership Program	Information & Computer Sciences	Equipment donation	18 years
			Professional Co.	Technology Park Atlanta—University of Georgia Res. Park	Multidisciplinary	Industrial Park	20 years
			Many	Georgia Tech Research Institute	Multidisciplinary	Nonprofit Organization	40-50 years
			Many	Advanced Technology Development Program (ATDP)	Multidisciplinary	Innovation Program (Technical Assistance Program)	New
			Many	Video Instruction Program	Multidisciplinary	Continuing Education	1 year (new)
			Georgia Power	Professorship	Electric Power	Professorship (partially endowed)	New
			Whirlpool	Professorship	Mechanical Engineering	Professorship (partially endowed)	New
			IBM	Professorship	Computer Science	Professorship (partially endowed)	Time Limited (5 years)

GREAT LAKES AREA

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
29	Public	Purdue U.	CDC	CAD/CAM Research Project	Computer Science	Indus. funded coop. research (contract)	Time limited 3 years
			12 Companies	Herrick Labs	Mech. Eng. & Agriculture	Industry funded cooperative research center	23 years
			Abbott Laboratories	Structure & Function of Bacillus Thuringiensis	Biochemistry	Govt. funded U/I coop. research (grant)	Time Limited 1 year*
			BGS System. Inc.	Operational Analysis of Queueing Phen.	Computer sci. & engrg.	Govt. funded U/I coop. res. (grant)	Time Limited 1 year*
			Hughes Aircraft	Kinetics of Phase Transitions	Materials Science	Govt. funded U/I coop. res. (grant)	Time limited 2 years*
				Industrial Affiliate Program	Computer Science	Industrial Affiliates (focused)	1 year
				Industrial Affiliate Program	Chemistry	Industrial Affiliates (focused)	New
				Industrial Affiliate Program	Materials Engineering	Industrial Affiliates (focused)	1 year
			Many	Purdue Research Foundation	Multidisciplinary	Industrial Park	50 years
				Industrial Associate Program	Electrical Engineering	Industrial Affiliates (focused)	2 years
			U.S. Steel, Inland Steel Honeywell, Shipboard Control Systems	PLAC-Purdue Lab for Applic. of Indus. Control	Computer Science	U/I Cooperative Research Center	10 years*
			Caterpillar, J. Deere, Int'l. Harvester	Fellowships in CAD/CAM	Computer Science & Hydraulics	Fellowship	1 year
			Corning Glass Works, Weyerhauser	Fellowships in Engineering	Engineering Chem Engrg.	Fellowship	3 years
			5 companies	Computer Integrated Design, Manufacturing & Automation Center (CIDMAC)	Computer Science, Mechanical & Electrical Engineering	U/I Cooperative Research Center	1 year
			NASA, USDA, NSF, Reyes Paper Co. (& Other Paper & Oil Cos.)	LARS-Laboratory for Applied Remote Sensing	Electrical Engineering. Agriculture. Geosciences	University-based institute serving industrial needs	16 years*
			NIH, NCI, Indiana Elks and Companies	Cancer Research Center	Medicine	University based institute serving industrial needs (contract)	5 years
			Many	"Peoples Exchange"	Multidisciplinary	Equipment sharing	Recent
			6 Food & Paper Cos.	LORRE-Laboratory of Renewable Resources Engineering	Chem., Agric., Biochemistry, (food sci.) Chem. Engrg.	University based institute serving industrial needs (contracts)	3 years
12	Public	University of Illinois	Texas Instruments	Collaboration in Field Effect Transistors	Electrical Engineering	Industry funded cooperative research (grant)	Time Limited 3 years
			DuPont	School of Chemical Research	Chemistry, Chemical Engineering	University-based institute serving industrial needs Unrestricted gifts	51 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Rockwell International	Avalanche Photodiodes Using Quarternary Alloys for Fiber Optical Comm. Sys.	Electrical Engineering	Government funded U/I cooperative research (grant)	Time Limited 1 year*
			Martin Marietta	Formation & Reactivity of Tricalcium Silicate & Dicalcium Silicate	Civil & Mechanical Engineering	Government funded U/I cooperative research (grant)	Time Limited 1 year*
			Effects Technology Inc.	Electromagnetics Natural Resonances	Engineering	Govt. funded U/I coop. res. (contract)	6 years
			Power Industry	Electromagnetics Propagations and Communications Affiliates Prog.	Electrical Engineering	Industrial Affiliates (focused,	3 years
				Chemistry Industrial Associates	Chemistry	Industrial Affiliates (focused)	New
			IBM, GE, Hitachi, Hughes, Honeywell, Texas, Inst. (& approx. 50 other co.)	Physical Electronics Industrial Affiliates (PEAP)	Electrical Engineering	Industrial Affiliates (focused)	13 years
			Caterpillar, John Deere, GM, International Harvester (10 co.)	Fracture Control Program	Multidisciplinary	Research consortia	8-10 years
			4-5 Power Companies	Industrial Power Program	Electrical Engineering	Industrial Affiliates (focused)	2-3 years
			Dow Chemical	Cooperative Research	Chemistry	Research contract	Pending
			CDC	Computer Based Education Research Laboratory (CERL)	Computer Science	U/I Cooperative Research Center (contracts)	21 years
			Coal Industries	Strip mining reformation	Agriculture, Civil Eng., Env. Studies	Research Consortia	2 years
			IBM, American Can, Amoco, Argo Starch, Standard Corning Products	Research Board Program	Agriculture Engineering Science	Gifts	Recent
			IBM, Alcoa, United Technologies	Electrical Materials Program	Ceramic Engineering	Research Contract	6 years
			Local Companies	Allerton Park	Multidisciplinary	Research Park (gifts)	35 years
			American Iron & Steel Institute, Trade Assoc.	Engineering Research	Engineering	Contracts-4 projects projects	Recent
			Owens Illinois, IBM	Plasma Display Band	Computer Science	Contract, Licenses	14 years
7	Public	University of Michigan	GM, Ford, Intl. Harvester, Goodrich, Dunlop, Motor Vehicle Mfg. Assn.	Highway Safety Research Institute	Engineering	University based institute serving industrial needs	10-12 years

Great Lakes Area—Cont.

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Dow Chemical Co., Env. Research Institute of Michigan, Michigan Consolidated Gas, Detroit Edison, others	(MERRA) Michigan Energy & Resource Research Association	Engineering	Research consortia	6 years
			Upjohn	Pharmacology Center	Pharmacology (medicine)	University based institute serving industrial needs	11 years
			Allied	Soybean Senescence	Plant science	Contract grant	Time limited 2 years
			Upjohn	Studies & Appl. of In-Situ Extraction in Fermentation Processes	Chemical Engineering	Govt. funded U/I cooperative research (grant)	Time limited 1 year*
			Ford Motor Company	Molecular Conformation of Polymers by Small-Angle Neutron Scattering	Materials Science	Government funded U/I cooperative research (grant)	Time limited 1 year*
			Prudential Life, IBM, GM, Detroit Edison, Nabisco, Merrill Lynch, W.W. Mutual Insurance, United Parcel Post	Organizational Behavior Program (Institute for Social Science)	Social Science	University based institute serving industrial needs	30 years
			UOP	Wolverine II Project	Chemical engineering	Contract, gift consulting	Time limited 2 years old (ended)
			GM, Ford, Eaton Corp.	Metal Cutting	Engineering	Industrial affiliates (focused)	3 years
			DeVilbiss, Cincinnati Milacron	Robotics Industrial Affiliates	Engineering, Computer Science	Industrial affiliates (focused)	New
			6 Companies	Micro-electronics liaison program	Electrical & computer engineering	Industrial affiliates (focused)	6 months
			Bendix, Bechtel, Park David	Michigan Technology Council	Multidisciplinary	Technology transfer, Industrial Dvlpmnt.	2-3 years
			Ford	Phoenix	Nuclear Energy	Research facility (research reactor)	22-23 years
			Consumer Power, Detroit Edison	Extension Courses	Engineering	Industry funded cooperative training (multi-client contract)	Recent
			Many	Institute of Science & Technology	Multidisciplinary	University based institute serving industrial needs	22 years
			20 Companies	Macro-molecular Research Center	Chemistry, Chemical engineering	Industrial Affiliates (focused)	8 years
				Division of Research & Development Adm.	Multidisciplinary	Technology transfer	19 years*
				Industrial Development Div.	Multidisciplinary	Innovation Center (Technology transf.)	New
			Bendix	Bendix Update	Business Engineering, Comp. Science	Continuing Education	3 years

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R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Bendix, GM, Ford, Burroughs Wellcome	Videoprogram	Engineering	Continuing Education	Recent
			Michigan Gas Association	Gas Research Program	Chemical Eng.	Fellowship	75 years
			30 companies	Electronic Warfare	Engineering	Research Consortia	Time limited 15 yrs (ended)
			Consumer Power Indiana Electric	Great Lakes Programs	Environmental Science	Contracts	10 years*
			13 Companies	Greater Ann Arbor Research Park	Multidisciplinary	Industrial park-started by gov't and university	21 years
			Burroughs Wellcome	Fellowship Program	Pharmacology	Fellowship	Recent
			EPRI	Steam Generation Modeling	Nuclear Engineering	Contract	3 years*
			CDC	Technotech	Computer Science	Technology transfer	Recent
			IBM	Equipment Loans	Computer Science	Gift	Time Limited recent
			TRW	Chemistry internship	Chemistry	Internship	Recent
			Burroughs Wellcome	Personnel Exchange	Medicine	Personnel Exchange Personal contact	Recent
			Burroughs Wellcome, Hoffman-LaRoche, Pharmaceutical Manuf. Assoc. Foundation	Training Grants/ Fellowships	Medicine, Pharmacology	Training grants/ Fellowships	On-going 2 years
			DuPont	Supplemental Fellowships	Chemistry	Fellowships	Recent
			American Soybean Assoc.	Soybean Research	Plant Science	Contracts	Recent
			SRDC, Syncom, Hewlett-Packard IBM, TRW, Texas Instruments, Eaton	TIP Committee	Engineering	Equipment grants	3 years
			Bell Labs, Sandia	Fellowships	Engineering	Fellowships	On-going (20 years)
2	Public	University of Wisconsin		WARF	All	Non-Profit Corporation Licensing (PMO)	54 years
				University/industry research program (UIR)	All	Technology transfer, Liaison program	19 years
			Local Companies	Industrial Park	Multidisciplinary	Industrial Park	New
			Many	Wisconsin for Research	Multidisciplinary	Industrial Development Org.	1 year
			Many	Wisconsin Foundation	Non-Profit Organization	Research foundation	36 years
			Many	Wisconsin Alumni Association	Non-Profit Organization	Alumni Foundation	120 years
			Food Producing Co.	Food Research Institute	Agriculture	University based institute serving industrial needs	15 years

Great Lakes Area—Cont.

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Trade Assoc.	Swine Producers Research Institute	Agriculture	University based institute serving industrial needs	Recent
			Texas Instruments	Electronics	Engineering	Govt. funded coop. research (contract)	3 years
			Many	Engineering Experiment Station	Engineering	Extension services	77 years
				Tactile Sensory Research Consortia (robotics)	Computer Sci. Mech. Engrg.	Industrial affiliates (focused)	2½ years
				Materials Science	Materials Science	Industrial affiliates (focused)	1 year
				Microelectronics	Electrical Engineering, Computer Sci. Engineering	Industrial affiliates (focused)	½ year
				Polymer Science	Chemical Engineering	Industrial affiliates (focused)	½ year
				Rheology	Mechanical & Civil Engrg.	Industrial affiliates (focused)	½ year
			Agrigenetics, Cetus	Genetic Engineering Program	Molecular Biology	Personnel Exchange	1 year
			Foundry industries	CAD/CAM Program	Engineering Mech. & Ind.	Industrial assoc. consortium (focused)	2 years
			20 companies	Wisconsin Electric Machines & Power Electronics Consortium (WEMPEC)	Engineering, Electrical Engineering	(Focused) IAP consortium	2½ years
54	Private	Case Western Reserve	Philips Petroleum, 3M Dow, Celanese, Goodrich, Tennessee Eastman, IBM, Diamond Shamrock, Borg-Warner, Shell, Sherwood Anderson (12 cos.)	Polymer Industrial Affiliates	Macromolecular sciences	Focused industrial liaison	17 years
			35 Companies	Control of Industrial Systems—Systems Control	Mechanical, Electrical, & Chemical Engineering	Focused industrial liaison	27 years
			Many	Case Institute of Technology	Engineering & Science	University based institute serving industrial needs	12 years
			Gould, Inc.	Formation & Control of Compacted Cast Iron	Metallurgy	Government funded cooperative research (grant)	Time Limited 1 year*
				Case Chemical Eng. Industrial Affl.	Chemical Engineering	Industrial affiliates (focused)	Recent
				Industrial Council	Industrial Economics	Industrial affiliates (focused)	Recent
			SOHIO	Petroleum Laboratory	Chemistry, Chemical Engineering	Equipment donation	New
				Laboratory equipment fund	Academic science & engineering	Unrestricted gifts	3 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
				Analytic instrumentation facility	Chemistry	Jointly operated facility-equipment sharing	7-8 years
			DICAR	Energy Research Program	Chemical Engineering	Not-for-profit corporation	4 years
			Dow, Celanese, Hydron Labs, B.F. Goodrich	Center for Applied Polymer Research	Macromolecular sciences, Chemistry, Chem. Eng.	Government funded U/I cooperative research center	New
			Many	Case Associates & Case Investors	Multidisciplinary	Industrial Liaison	10 years*
			Many	University Circle Research Center	Multidisciplinary	Industrial Park	15 years
19	Private	University of Chicago	Oil Co.	Energy-Mineral Resources Analysis Group	Physics, Science	Government-industry funded cooperative research (grants)	3-5 years*
			Oil Co.	Atlas Project	Geophysics	Government-Industry funded cooperative research (grants)	3-5 years*
			Hughes	Development of New High-Resolution Scanning Ion Microprobe	Physics	Government funded U/I cooperative research (grant)	3 years
			Many	Industrial Relations Conference	Multidisciplinary	Conference	Time limited Recent
			Sohio	Physical Sciences Grant	Physical Sciences	General gift	Recent
			ARCO	Professorship	not yet determined	Grant	Recent

NORTHWEST AND GREAT PLAINS

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
4	Public	University of Minnesota	Honeywell, Sperry, 3M, CDC (and others)	Center for Microelectronics and Information Sciences (MEIS)	Chemistry, Computer Science, Elec. Eng.	Research Consortia	1 year
			General Mills, Pillsbury (& other food cos.)	Agricultural Experiment Station	Agriculture	Contract, Affiliates and Fellowship Extension Services	96 years
			Iron Ore Co. and Engineering Contractor Co.	Mineral Resources Research Center (MRRC)	Civil and Mineral Engineering	University based institute serving industrial needs	58 years
			Engineering Consulting Firms (e.g., EBASCO)	St. Anthony Falls Hydraulics Laboratories	Engineering-Hydraulics	University based institute serving industrial needs	43 years
			Many	Institute of Technology	Engineering & Science	Industrial Liaison (Partners Program)	2 years
			Chemical Co.	Chemistry	Chemistry	Unrestricted gift (grants-in-aid)	Ongoing, recent gifts
			Many	Leukemia Research Program	Medicine	Corporate Foundation Gift	Ongoing Prog., 10 yrs. Recent gift
			Company connected gift	Applied Math Institute	Mathematics	Endowed Chair	New

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Many	Minnesota Well-spring (Minnesota Inc.)	Multidisciplinary	Tech. Transfer, Ind. Development Org.	New
			LOL, Pillsbury, Carlisle, General Mills	Endowed Chairs	Food Science	Endowed Chairs	New
			Many	Minnesota Foundation	Non-Profit Institute	Research Foundation	19 years
			General Mills, Pillsbury (& other food cos.)	Food, Science and Nutrition Department	Agriculture	University based department serving industrial needs	9 years
			Several Cos.	Institute of Agriculture, Forestry & Home Economics	Agriculture	University based institute serving industrial needs	7 years
				Electrical Engineering Industrial Affiliates	Electrical Engineering	Industrial Affiliates (focused)	New
			Local bioengineering firm	Dwight Institute of Genetics	Genetics	Consulting	New
5	Public	University of Washington	Intel, DEC, Honeywell, Boeing, Tektronix, John Flake Mfg., Microtel	Regional Northwest VLSI Design Consortium	Computer Science	Research Consortia & Personnel Exchange	1 year
			Physio-Control	Center for Bioengineering	Engineering & Medicine	Ind/Gov't. Funded U/I coop. research (grants-royalties)	7 years
			Weyerhauser, Crown Zellerbach (28-30 paper cos.)	Forestry Program (Nutrition)	Forestry	Gov't funded U/I cooperative research (jointly used research facilities)	15 years
			Math Sciences Northwest	Controlled Fusion Program	Math, Physics Engineering	Gov't funded U/I cooperative research (contract)	Time Limited 2 years*
			10 Petroleum Cos.	Ocean Margin Drilling Program	Oceanography	Research Consortia (government, university, industry)	New (discontinued)
			25 Co.	Washington Pulp & Paper Foundation	Forestry	Research Consortia (ed. oriented)	14 years
			Boeing	Wind Tunnel Facility	Engineering	University based institute serving industrial needs	2-3 years
			Weyerhauser	Optimal Mgmt. of Chum Salmon Based upon Estuarine & Nearshore Carrying Capacity for Outmigrating Juveniles in Hood Canal	Biological and Ecological Applications	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*
			Polar Research Lab	Arctic Environment	Environmental	Gov't funded U/I cooperative research (contract)	5 years
			10-15 Cos.	Chemical Engineering Industrial Affiliates	Chemical Engineering	Industrial Affiliates (focused)	5 years
			Hewlett Packard, ..el, Fairchild, Texas Inst., Physio-Control, Boeing, Honeywell, Tektronix	Electrical Engineering Affiliates Program	Electrical Engineering	Industrial Affiliates (focused)	2 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			29 Cos.	Industrial Affiliates	Engineering	Industrial Affiliates	5 years
			5 Cos.	Computer Science Corporate Liaison Program	Computer Science	Industrial Affiliates (focused)	6 months
				Mechanical engineering	Mechanical engineering	Industrial affiliates (focused)	New
				Civil engineering liaison program	Civil engineering	Industrial Affiliates (focused)	New
				Department of Oceanography Liaison Program	Oceanography	Industrial affiliates (focused)	New
			Dom. Sea Farms, Inc. (subsidiary of Campbell Soups, Inc.)	Marine Net Pen Culture of Salmon	Fisheries —genetics	Government-Industry funded cooperative research (contracts-grants)	3-5 years

CALIFORNIA AND THE WEST

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
6	Private	Stanford U.	Hewlett Packard, Xerox, Varian, Syntex, Alza, EPRI, etc.	Stanford University Industrial Park	Many	Industrial Park	30 years
			Many	Industrial Affiliates	Many (23) e.g., biochem. elec. eng.	Industrial Affiliates (20 focused programs)	30 years to new
			3 Drug Cos.	Monoclonal Antibodies	Immunology	Industry funded U/I cooperative research (contract)	New
			HP, Xerox, Bell Labs, IBM, Intel, Fairchild	Center for Integrated Systems	Engineering/ Comp. Science	Industry funded U/I cooperative research center	1 year
			Oil Co.	Endowed Chair	Chemical Engineering	Endowed Chair	New
			118 Co. (incl. HP, IBM, Lockheed, Sandia, Livermore Labs)	Video program	Engineering	Continuing Education	13 years
			Lockheed Missiles and Space Co.	Multiplexed Holographic Reconstruc. Methods for 3-Dim. Structures	Elec. Eng., Comp. Science	Gov't. funded U/I cooperative research (grant)	Time Limited 1 year*
			John Deere & Company	Investigation of Multiaxial Fatigue	Civil & Mech. Engineering	Gov't. funded U/I cooperative research (grant)	Time Limited 1 year*
			RCA	Fundamental Studies of Cements	Materials Science	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*
			IBM	Discrete Event Methods for Computer System Stimulation	Math and Computer Science	Gov't. funded U/I cooperative research (grant)	Time Limited 1 year*
			Systems Control	Intelligent System for Analysis of Acoustic Signals	Math and Computer Science	Gov't funded U/I cooperative research (grant)	Time Limited 1 year*

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Xerox	Theory of Coop. Phenomena in Superfluid Systems	Materials science	Gov't. funded U/I cooperative research (grant)	Time Limited 1 year*
			Nielsen Engineering and Research, Inc.	Fluid Mechanics	Engineering	Gov't. funded U/I coop. res. (contract)	Time Limited
			Honeywell, GE, Elec. Boat (G.D.), Hughes Channel Products (with Penn St.)	Transducer ceramics	Materials Science, Physics, Elec. Eng., Chemistry	Gov't. funded U/I cooperative research (contract)	Time Limited 5 years
			Hercules	Revers. Oxygen Electrode: Collab. Search for New Catalysts & Phys. Textures	Chemistry	Gov't. funded U/I cooperative research (grant)	Time Limited 2 years*
			Koppers, Mead, GF, Elf Technologies, Bendix, Maclaren Power & Paper	Center for Biotech. Research	Molecular Biology	U/I non-profit cooperative research center	New
25	Private	University of Southern California	Arco, Dow, Chevron, Occidental, PPG, Shell, UOP	Hydrocarbon Research Institute	Chemistry	U/I coop. res. center/ Ind. liaison (focused) contracts	4-5 years
			Hughes Aircraft	VLSI Computing Structures	Elec. & Comp. Engineering	Gov't. funded U/I cooperative research	Time limited 1 year*
			TRW	U/I Coupling Program	Elec. Eng.	Gov't. funded U/I cooperative research (grant)	
			EPRI, Power Cos.	Power Engineering Program	Elec. Eng.	Contracts	On-going 73 years
			14 Co.-TRW, GE, Union, PG&E, Exxon, Starkist, S. Cal Edison, L.A. Dept. of Water & Power	Inst. for Marine & Coastal Studies	Biological & Environmental Sciences	U/I Coop. research center/Industrial affiliates program	5 years
			L.A. Veritas Seismic Prcsrs., McAdams, USGS, Exxon, Cities Service, Getty, Geo-x-Systems, Ltd., Roux, O'Connor Assoc. Inc., Amoco, Shell, Chevron, Teledyne	Geosignal Processing Program	Electrical Engineering	Industry funded cooperative research/ Industrial Associates (focused	2 years
			OMARK (Mfg., Co.), Alcoa, Exxon	Center for Laser Studies	Applied Physics	University based institute serving industrial needs (contracts)	7 years
			Dynamics Technology Inc.	Particle Motion in Turbulent Boundary Layer	Civil and Mechanical Engineering	Gov't. funded U/I cooperative research (grant)	Time Limited 1 year*
			Dr. L. Kroko Laboratories, Texas Instruments	Gallium Arsenide Micro-Tunnel Diodes	Electrical Engineering	Gov't. funded U/I cooperative research (grant)	3 years (expired)
			GE, Compshare, Dynamic Science Inc.	Pharmokinetic Comp. Modeling for drug delivery	Medicine	Equipment development	8 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Oil co., insurance co., banks, aerospace co., drug co., information processing co.. (approx. 60 cos.)	Center for Futures Research	Social Science	U/I coop. research center/industrial liaison (focused)	10 years
			Many	School of Engineering, Industrial Associates	Engineering	Industrial associates (focused)	5-10 years
			Texas Instruments	Impurities in Device Type Semi-conductors	Electrical Engineering	Government funded cooperative research (grant)	5 years
56	Private	California Institute of Technology	Inf. processing cos., (IBM, Intel, Xerox, HP, Burroughs, Fairchild, DEC, Motorola, Sperry. Univac)	Silicon Structures Program	Computer Science	Research Consortia	2 years
			57-60 Cos.	Industrial Associates	Multidisciplinary	Industrial Associates, General	34 years
			Hercules	Rev. Oxyg. Electrode Collab. Search for New Catalysts and Phys. Textures	Chemistry	Gov't. funded U/I cooperative research (grant)	Time Limited 2 years
			Union Carbide Corp.	Flow and Heat Transfer in Granular Media	Civil and Mechanical Engineering	Government/univer. funded cooperative research (grant)	Time Limited 1 year*
			IBM, Intel, Burroughs, DEC	Design of Silicon Structures	Math and Comp. Science	Government funded cooperative research (grant)	Time Limited 2 years*
			Hughes Research Labs	Electronics	Engineering	Government funded cooperative research (grant)	3 years
			Chemical Cos.	Catalysis Program	Chemistry, Chem. Eng.	Industrial Affiliates (focused)	New
			American Petroleum Institute	Project 6—Study of the composition of petroleum	Chemistry	Grants (graduate research)	40 years
			Merck	Vesicle Formation	Chemistry	Grant	Time Ltd. 2 yrs (ended)
			DuPont	Genetic Engineering	Genetics	Grant	1 year
			Ford, Exxon, Tenneco, Chevron	ENERGY Project	Multidisciplinary	Unrestricted gift	3-4 years
			Chevron	Chemical Engineering in Energy Science	Chemical Engineering	Professorship	1 year
			Xerox. Hewlett Packard	Chip Fabrication and Design	Computer Science	Research Consortium	Time limited 2 years
13	Public	UCLA	Lockheed, Hughes, North American Rockwell, Northrop	CAD	Engineering & Appl. Science Comp. Science	Industry funded U/I cooperative research (Equip. donation and student support)	1½ years
			Aerospace & oil cos. (approx. 29)	Industrial associates	Engineering	Industrial Assocs. (focused)	4 years
			Hughes Aircraft	Highly Nonlinear Phenomena & Physics of Confinement	Physics	Gov't. funded U/I research cooperation (grant)	Time limited 2 years*

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Drug co.	Crump Institute for Medical Engineering	Medicine, Biomedical Engineering	University based institute serving industrial needs	1 year
			Tobacco Industries, Trade Assoc.-Council for Tobacco Research	C cer Research	Medicine	Grants	Ongoing-Recent
3	Public	UCSD	Chemical cos. (Shell, Chevron)	Industrial Advisory Committee	Chemistry	Gifts	4 years
			Oil co., biomedical co., pharmaceuticals, mining co., power co. (approx. 12-16 cos.)	Scripps Industrial Associates	Oceanography Engineering	Industrial affiliates (focused)	14 years
			Oil cos. (many)	Chancellor's Associates	Multidisciplinary	Industrial Associates (general)	New
			Amatek-Straza Corp.	Upper Ocean Frontal Studies	Physics, Electronics, Oceanography	Gov't. funded U/I cooperative research (contract)	4 years
43	Public	University of Utah	Ceramatek, Tetratec	Utah Research Park	Multidisciplinary	Industrial Park	16 years
			Many	UURI Research Institute	Multidisciplinary	Contract research institute	9 years
			Many (approx. 17 cos.)	Solution Mining Program	Engineering Mining and Minerals	Conference	Time limited -recent
			Boeing, Univac, Genl. Inst. Burroughs (approx. 7 cos.)	Technical Liaison Program	College of Engineering	Industrial Associates	1 year
			Kennecott, AMAX, Exxon, City Services, Hammond Mining, Bethlehem Steel, Chevron, Allis-Chalmers, Rexnord, Koppers (approx. 10 cos.)	Computer controlled processing for mining	Mines, Minerals	Government/industry funded U/I Cooperative research Multiclient contract	1 year
			Brunnel Life Systems Weathercasters (new cos.)	Utah Innovation Center	Multidisciplinary	Innovation Center	2½ years
			Genl. Inst., Boeing, Burroughs-Wellcome	Microelectronics Lab	Electrical Engineering	Contracts	Recent
			Chevron	Energy Program	Coll. Engrg. Coll. Mines & Mineral Stds.	Gift	New-1 year
32	Public	University of Arizona	Diamond Shamrock, Philips Petroleum, etc.	Plant Sciences—Office of Arid Land Studies	Biology, Plant Science	University based institute serving industrial needs (Contract to center)	2 years
			Coca Cola, Disney, Kraft, FH Prince	Environmental Research Laboratory (Shrimp Project)	Biology—Env.	University based institute serving industrial needs (contracts)	13 years
			Many	Division of Industry Cooperation	Science and Engineering	Not for profit within foundation	New

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			12 Cos.	Engineering Ind. Affiliate	Electrical Engineering	Industrial Affiliate (focused)	2½-3 years
			2 Cos.	Optical Science Industrial Affl.	Optics	Industrial Affiliate (focused)	2 years
			G.D. Searle, West Plant Sciences	Seed Development Program	Plant Science, Agriculture	Industry funded cooperative research (Multiclient Contract)	1 year
			New Business	Tumbleweed Project	Plant Sciences	University based institutes serving industrial needs (Tech. Transfer)	2 years
			Motorola	Correlation of Elec. Active Defects in Silicon Wafers with Structural Inhomogeneities in As-Grown Crystals	Materials Science	Gov't. funded U/I cooperative research (grant)	Time Limited 1 year*

SOUTHWEST AND SOUTH CENTRAL

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
33	Public	Louisiana State University	Oil Companies (19)	Applied Carbonate Research Programs	Geology	Industrial affiliate (focused)	4 years
			American Sugar Cane League	Audubon Sugar Institute	Engineering	University-based institute serving industrial needs	5 years
			Lumber & Minerals Co.	Remote Sensing and Image Processing Laboratory	Engineering	University based institute serving industrial needs	2-4 years
				Chemistry Industrial Affiliates	Chemistry	Industrial Affiliates (focused)	New
				Computer Aided Design	Computer Science	Industrial Affiliates (focused)	New
				Digital Electronics	Electrical Engineering	Industrial Affiliates (focused)	New
				Control Processors	Engineering	Industrial Affiliates (focused)	New
			Exxon, Shell, Chevron, Mobil	Environment, Energy	Geology, Oceanography	Government funded cooperative research (contracts)	2-5 years
				Communications, Remote Sensing	Oceanography, Engineering	Government funded cooperative research (contract)	5 years
			Local Chemical & Oil Co.	Siva Building	Business, Engineering	Gift	Time Limited 3-5 years
				Chemtech	Chemistry, Env. Science	Spin-off Co.	25-30 years
				West Payne	Chemistry, Env. Health	Spin-off Co.	5-10 years
				Synmet	Organic Chemistry	Spin-off Co.	3-5 years
				Petroleum Eng. Blowout Training School	Petroleum Engineering	Government/Industry funded coop. training, internships, gifts from industry	New

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Tenneco, Gulf, Superior Oil	Geology Training Program	Geology	Fellowships	
			Oil Co. (& others)	Joint Oceanographic Institute	Geology	Research Consortia	53
17	Public	University of Texas (Austin)	Construction Co., Oil Co., API	Engineering	Civil Petroleum	Contract (Industry and government)	2 years
			Mobil, American Smelting Co. (& approx. 30 other gas & oil cos.)	Marine Sciences Institute	Oceanography & Ocean engineering	Industrial Affiliates (focused)	15 years
			Bristol Meyers, Eli Lilly, Hoffman LaRoche, Johnson & Johnson	Drug Dynamics Institute	Medicine Pharmaceuticals	University based institute serving industrial needs	8 years
			Texas Instruments	Computer Science Program	Computer science	Gift	New
			Rousseau	Chemistry	Chemistry	Professorship	New
			Tracor, Inc.	Military Science	Math, Engineering	Government funded cooperative research (contract)	2 years
			Bendix Corp. (with University of North Carolina)	Military (Surveillance)	Mathematics	Government funded cooperative research (contract)	3 years
			Oil Cos. (15-20)	Enhanced Oil Recovery	Chemical Engineering	Industrial Affiliates (focused)	9 years
			Association of American Railroads, GM, Ford, Federal Railroad Administration, EPRI	Center for Electromechanics	Engineering	Government-industry funded cooperative research center (contracts)	8 years
			50-100 Companies	Structural Engineering Laboratory	Civil Engineering	Seminar	Time Limited -recent
			Many	Geothermal Program	Engineering	Gifts & Government funding	New
			93 companies	Bureau of Engineering Research	Engineering Multi-disc.	Technology transfer Research Adminis.	71 years
				Mining Program	Earth Science Petroleum Engineering	Industry funded cooperative research	New
			Many	Senior design program	Nuclear Eng., Mat'ls. Sci., Biomed. Sci., Mechanics	Training and education internship Senior Design Projects	New
			Oil Co. (& others)	Gulf Universities Research Consortia	Energy & Environmental Science	Research Consortia	16 years
			Texas Atomic Research Foundation (& other energy cos.)	Fusion Research Center	Engineering & Applied Science	Government-Industry funded cooperative research (gifts)	New
123	Public	University of Houston	Gulf, Exxon, Mobil (& approx. 40 other oil & gas co.)	Seismic Acoustic Laboratory	Geology, Engineering, Computer Science	Industry funded cooperative res., Personnel exchange & Industrial affiliates	4 years
			McDonnell-Douglas and others	Energy Laboratory	Engineering (Solar), Coal & Synfuels	University based institute serving industrial needs (contracts)	10 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			Gulf, Exxon, Maxwell House	Center for Public Policy	Social Science	Consulting/Gift Account	1 year
			Shell	Ability of men and women to handle offshore oil drilling	Social Science	Contract	New
39	Public	Colorado State University	Hewlett-Packard, Kodak	Graduate Assistant Fellowships	Multidisciplinary	Grant—campus wide	Time limited -new
			Chrysler, GM, American Motors, Ford	Auto Emissions Control Laboratory	Environmental Science	Research Consortium	New
			Many	CSU Alumni Foundation	Multidisciplinary	Non-Profit Organization	8 years
			Many	CSU Foundation	Multidisciplinary	Non-Profit Organization	9 years
			Many	CSU Research Foundation (CSURF)	Multidisciplinary	Technology brokerage	40 years
			Ideal Basic Indus.	Cement Dust Project (Feedlot research)	Animal Science, Agriculture	Contract	Time Limited 2 years (ended)
			Eli Lilly, American Cyanimid, Upjohn, Ciba Geigy, Merck	Feedlot research	Agriculture	Contract	Time limited 2 years*
			Boeing, Bechtel, Sandia, McDonnell-Douglas, Johns Manville	Wind Engineering Program (Part of Fluid Dynamics & Diffusion Lab.)	Civil Engineering	University based laboratory serving industrial needs (contracts)	16 years
			Trade Assoc. (& others) Exxon, Libbey-Owens, Ford, GRI, EPRI, AMEX Foundation	Wind Engineering Research Council	Civil Engineering	Technology transfer, Advisory group, Consortial assoc.	11 years
			Local Cos.	Industrial Park	Multidisciplinary	Industrial Park	22 years
191	Public	Colorado School of Mines	Steel Companies, e.g., ARCO Steel	Steel Cooperative Program	Engineering	Personnel exchange & U/I cooperative training program	6 years
			WR Grace, ARC, Rocky Mountain Engineering	Energy & Materials Field Institute	Mineral economics	Workshop-Technology transfer	3 years
			Coors Engineering, Johns Manville	Welding Institute	Metallurgical engineering	Government funded U/I cooperative research (grant-contract)	9 years
			Johns Manville, Gas Processing Assoc., Phillips Petroleum	Research on Natural Gas Hydrates	Chemical and Petroleum Refining Eng.	Contracts, grants, & personnel exchange	2 years
			Mobil Oil	Synfuels Research	Chemistry, Geochemistry	Contract	Time Limited 2½ years
				Oil Shale Institute	Chemical Engineering, Chemistry	University based industry serving industrial needs	New
			U.S. Steel	Earth Mechanics Institute	Mining, Engineering	Contribution of equipment	7 years

R&D Rank	Public/ Private	University	Industry	Program Name	Discipline	Mechanism of Interaction	No. of Years In Existence*
			24 Cos.	Exploratory Research Laboratory	Geophysics	Incorporation and Geophysics Fund	2 years
				Earth & Mechanics Liaison Program	Geophysics, Engineering	Industrial affiliates (focused)	New
			Hewlett-Packard, IBM, Caterpillar & others	Continuing Ed.	Engineering	Short courses	7 years
			Phillips Petroleum	Fellowship Program	Engineering	Fellowship	1-2 years
28	Private	Washington University	Monsanto, GE, Air Products, ACF Industries, DuPont	Materials Science Laboratory (DARPA Coupling Program)	Materials Engineering	U/I Cooperative research laboratory industrial liaison	14 years
			DEC, BBN, Picker	Biomedical Engineering and Computer Science	Biomedical engineering, Computer Science	University based program serving industrial needs	21 years
			Local cos.	Washington Univ. Technology Assoc. (WUTA)	Engineering	For Profit Corporation-Institutional Consulting	1 year
			No Companies	Industrial Park	Multidisciplinary	Industrial Park	17 years
			Delmar	Development of Phosphite Selective Ion Exchanger	Engineering	Industry funded cooperative research (contract)	Time Limited 3-5 years*
			Monsanto Company	Relaxation Studies on Glassy Polymers	Materials science	Government funded U/I cooperative research (grant)	Time Limited 1 year
			Central Microwave	Electronics	Electrical engineering	Government funded U/I cooperative research (contract)	3 years
			Charles Evans & Assoc.	Electronics	Electrical engineering	Government funded U/I cooperative research (contract)	5 years
			McDonnell Douglas	Endowed Chair	Genetics	Endowed chair	New
			American Hospital Supply	Developed artificial heart value	Civil & Mechanical Engineering, Materials Science	U/I cooperative research Contracts Personal interaction	[illegible]
			Mallinckrodt	Hybridoma Research	Medicine	Partnership contract	Time Limited (3 years)
			Varian, Georgia Pacific	Chemistry	Chemistry	Equipment gifts	New
146	Private	Rice University	Exxon, Dow (& local Houston Co.)	REDDI	Engineering	Non-profit Corp. (Institutional Consulting)	1 year
			McDonnell Douglas, NASA (& other foundations & individuals)	Mass Spec. to detect H_2O vapor on moon, Solar power satellite project	Space physics	Contract	2 years
			21 Companies	Rice Corporate Association	Multidisciplinary	Industrial associates (general)	30 years
			Houston Companies	Rice Center for Community Design & Research Design	Social sciences, Architectural engineering,	Non-profit corporation (contract research)	9 years

*Approximately

**Government funded cooperative research frequently includes matching funds or contributions in time from industry.

STATE COLLEGE SCIENCE AND ENGINEERING FACULTY: COLLABORATIVE LINKS WITH PRIVATE BUSINESS AND INDUSTRY IN CALIFORNIA AND OTHER STATES

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CONTENTS

CHAPTER I

INTRODUCTION

This report was prepared in response to a request from the National Science Board for information on science and engineering faculty at state colleges and their links with local and other industry. The paper follows a more limited presentation by the principal investigator at the Symposium on "Successful Models of University—Industry Collaboration on Research" at the annual meeting of the American Association for the Advancement of Science at Toronto in January, 1981. That report discussed California state colleges; it has been expanded here to include data from a survey of science and engineering faculty at five campuses of that statewide system, known officially as the California State University and Colleges (CSUC). That survey was carried out by the principal investigator two years ago; and it has been supplemented here with interviews at several other CSUC facilities in the summer of 1981, and by information received from a number of other state colleges throughout the country.

Chapter II presents a short history of the development of state colleges in American mass higher education; Chapter III analyzes some research and consulting data from a recent questionnaire survey of science and engineering faculty at five state colleges in California; Chapter IV discusses the organizational aspects of such state college-based research and development activity. Chapter V provides concrete cases of R&D linking state college faculty and private industry in California, and Chapter VI presents additional cases from around the country. Chapter VII provides concluding comments.

STATE COLLEGES: ORIGINS, GROWTH AND TRANSFORMATION

While the process of industrialization did not originate in the United States, mass higher education in the context of an industrial society certainly did. Further, it can be argued that this expansion of higher education was initiated within the pace-setting state of California.[1] If so, it is appropriate that the original data which gave rise to this present report comes from a study of faculty at the mass-oriented California State University and Colleges (CSUC) system.

State colleges have an apple-pie ubiquity within the American scene. Their familiar presence throughout the land follows from the fact that many began as normal schools in the 19th century, training teachers to provide mass public education through local school districts. Later, as teachers' colleges and colleges of education, they broadened their offerings in response to growing demand for postsecondary education, ultimately evolving into state colleges. Today they are to be found in all fifty states; their distribution varies for reasons of history and state educational policy but, in general, there are more in the large and populous states.

The state colleges comprise a "second-tier" of the higher education hierarchy: more than 300 non-elite, public, four-year colleges and universities described by Dunham[2] as "colleges of the forgotten Americans". These must be clearly differentiated from the "first-tier," approximately 200 elite-oriented public and private institutions which grant doctoral degrees and which are known as "research universities" (or "doctoral universities"). By this time many, if not most, of the second-tier campuses have upgraded their titles to include the word "university," even though they do not in most cases grant doctoral degrees or grant too few to fit the doctoral category in the Carnegie Classification (see below).

While most of the cases presented in the following chapters involve California state colleges (the older "state college" designation will be used from here on in the text for sake of simplicity), Table 1 shows how state colleges stand in terms of the numbers of students enrolled relative to other public and private facilities—including public two-year community colleges. The table is excerpted from 1976 data published by the Carnegie Council for Policy Studies (CCPSHE) and displays the student enrollments of the various sectors of American higher education (state colleges correspond roughly to what CCPSHE categorized as "Public, Comprehensive Universities and

Table 1

Enrollments in Institutions of Higher Education by Type of Institution and Control, United States, 1976—in Thousands*

	Public	*Private*	*Total*	*% Public*	*% Total*
Doctorate Institution	2,389.0	673.4	3,624.4	78.0%	27.4%
Comprehensive University or College	**2,372.6**	**796.9**	**3,169.5**	**74.9%**	**28.4%**
Liberal Arts College	19.5	511.7	531.3	3.7%	4.8%
Two-year Institution	3,825.2	152.2	3,978.0	96.2%	35.6%
Other	150.3		429.8		• 3.8%
TOTAL	8,750.3	2,414.4	11,164.6	78.4%	100.0%

* Source: Carnegie Council on Policy Studies in Higher Education[3]

[1] Frank A. Darknell, "The Carnegie Philanthropy and Private Corporate Influence on Higher Education," pp. 385-411 in Robert F. Arnove, ed., *Philanthropy and Cultural Imperialism: The Foundations at Home and Abroad* (Boston: G.K. Hall & Co., 1980).

[2] E. Alden Dunham, *Colleges of the Forgotten Americans: A Profile of State Colleges and Regional Universities* (New York: McGraw-Hill Book Company, 1969).

[3] Table 1 excerpted from Table 2 (page xii) in *A Classification of Institutions of Higher Education* (Revised Edition). A Report of the Carnegie Council on Policy Studies in Higher Education, Berkeley, California, 1976.

Colleges"). It can be seen that, in terms of 1976 enrollments, the state colleges ("Comprehensive Universities and Colleges, Public") enrolled about as many students as the public doctoral institutions. Enrollments have since increased more rapidly in the state college sector and these now constitute the largest four-year enrollment sector.

Turning next to recent national comparisons of faculties in terms of the numbers and proportions of faculty with doctoral degrees in science or engineering, Table 2 provides comparative data over time. In this case, the state colleges are represented by the "public, master's and bachelor's institutions" in data provided by the National Science Foundation.

Table 2

Fulltime Scientists and Engineers with Doctoral Degrees: Faculty and Others, at Public Universities and Colleges Classified by Highest Degree Granted, January, 1976 and 1981*

	Total Doctoral Degrees	Doctoral Institutions	Master's and Bachelor's Institutions
1976	86,049 (100.0%)	65,753 (76.41%)	20,296 (23.59%)
1981	96,221 (100.0%)	75,713 (78.68%)	20,508 (21.31%)

*Source: N.S.F./S.R.S.[4]

It can be seen that although state colleges have been enrolling increasing numbers of students, at the same time they have not recently been increasing the numbers or their share of science and engineering faculty with doctoral degrees—compared with the research and doctoral universities. Between 1976 and 1981 the number of science and engineering faculty employed at state colleges has increased from 20,296 to 20,508, but this has represented a percentage drop when institutions limited to bachelor's and master's degrees are compared with the doctoral campuses. Data presented in Table 3 demonstrates the overall increase in doctoral faculty at California state colleges before the mid-seventies. But returning to the figures in Table 2, the obvious imbalance of total science and engineering doctoral faculty between the doctoral and research universities and the state colleges is more easily comprehended when the relative teaching loads carried by teaching faculty in the two kinds of institutions are noted. State college faculty members, in general, teach about twice as many hours; and, therefore, could be said to be used more "productively" as teachers than are doctoral and research university faculty. Furthermore, because state colleges are not designated nor funded as research institutions, they do not hire large numbers of non-teaching scientists and engineering scientists as do major research universities.

[4]Excerpted from special data run for National Science Foundation (SRS), October, 1981.

Table 3

Number and Percent of Fulltime Faculty: U.S. Higher Education, Selected Public Universities, California State (Colleges) University***

	California State University and Colleges		Selected Public Universities**		All Higher Education	
	N	Annual Growth Rate	N	Annual Growth Rate	N	Annual Growth Rate
1961/62	4,341	11.3%	8,921	10.1%	162,000	13.2%
1965/66	6,410	11.3%	12,545	10.2%	248,000	10.4%
1969/70	10,235	14.9%	16,435	7.8%	350,000	10.4%
1973/74	11,074	2.0%	19,000	3.9%	389,000	2.8%
1977/78	11,296	0.1%	18,400	-0.1%	449,000	3.8%

*Source: National Academy of Science[5]

**Universities of California, Illinois, Michigan, Minnesota, Washington, and Wisconsin

Since the end of World War II, state colleges have developed in the context of several factors which have influenced the demand for higher education, college enrollments, and the overall structure of American postsecondary education. Beginning with the Servicemen's Resettlement Act of 1944, the various G.I. bills brought a dramatic spread of opportunity and subsequent mass demand for higher education among the American population. The large numbers of ex-servicemen and women who chose to go to college surprised even the original sponsors of the 1944 Act.[6] Many of these veterans were drawn from families that did not customarily send children to college; thus,the G.I. bills had a significant "seeding" effect in stimulating further college attendance in the 1950's and early 1960's among lower middle and working class families. The role of the Vietnam War in the middle and late 1960's was even more complex; college enrollments were stimulated not only by veterans' benefits, but also by the interaction between the military draft and college draft deferments.

Such increases in the participation rate present one dimension in the demographic analysis of college enrollments; another involves simply an increase in the traditional college-age cohort. The "baby boom"—the children born in the high birthrate period from the late 1940's through the 1950's—comprised what educators foresaw as a coming tidal wave of demand. Its

[5]Excerpted from Table 1 (page 13) of *Research Excellence Through the Year 2000: The Importance of Maintaining a Flow of New Faculty into Academic Research*. A Report with Recommendations of the Committee on Continuity in Academic Research Performance, Commission on Human Resources, National Research Council, National Academy of Sciences, Washington, D.C., 1979.

[6]Keith W. Olson, *The G.I. Bill: The Veterans and the Colleges* (Lexington, Kentucky: The University Press of Kentucky, 1974), p. 27; David D. Henry, *Challenges Past, Challenges Present: An Analysis of American Higher Education Since 1930* (San Francisco: Jossey-Bass, 1975), Chapter 4.

threat often produced near panic among planners and government officials.[7]

All these factors called for an increase in numbers of university and college places and in their accessibility to students throughout the country. This meant the development of entirely new institutions, and eventually systems of institutions to meet the expanding demand. California, where approximately twenty junior colleges and a handful of state colleges had existed since the 1920's, was the first to move toward systematic statewide expansion after World War II. By the late 1950's, California had become an industrial region of great potential growth. Industrial development—in aerospace, electronics and related industries—was stimulated first by war production in the 1940's, and later in the mid-fifties by the unexpected achievements of the U.S.S.R. in space technology. *Sputnik I* and subsequent Soviet accomplishments came as a profound shock to American complacency about advanced scientific development. When it became startlingly clear that the Russians were leading in the "space race," there was nationwide demand for the immediate upgrading of "human capital" in the form of more highly educated and fully trained personnel to meet the new threat. In California, cheap higher education and advanced technical training became a widely-supported solution to industry's post-Sputnik needs for masses of technicians, experts and administrators.[8]

This difficult political, fiscal and educational situation was stabilized, if not fully resolved, in the early 1960's by the establishment of a California Master Plan for Higher Education by the legislature. The Donahoe Act (1960) set up a stratified system providing for a hierarchy of three "segments" which were further "differentiated by function".[9] These were: (a) an elite doctoral and research university system of "world class" campuses: the nine campuses of the University of California at Berkeley, Los Angeles, and seven additional locations, (b) a less than doctoral and less than elite range of facilities for mostly four-year students at what ultimately came to be 19 state colleges scattered the length of the state, and (c) two-year "community" colleges (formerly junior colleges), ultimately 100 or more of them providing academic transfer or terminal vocational training and education at the local level everywhere in the state.

Of particular interest here is the fact that the University of California by monopolizing the doctoral degree under the plan, continued to attract the greater share of federal funds, which was the planners' intent. This together with the heavier teaching load for faculty at the state colleges (100% greater), meant that serious academic research was not expected to be done there. In many ways, the California master plan became a kind of model for similarly rationalized and stratified systems of mass higher education in other states and was promoted as such by the Carnegie Corporation of New York.[10]

An indication of the somewhat uneven but rapid expansion of mass higher education in the U.S.A. at the time, and the comparative growth of the California state colleges together with a number of selected major public research universities, is available in data published by the National Academy of Sciences. The data give a picture of the post-Sputnik expansion (after 1957) at several levels in the nation's system of mass higher education (Table 3).

By 1970, the end of the first decade of the operation of the master plan for higher education in California, some questioning of the original concept was beginning to occur, especially with regard to the role of state college faculty. Prior to the 1960's a few Ph.D.'s had found their way into the state colleges, but they were usually a minority among the Ed.D.'s remaining from teachers' college days. Indeed from the perspective of the Ph.D. graduate school, state colleges appeared as an academic Siberia where candidates who failed to finish dissertations were consigned. By the mid-sixties, however, Ph.D.'s began to appear in greater numbers—partly in response to the move by state colleges to redirect their curriculum away from an emphasis on teacher training toward the traditional undergraduate departments of the liberal arts college. This move was encouraged by prevalent critiques of teacher education[11] and, in California, legislation requiring that prospective teachers acquire a "subject-matter" major rather than concentrate on education methods.[12]

New and expanded doctoral programs at the nation's research universities, responding to the previously mentioned "Sputnik demand" for skilled and specialized experts as well as for "fully qualified" faculty at the many new or upgraded universities and colleges throughout the country, ultimately saturated

[7]Henry, *Challenges Past, Challenges Present*, Chapter 7.

[8]William Barlow and Peter Shapiro, *An End to Silence: The San Francisco State Student Movement in the '60s* (New York: Bobbs-Merrill, Inc., 1971), Chapter 1; T.W. Schultz, "Investment in Human Capital," *American Economic Review* 51 (March 1961), 1-17; Gary S. Becker, *Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education* (New York: Columbia University Press, 1964).

[9]T. R. McConnell, T. C. Holly, and H. H. Semans, *A Restudy of the Needs of California in Higher Education* (Sacramento: California State Department of Education, 1955).

[10]T. R. McConnell, *A General Pattern for American Public Higher Education* (New York: McGraw-Hill Book Company, 1962).

[11]James B. Conant, *Shaping Educational Policy* (New York: McGraw-Hill Book Company, 1964), pp. 88-96.

[12]The Licensing of Certificated Personnel Law, commonly known at the time as the Fisher Bill, was passed in 1961. See James B. Conant, *The Education of American Teachers* (New York: McGraw-Hill Book Company, 1963), pp. 24-25; Conant, *Shaping Educational Policy*, pp. 88-96; Roy E. Simpson, "The Development of New Credential Requirements" *California Schools* 33 (August 1962), 265-288; and Frank Laycock, "Academic Majors for Elementary School Teachers: Recent California Legislation," *Harvard Educational Review* 32 (Spring 1962), 188-199.

the market for science and engineering Ph.D.'s. As early as 1967, graduate schools at the expanded research universities were being warned against producing too many Ph.D.'s.[13] By the early 1970's over-production of Ph.D.'s matched over-production of goods in other industries, which along with increasing inflation, was felt throughout the nation's research universities and ultimately through all of higher education.

The new abundance of Ph.D.'s expanded the pool of academic talent available to all universities including the state colleges in California and elsewhere, especially in the sciences and engineering—the result, in part, of mass layoffs in the aerospace and electronics industries following the successful moon landing. Table 4 shows the increase in the proportion of doctoral relative to master's degrees among faculty respondents in all disciplines at two- and four-year colleges and universities covered by the Carnegie National Surveys of Higher Education in 1969 and 1975.

Table 5, next, shows that during approximately the same period the state colleges of California added substantially to their doctoral faculty during this period of "Ph.D. surplus." Table 6 focuses on the five California state colleges which were the locations of a survey discussed in following chapters, and demonstrates that these campuses in the key ten-year period between the mid-sixties and the mid-seventies were able to "top-off" the significant majorities that Ph.D.'s comprised in science departments (biological sciences, mathematics and statistics, physics, chemistry and geology) and significantly raise the proportion of engineering faculty with Ph.D.'s. The increase in absolute numbers of scientists and engineers, both with and without doctoral degrees, at the five colleges during this historic period of expansion is also visible in the numbers in parentheses.

Table 4

Percent of Faculty Respondents Reporting Doctoral and Master's Degrees, Carnegie National Surveys of Higher Education (Criterion Samples), 1969 and 1975*

	1969	*1975*
Doctoral	50.3	58.7
Master's	35.6	30.0

*Source: Carnegie Commission/Council National Surveys of Higher Education, 1969 and 1975[14]

Table 5

Percent of All Faculty with Doctoral Degrees, California State Colleges, 1967/68 and 1979/80*

1967/68	*1979/80*
52.2	71.8

*Source: California State University and Colleges and California Postsecondary Education Commission[15]

Table 6

Percent of All Science and Engineering Faculty with Ph.D., Five CSUC Campuses, 1966/67 and 1976/77*

	1966/67	*1976/77*
Sciences	79.6 (329)	91.7 (590)
Engineering	33.8 (65)	67.0 (106)

*Source: CSUC college catalogs from the five campuses used in the Survey[16]

As the number of Ph.D.'s in the state colleges increased, it was felt by some that faculty of this type inevitably threatened to distract the second-tier institutions from the purely teaching function envisioned under the stratified model of the master plan. Their doctoral preparation—and, in many cases, their work experience—had promoted the value of research; relegated to a setting exclusively devoted to teaching, they often became restless. In his Carnegie Commission profile of the state colleges in 1969, Dunham predicted the conflict in which Ph.D. faculty at state colleges would inevitibly find themselves:

> A Ph.D. at a state college will always compare his status with that of a colleague at the state university and will seek to do the same kind of things and want to receive the same kind of rewards.[17]

Looking at the situation from the point of view of highly educated and trained personnel, i.e. the Ph.D.'s in all-teaching institutions, such a conflict might be seen instead as breeding resignation and denial of research, part of a process referred to elsewhere as "rustication."[18]

This report, however, focuses on some state college science and engineering faculty who have responded to their situations more positively by forging new links of service with their surrounding communities.

[13]Cartter, Allan M., *Ph.D.'s and the Academic Labor Market* (New York: McGraw-Hill Book Company, 1976).

[14]Martin Trow, ed., *Teachers and Students: Aspects of American Higher Education* (New York: McGraw-Hill Book Company, 1975), pp. 342-343; Judy Roizen, Oliver Fulton, and Martin Trow, *Technical Report: 1975 Carnegie Council National Surveys of Higher Education* (Berkeley: Center for Studies in Higher Education, University of California, 1978), p. 87.

[15]California State University and Colleges, Division of Institutional Research, *Statistical Abstract to July 1977* (Long Beach: 1978), p. 308; California Postsecondary Education Commission, *Information Digest 80* (Sacramento: 1981), p. 213. (The statewide system is hereafter referred to as CSUC.)

[16]Source: college catalogs for the year 1966/67. Included: San Diego State College; California State College, Fullerton; Fresno State College; Chico State College; and Humboldt State College. For 1976/77 year catalogs: San Diego State University; California State University, Fullerton; California State University, Fresno; California State University, Chico; and Humboldt State University.

[17]Dunham, *Colleges of the Forgotten Americans*, p. 164.

[18]Frank A. Darknell, "Mass Higher Education and the Distribution of Scientific Inquiry: an Essay in the Sociology of Rustication" (paper presented at meetings of the American Sociological Association, San Francisco, September 1978).

CHAPTER III

CALIFORNIA: A SURVEY OF FIVE CAMPUSES

The following three chapters focus on links between California state college science and engineering faculty and industry. The present chapter presents pertinent survey data from an on-going study of California state college faculty in the same fields. Chapter IV in turn will discuss the organizational context in which state college faculty and industry interact in California; and Chapter V will present in greater detail some specific cases.

A. The Science and Engineering Survey—CSUC

The Science and Engineering Study, from which the data that follows is drawn, was designed to gather information on the prevalence of research and consulting activity among science and engineering faculty at teaching-oriented institutions. A pilot study at California State University, Sacramento (formerly Sacramento State College) in 1978 was followed in 1979 by a mail survey of five other campuses in the California State University and Colleges (CSUC) system: San Diego State; California State, Fullerton; California State, Fresno; California State, Chico; and Humboldt State in Arcata. The five were chosen from the nineteen CSUC campuses according to criteria allowing for productive comparison, including location, age of campus, and faculty publication rate (as determined by recent citations).[1]

The survey achieved an average response rate of about 65%, with a low of 54% (Fresno) and a high of 69% (Fullerton and Humboldt). Some questions were not always answered— possibly because for some of the faculty the topic treated was sensitive—and, sometimes apparently because busy respondents accidentally turned two pages of the staple-bound questionnaire at a time. In general, there were higher returns from senior faculty and faculty with doctoral degrees.

B. The Question of Ph.D. Quality

Measures of the quality of graduate schools and their programs included in the survey analysis do not provide direct information on the standing of each Ph.D. within his or her graduating class, but they do provide a distribution of respondents on the basis of the standing of the graduate schools they came from—and particularly of the programs that produced them.

As shown in Table 7, about 88% of the survey respondents with the Ph.D. report having degrees from graduate schools classified by the Carnegie Council as "Research Universities I or II."[2] The Carnegie classification reflects certain objective measures such as the fact that institutions in these categories absorb the largest amounts of federal funds and turn out the larg-

Table 7

Percent of Science and Engineering Faculty Respondents at Five CSUC Campuses with Ph.D. Degrees from Graduate Schools Ranked by Carnegie Classification

Carnegie Classification	*Percent of Ph.D. Faculty*
Research University I	73.1 } 88.2
Research University II	15.1 }
Doctoral University I	8.6
Doctoral University II	.2
Comprehensive Universities and Colleges	.7
Special and Foreign	2.2
	99.9 (N=417)

[1] This survey began in 1978 with a pilot study at California State University, Sacramento, sponsored by the National Science Foundation, and was followed in 1979 by a survey of five other campuses of the CSUC system, supported in part by faculty research funds from the CSUS Foundation.

[2] Carnegie Foundation for the Advancement of Teaching, *A Classification of Institutions of Higher Education*, rev. ed. (Berkeley: 1976).

est numbers of Ph.D.'s in a year. However, we also have a more direct measure of quality: an attempt to rate actual doctoral programs within their various fields. This is the set of ratings published by the American Council on Education (ACE) in 1970, based on reputational rankings by experts from the various disciplines.[3]

Table 8 shows that approximately 51% of the California state college respondents obtained degrees at institutions in the highest of the ACE categories; and that altogether, about three-quarters of the respondents were from American graduate programs which were important enough to be included in the ACE program.[4]

Table 8

Percent of Science and Engineering Faculty Respondents at Five CSUC Campuses with Ph.D. Degrees from Graduate Programs Ranked by ACE Rating

ACE Rating	Percent of Ph.D. Faculty
3.0 - 5.0 (highest category)	50.8
2.5 - 2.9	15.6
2.0 - 2.4	11.5
School program not listed	8.6
No rating for field	11.5
Foreign	1.9
	99.9 (N=417)

C. Interpreting Survey Responses

With regard to the interpretation of survey material below, certain caveats are in order. Although the discussion that follows attempts to distinguish between "research" and "consulting" activity, it may well be that consulting, advising and research—especially applied research—are linked in the minds of at least some respondents to the point of being interchangeable. The key questionnaire items were as follows:

Q. 68. Have you, as an individual, provided professional services in your field off campus, such as advisory, consulting, or educational services since coming to your campus?

Q. 69. Do you regularly receive income from professional work such as consulting or extra teaching off campus in addition to your salary from CSUC?

[3] Kenneth D. Roose and Charles J. Andersen, *A Rating of Graduate Programs* (Washington, D.C.: American Council on Education, 1970).

[4] Recent evidence of the recruitment of faculty from major graduate schools by state colleges is to be found in John A. Muffo and John R. Robinson, "Early Science Career Patterns of Recent Graduates from Leading Research Universities", Institutional Research Office, Cleveland State University, (mimeo).

Q. 98. Do you presently have a research or design project in progress?

Q. 99. If yes, is it funded?

For many faculty, consulting stands for a broad and diverse category of professional activities: it can include everything from brief on-the-spot judgements followed by advice over the telephone; to special courses frequently arranged for external client companies or government agencies; to extensive research directed at problems brought by clients who stand ready to pay for solutions. At the same time, research may be linked with design, especially for engineering faculty, who tend to undertake applied research leading to both the advancement of knowledge and the development of devices ("hardware") or methods ("software").

Put another way, because of the applied nature of many opportunities open to state college faculty for engaging in non-teaching professional work, it is probably advisable to avoid too strict an interpretation of the following data on "researchers" as opposed to "consultants." With this in mind then, both the "research" question and the "professional services" question (which will be called "consulting" here for convenience) may best be seen as representing a single continuum of activity for both science and engineering faculty. (For illustrations of the manner in which distinctions between research and consulting tend to be blurred, see cases cited in Chapters V and VI. For a particularly cogent example of "pure" research carried out within the framework of a paid consulting contract, see the case of the ornithologist at California State Polytechnic, Pomona in Chapter V).

One other caveat: the "consulting" question asks if the faculty member has provided services "since coming to your campus," allowing respondents to consider all past activities. The "research" question, on the other hand, asks only about projects currently in progress. Thus, it might be expected that affirmative consulting responses would be somewhat inflated compared to those for research. The questions—which were not designed with this present report in mind—were intended to reflect certain differences in the two activities: consulting is frequently an intermittent activity where recognized expertise is drawn upon in response to a specific need, whereas research is often considered as part of a continuing program or "career", involving an expectation of cumulative results.

Now turning to the survey data, Table 9 shows that 80.1% of the survey respondents reported they had provided consulting services off-campus, and 73.9% reported having research in progress. While these figures indicate a high level of activity, fewer respondents report regular income from off-campus work (34.4%) or funding for current research (27.5%).

Table 10 shows that 93.5% of the respondents reported themselves as currently active or as having been active professionally beyond their teaching duties. In other words they reported doing research, consulting, or both. However, fewer faculty reported having funded research underway, having done paid consulting, or both.

Table 9

Percent of Faculty* Ever Providing Professional Services Off-Campus ("Consultants") or Having a Research or Design Project in Progress ("Researchers") and Percent of Faculty with Regular Consulting Income ("Paid Consultants") or with Funding for Research ("Funded Researchers")

Consultants	*Researchers*
80.1 (417)	73.9 (418)
Paid Consultants	*Funded Researchers*
34.3 (419)	27.5 (414)

*"Faculty" in this and subsequent tables refers to all science and engineering faculty respondents. Parentheses in all tables contain base N's.

Table 10

Percent of Faculty engaged in Research, Consulting or Both, and Receiving Income or Funding for these Activities

Faculty doing Research, Consulting, or Both	95.3% (404)
Faculty doing Funded Research, Paid Consulting, or Both	46.6% (400)

D. Academic Fields

Tables 11 and 12 show the distribution of consulting and research activity and associated income or funding by academic field. The tables highlight some striking differences between fields. A lower percentage of mathematics and statistics faculty report involvement in non-teaching professional activity than do those in other fields, although they are more likely to be engaged in providing consulting services than to have a research project underway. This suggests that state college mathematics and statistics faculty have comparatively little opportunity to engage in "pure" scientific work which, particularly in this field, requires large blocks of uninterrupted "thought" time. Much of the off-campus consulting service that *is* done is statistical in nature.

Compared to other fields, a higher percentage of faculty in engineering and other applied sciences (forestry, fisheries, etc.) report consulting activity, as well as regular income from this source. This reflects the mutually reinforcing relationship between teaching and outside practice in these fields where outside problems are routinely brought into the classroom—sometimes leading to class-developed solutions. Students often prefer to draw their term projects from the "real world" rather than working with simulated laboratory exercises. Thus faculty with off-campus obligations can involve willing students in practical projects that come their way. This cannot be said—at least to the same extent—about undergraduate teaching in the basic or pure sciences. Here, outside practice is more likely to be regarded as "moonlighting"—a personal activity largely separated from the classroom.

Another factor in professional activity off-campus is the occupational history of faculty concerned. In the California state colleges under study, previously established ties between private industry and engineering faculty are not uncommon. Personal interviews at several campuses have confirmed that the massive layoffs in the California aerospace industry in the late 1960's, mentioned in Chapter II, did release a considerable number of engineering and scientific personnel to positions in higher education which was rapidly expanding at the time.

E. Sponsoring Agencies

Table 13 gives some indiction of the extent of faculty involvement with differing sponsoring agencies in their non-teaching professional activities. Respondents with regular consulting income or funding for current research were asked to rate the importance of various off-campus agencies for their own research and consulting activities.

For both groups government agencies (local, state and federal) were most important, followed by industrial organizations. Of the three major types of organizations, military agencies were rated least important. (It is, of course, possible that some defense-related research and consulting work may be perceived by respondents as government or industrial activity.)

Table 11

Percent of Faculty Providing Consulting Services or Having Research in Progress, by Academic Field

	Biol. Sci.	*Phys. Sci.*	*Math./Stat.*	*Eng./Appl. Sci.*
Consultants	80.8 (130)	76.5 (136)	72.5 (69)	93.9 (82)
Researchers	84.4 (128)	80.4 (138)	58.8 (68)	59.5 (84)

Table 12

Percent of Faculty with Regular Consulting Income or Funding for Research, by Academic Field

	Biol. Sci.	*Phys. Sci.*	*Math./Stat.*	*Eng./Appl. Sci.*
Paid Consultants	29.5 (132)	31.3 (134)	25.4 (71)	54.9 (82)
Funded Researchers	32.8 (128)	30.1 (136)	10.4 (67)	28.9 (83)

Table 13

Percent of Faculty with Regular Consulting Income or Funding for Research Rating Importance of Sponsoring Agencies

Major Sponsoring Agencies	Paid Consultants				Funded Researchers			
	Importance				*Importance*			
	Higher	*Mixed*	*Lower*	*(N)*	*Higher*	*Mixed*	*Lower*	*(N)*
Government	77.2	11.8	9.5	(136)	89.2	5.4	2.7	(111)
Industrial	58.6	14.6	19.0	(137)	37.5	17.3	33.6	(104)
Military	9.6	7.9	56.1	(114)	4.3	8.5	56.3	(94)

Table 14 shows the "higher importance" ratings made by these same faculty grouped by academic field. Industrial organizations are more often rated important or very important by faculty with regular consulting income than by those with funding for current research. This follows from the fact that while research funds are usually obtained from government agencies, consulting income is more likely to emanate from several types of organizations.

Of faculty receiving regular consulting income, those in mathematics and statistics, and engineering, tend to rate government and industrial organizations as equally important. The percent of these mathematics and statistics faculty rating *either* type of organization as important is relatively low; this may reflect the generally lower salience of non-teaching professional activity among state college faculty in this field. The percentage of engineering faculty who rate industrial support as important or very important is greater than those in all other fields; this might be expected to follow from the connection between engineering teaching and practice mentioned previously.

Table 14

Percent of Faculty with Regular Consulting Income or Funding for Research Giving Higher Importance Rating to Government or Industrial Sponsors, by Academic Field

	Biol. Sci.		*Phys. Sci.*		*Math./Stat.*		*Eng./Appl. Sci.*	
	Govt.	*Ind.*	*Govt.*	*Ind.*	*Govt.*	*Ind.*	*Govt.*	*Ind.*
Paid Consultants	83.8 (37)	47.2 (36)	84.6 (39)	65.0 (40)	44.4 (18)	41.2 (17)	78.6 (42)	75.0 (44)
Funded Researchers	92.9 (42)	27.5 (40)	89.8 (39)	45.9 (37)	* (7)	* (6)	91.3 (23)	52.3 (21)

*No. of cases too small for percentaging.

CHAPTER IV

CALIFORNIA: FUNDING AND ORGANIZATIONAL STRUCTURE OF STATE COLLEGE RESEARCH AND CONSULTING

After presenting further data from the faculty survey, this chapter offers documentary evidence on non-teaching activities in the form of official figures. These are dollar amounts of current research and consulting activity of faculty as recorded by the research offices or "foundations" at seven of the 19 campuses of the CSUC system. The chapter also discusses some of the formal and informal structures through which these kinds of activities take place.

A. Inter-Campus Variation: Further Data from the Survey

The impact of differing campus environments on science and engineering faculty consulting and research is suggested in Tables 15 and 16. Faculty at San Diego and Fullerton report both types of non-teaching activity fairly equally. At other locations, consulting is reported more frequently than research in progress. These relationships shift somewhat for income-producing consulting and funded research.

The highest percentages for both income from consulting (45.3%) and funding for current research (46.1%) are reported by faculty at Fullerton, followed by those at Humboldt, with 41.2% and 31.7% respectively. San Diego, which by some official measures to be discussed below, tends to lead these state colleges in California in research and consulting activity, nevertheless ranks third here. This discrepancy may reflect the somewhat higher survey response rate—approximately 69%—for Fullerton and Humboldt than for San Diego where about 64% responded, or a number of other contextual factors. Those include unique opportunities to do off-campus work at some campuses, and/or the possible tendency of faculty to report more of their outside work done through a campus research foundation than done as private practice. Yet other factors might include differing mixes of engineers and science faculty relative to local opportunities for extramural work, *etc.*

Table 15

Percent of Faculty Providing Consulting Services or Having Research in Progress, by Campus

	San Diego	Fullerton	Fresno	Chico	Humboldt
Consultants	78.6 (131)	80.0 (75)	89.5 (57)	73.5 (68)	83.3 (84)
Researchers . . .	78.5 (135)	82.9 (76)	66.1 (56)	58.2 (67)	75.9 (83)

Fresno and Chico faculty report the lowest percentages of regular consulting income or current research funding. The contrast—at these and other older campuses—between all reported activity and funded or income-producing activity may partly reflect a tradition stemming from normal school days that local faculty should render voluntary "community service" based on their expertise. More detailed discussion of the differences between campuses with regard to their emphasis on research and consulting activity, and their relationship with surrounding communities, follows.

B. Grants and Contracts: Expenditures and Awards According to Campus Records

Several sources provide reports on the extent of research, development and consulting by faculty at

Table 16

Percent of Faculty with Regular Consulting Income or Funding for Research, by Campus

	San Diego	Fullerton	Fresno	Chico	Humboldt
Paid Consultants	31.3 (134)	45.3 (75)	25.0 (56)	28.4 (67)	41.2 (85)
Funded Researchers ..	28.8 (132)	46.1 (76)	19.6 (56)	6.0 (67)	31.7 (82)

American universities and colleges[1], but there is considerable variability and limited comparability in available data. For example, the National Science Foundation surveys doctoral and non-doctoral universities and colleges regarding research and development (R&D) activity.[2] While the data from this survey would be especially pertinent here, it is not available for all CSUC campuses under discussion.

The CSUC system does publish data on all grants and contracts awarded and expended through research offices and foundations at its 19 campuses[3] from which some information on research and consulting activity can be drawn. The campuses discussed here are: California State, Sacramento, site of the 1978 pilot study, and the five campuses surveyed in 1979: San Diego, Fullerton, Fresno, Chico, and Humboldt. In addition, we have added two campuses where science and engineering faculty might be expected to be heavily involved in research and consulting activity with private industry either formally or informally—San Jose State and California State Polytechnic at Pomona. (A brief description of each campus may be found in Section F below.)

Table 17 ranks the campuses according to the percent of expenditures from all grants and contracts received for R&D purposes. San Diego State and San Jose State are the clear leaders in R&D expenditures, with both showing similar dollar amounts. But while San Jose's more than $2.4 million in R&D represents nearly half of all external money spent by that campus,

Table 17

Total Dollars and Relative Percentages of R&D and Industrial R&D Expenditures, at Eight CSUC Campuses: Fiscal Year Ending June 30, 1980

		A	B	C	D	E
Rank*	Campus	*Total Extramural Expenditures*	*Total R&D Expenditures*	*% R&D of Total Expenditures*	*Total Industrial R&D Expenditures*	*% Industrial of Total R&D Expenditures*
(1)	San Jose	$ 5,420,243	$2,422,137	44.7	$502,346	20.7
(2)	Humboldt	1,431,228	446,735	31.2	60,000(est.)**	13.4**
(3)	Fresno	1,741,366	364,925	21.0	178,500***	48.9
(4)	San Diego	12,087,805	2,4[illegible]8,974	20.2	363,050	14.9
(5)	Chico	2,971,481	[illegible]99,360	16.8	27,500	5.5
(6)	Fullerton	3,467,260	533,007	15.4	51,942	9.7
(7)	Pomona	1,053,050	102,391	9.7	11,001	10.7
(8)	Sacramento	3,813,508	243,327	6.4	1,788	.7

Source: CSUC[4]

* Ranked according to percent R&D of all expenditures (Column C).

** Local estimate; all industrial grants and contracts were under $10,000 and not reported individually.

*** Most of Fresno's industrial R&D came from one two-year Environmental Impact Study grant from Pacific Gas and Electric; note that Fresno's total R&D is considerably lower than that of Chico's which is similar in size, indicating a comparatively lower level of R&D activity.

Column A: Total dollar amount of all foundation expenditures (i.e., external monies spent for research, training and other educational projects).
Column B: Total dollar amount of all expenditures for R&D.
Column C: Percent R&D of total expenditures (B/A).
Column D: Total dollar amount of expenditures for R&D from private industry sources.
Column E: Percent industrial R&D of total R&D expenditures (D/B).

the similar amount spent by San Diego represents just over one-fifth of its total grant and contract expenditures. It appears, then, that R&D activities at San Jose constitute a more important role among externally-sponsored programs than at San Diego. San Jose also has the largest dollar amount of industrial R&D (i.e., grants and contracts from private industry), and leaving aside the temporary anomaly presented by Fresno State (see note to Table 17) the highest percentage of industrial to all R&D expenditures (20.7%).

San Jose State's location at the southern end of the industrial concentration known as "Silicon Valley," south of San Francisco, with its many opportunities for research and consulting by scientists and engineers—especially electrical and electronics engineers and physicists of various kinds—clearly must be expected to influence faculty activity. Also nearby is Ames Re-

[1]For other data on consulting activity at elite and non-elite universities, see Oliver Fulton and Martin Trow, "Research Activity in American Higher Education," pp. 39-83 in Trow, *Teachers and Students*; Martin Trow, *Aspects of American Higher Education 1969—1975* (Berkeley: Carnegie Council on Policy Studies in Higher Education, 1977), p. 26; James D. Marver and Carl V. Patton, "The Correlates of Consultation: American Academics in 'The Real World'," *Higher Education* 5 (1976), 319-335; Carl V. Patton, "Consulting by Faculty Members," *Academe* 66 (May 1980), 181-185; and Carlos E. Kruytbosch and David D. Palmer "Academic Role Performance and Organizational Environment," *Proceedings of the 1979 IEEE Engineering Management Conference*. A less formal study of state college faculty R&D activity is reported in: American Association of State Colleges and Universities, *Background* (June 1981), 1-6.

[2]National Science Foundation, *Academic Science: R&D Funds, Fiscal Year 1979* (Washington, D.C.: 1981).

[3]CSUC, *Reporting Activity in Research, Workshops, Institutes, and Other Special Educational Projects for Fiscal Year Ended June 30, 1980* (Long Beach: 1980).

[4]Ibid.

search Center operated by the National Aeronautics and Space Administration (NASA), through which San Jose faculty currently have 45 contracts (FY 1980-81).

Data from other campuses indicate varying degrees of R&D activity linked to local industry: Humboldt, located near extensive lumber and fishing industries; Fullerton, with a wide range of medium- and high-technology industries nearby; and Fresno and Chico, located in communities where agriculture is the primary industry. (Section F of this chapter lists specific grants and contracts at each campus included in Table 17.)

Pomona, one of the two state polytechnics, appears strangely inactive in terms of formal R&D expenditures. Yet a campus visit in June, 1981, made clear that considerable research and consulting activity was occurring off campus, including work at the Jet Propulsion Laboratory in nearby Pasadena. In addition, there appeared to be a lively interest in further development of campus-based research. Table 18 (Awards) indicates a noticeable increase in R&D at Pomona: this suggests that faculty there may be bringing more of their non-teaching professional work on campus, perhaps as criticism of faculty "moonlighting" declines. (See further discussion of this point below, under "Private Professional Practice.")

research, are implemented through a brief Request for Proposal (RFP) process and thus are excluded from prior awards listings. Clearly, a comprehensive study of R&D awards *and* expenditures would require an analysis of trends over several years and a closer examination of each foundation's records.

C. Formal Structures: the Campus Foundations

The state college research foundations are auxiliary non-profit organizations established on each campus to handle extramural funds. Their appearance in the 1950's also marked the arrival of research-oriented Ph.D. faculty on the state college campuses. While rules governing the operation of auxiliary organizations published in 1953 did not even mention research grants, by 1959 new rules had been formulated to allow faculty to receive research grants and contracts, make arrangements for compensated release-time, and so on.[6] At the present time, virtually all campus R&D money is funneled through the research foundations.

Generally, the role of the foundations has been relatively passive. While some have actively assisted in locating sources of grants and contracts, by and large

Table 18

Total Dollars and Relative Percentages of R&D and Industrial R&D Awards, at Eight CSUC Campuses: Fiscal Year Ending June 30, 1980

		A	B	C	D	E
*Rank**	*Campus*	*Total Awards*	*Total R&D Awards*	*% R&D of Total Awards*	*Total Industrial R&D Awards*	*% Industrial of Total R&D Awards*
(1)	San Jose	$ 7,232,589	$3,729,226	51.6	$511,39[illegible]	13.7
(2)	San Diego	14,717,797	4,890,826	33.2	377,635	[illegible]
(3)	Humboldt	1,521,451	466,850	30.7	60,000(est.)**	12.9**
(4)	Fullerton	3,640,597	770,103	21.2	91,068	11.8
(5)	Fresno	1,888,027	317,324	16.8	96,743***	30.5
(6)	Pomona	1,487,920	205,731	13:8	85,980	41.8
(7)	Chico	3,573,116	383,601	10.7	27,451	7.2
(8)	Sacramento	4,211,315	301,003	7.1	14,820	4.9

Source. CSUC

* Ranked according to percent R&D of all awards (Column C).
** See note to Table 17.
*** See note to Table 17.

Column A: Total dollar amount of all foundation awards (i.e., external monies announced) for research, training, and other educational projects.
Column B: Total dollar amount of all awards for R&D.
Column C: Percent R&D of total awards (B/A).
Column D: Total dollar amount of awards for R&D from private industry sources.
Column E: Percent industrial R&D of total R&D awards (D/B).

The "awards" data shown in Table 18 should be regarded cautiously. Unlike the data on expenditures, these figures are relatively incomplete or unreliable because (a) not all awards are necessarily spent the following year, (b) not all money to be spent the following year is necessarily announced by the fiscal year cutoff date, and (c) many contracts, especially in applied

they have emphasized providing technical assistance and clerical support in the submission of grant applications and responses to contract RFP's. In the view of some faculty, the foundations have concentrated too much on the fiscal and regulatory compliance aspects of grant and contract activity, a purely bureaucratic function.

[5] Ibid.

[6] Ibid.

In any case, the separation between the foundations and the regular academic structure has probably helped to increase tension between faculty and foundation staff. Adding to the strain is the perception of some research-interested faculty that "overhead" or charges for indirect costs (the percentage of grant or contract value charged by the foundation) are excessive, especially on larger grants and contracts. Sometimes faculty agitate to get some of this money back—for small "seed" grants to help establish research projects, stipends for graduate research assistants, and so on.

At two of the eight campuses discussed here, this kind of conflict appears to have resulted in a separation of the application and administration functions. At San Jose State and California State, Fullerton, the foundations handle only the fiscal or bookkeeping responsibilities of grant and contract administration, while the application function is handled by a separate research office located within the regular administrative structure and headed by a former faculty member with a demonstrated "track record" for getting his own funding. At both campuses—perhaps because they have greater confidence in the more visible research office—science and engineering faculty seem relatively content with this dual arrangement.

On the other hand, on several campuses where the application and fiscal functions are combined in the campus foundation, science and engineering faculty have set up various kinds of research centers. Their intention is, among other things, to gain greater off-campus visibility for their special skills and abilities than can be achieved operating through the foundation alone. Along with the emergence of these structures there are, frequently, intensified demands for a larger return of overhead money to help meet research costs of various kinds.

It should be made clear, however, that dissatisfaction with the present structure of campus foundations does not appear to be uniform at all campuses visited. The figures for expenditures and awards presented above suggest that on some campuses—San Diego, for example—there could well be considerable support for the single dual-function research foundation. With a total dollar amount of expenditures and awards amounting to about twice as large as that of its nearest competitor, the San Diego foundation might be expected to be able to marshal considerable support for things as they are. At San Diego overhead money from external grants supports a number of activities apart from research, but it also helps pay for the participation by that campus in several "joint-Ph.D." programs with campuses of the University of California—the only way in which state colleges in California are allowed to participate in doctoral programs under the Master Plan described above. Possibly the departments privileged to advance candidates in this program (chemistry, for one) would have more of a stake in supporting existing foundation arrangements than might chemistry departments on other campuses.

D. Visible Structures: Centers, Institutes and Laboratories

A common form of organized research and consulting unit on CSUC campuses is the department- or interdepartment-based center or institute. An example is the Cellular Molecular Biology Institute at Pomona, recently established with the aid of a $20,000 campus foundation grant (derived from overhead from outside grants).

> The institute supports pilot investigative research by faculty and students who are interested in molecular biological techniques, in the . . . schools of Science and Agriculture.[7]

The scope of the institute's activity may encompass potentially commercial applications in the field of applied molecular biology. It is worth noting that such research units may still be viewed as departures from the traditional teaching mission of the state college. The director of the Institute justified it in the context of an instructionally-oriented campus:

> I think, in order to be a scientist and to be responsible for education of the scientists of tomorrow you have to keep up with your work, talk to other scientists, actually get into the lab, do the research, and find out all the new techniques.[8]

At Sacramento, the Applied Research and Design Center was formed in the School of Engineering

> . . . to secure and execute research conducted by faculty and students of its departments and special programs.[9]

The Center is intended to foster collaborative efforts between campus scientists and engineers and those in government and industry. Its work is directed towards a general market for creative applied science; it draws upon a pool of 53 full-time engineering and computer science faculty to work on projects such as designing an industrial solar heating system or analyzing foreign material on cable used to power light rail vehicles. The Center has proposed using overhead from grants for graduate student stipends (although it is apparently the case that the campus foundation has strongly resisted the release of more overhead monies for student support).

On the San Diego State campus there is an interesting example of a large multi-focus research unit. Based in a single department, the recently organized

[7] California Polytechnic State University, Pomona *News and Publications* (May 5, 1981), p. 1.

[8] Ibid., p. 2.

[9] California State University, Sacramento, School of Engineering, *The ARDC Effect* (Sacramento: 1979), p. 3.

Applied Physics Research Laboratory consists of five subsidiary labs. Its primary function

> . . is to supply research, development and consulting services in the applied sciences to industrial and government organizations.[10]

The Lab appears to have attracted interest from industrial firms in the area. The Acoustics Measurements Laboratory has gained contracts with General Atomics Corporation; the Nuclear Radiation Lab, with IRT Corporation and General Atomics; and the Electro-Optical Measurements Lab, with Teledyne-Ryan Corporation, General Atomics National Semiconductor, and Lifeguard Signals and Science Applications, Inc. The Thin Film Laboratory is a newly developed facility which offers a range of capabilities related to thin-film fabrication and processing. An important application of this field lies in photovoltaics (solar cells). The Image Processing Laboratory is scheduled to open in mid-1982; at that time ". . . both digital and optical image processing services will be available".[11]

E. Private Professional Practice

One of the difficulties in assessing the extent of off-campus professional activity at California state colleges is that an undetermined amount of consultation is arranged privately by individual faculty members. In the course of this investigation, several academic officials responsible for on-campus research suggested that work done privately by their science and engineering (and business school) faculty greatly exceeded the volume of work done through the designated research or grant-processing office on campus.

Such private practice may range from an informal one-to-one relationship with a client to a group practice carried on with other campus colleagues.[12] Because such arrangements are not linked to any campus office, they are not subject to official recording or supervision, or—more important, perhaps—overhead charges of any kind. In addition, faculty may work through the three-month summer or shorter winter and spring recesses without formally notifying any campus officer. This kind of arrangement is, of course, much more likely to involve work for private companies than for government agencies which typically do not contract directly with individuals where larger dollar amounts are involved.

A full determination of the extent of such private practice in the state colleges would require study beyond the scope of this report. It has been a sensitive subject: formal CSUC systemwide policy states that faculty cannot earn from outside work more than 25% over their regular income[13], and in past years, criticism from the legislature and the board of trustees has been directed at faculty who they fear take time or energy away from teaching to earn extra consulting income or do research. At the same time, there has been a common expectation that faculty will involve themselves in "community service" in their area of expertise (an element that enters into promotion evaluations).[14]

In any case, a degree of legitimacy has recently been cast upon private consulting by the establishment in 1978 within the CSUC system of a Technical Assistance Program (TAP) in energy conservation and technology. The TAP was organized in response to demands for *active assistance* from various groups, following a series of extension lectures.

> The availability of CSUC campuses throughout the state, and the fact that they were already involved in the energy picture, obligated them to also provide professional assistance to this segment of the population.[15]

Using funds from private utilities and the U.S. Department of Energy, the TAP published a *State Directory of Energy Consulting Service*[16] which proffered the services of 150 CSUC scientists, social scientists and engineers. The introduction to the *Directory* notes:

> As independent consultants (faculty) may or may not charge for their services, as they see fit.[17]

Evidence of official approval of the *Directory* came with its introduction by the CSUC Chancellor:

> Chancellor Dumke said each of the campuses has faculty with expertise in energy fields who with (undergraduate) and graduate students can provide consulting help to citizens, public agencies and businesses.[18]

Thus it appears that CSUC faculty are sanctioned, and even encouraged, to undertake extramural or private practice. There is, unfortunately, no way of measuring the success of the Technical Assistance Program, just because any requests for assistance go directly to individual faculty and no official records are kept. But the significance of this program for our discussion here is the apparent license it has given CSUC faculty to operate "on the side."

[10] San Diego State University, Department of Physics, *The Applied Physics Research Laboratory* (San Diego: n.d.), p. 1.

[11] Ibid., p. 3.

[12] Marver and Patton, "The Correlates of Consultation," p. 322.

[13] CSUC, "Additional Employment Policy of the California State University and Colleges," FSA 79-30 (Long Beach: June 14, 1979).

[14] California State University, Sacramento, *Academic Personnel Policies and Procedures* (Applicable for the 1977-78 Academic Year), (Sacramento: 1978), p. 8. Arguments which contradict common criticisms of faculty consulting may be found in Carl V. Patton (Univ. of Illinois) "Faculty Consulting: Boon or Bane to Science Research?" (n.d.); James D. Marver and Carl V. Patton, "The Productivity of American Academic Consultants," (n.d.); and Carl V. Patton, "Consulting by Faculty Members."

[15] G. Cleve Turner and Robert V. Giocosie, "The Statewide Energy Consortium: A California Concept," *Journal of College Science Teaching* (February 1981), 238-240.

[16] CSUC, Statewide Energy Consortium, *State Directory of Energy Consulting Services* (1980).

[17] Ibid.

[18] "Dumke Reveals Energy Plan," *CSUS Hornet*, April 18, 1978, p. 1.

F. Industrial Supporters of R&D at the Surveyed Campuses

This section lists for each campus discussed in this report, private industrial sources of current grants and contracts, and the dollar amounts involved—according to official campus sources. It should not be interpreted as a comprehensive report; the intent is rather to give the reader a sense of the scope of work being done. The figures are drawn from two sources: the annual report of activities ending June 30, 1980, summarizing the activity of campus foundations[19] which gives the dollar amounts of both awards and expenditures during the fiscal year; plus, a variety of official local records and news releases obtained during personal visits to some campuses.

San Diego State: One of the largest of all CSUC campuses, with nearly 25,000 full-time equivalent students (FTE), and more than 1,000 full-time faculty. It is located in a large city with a major naval base and several large aerospace and electronics firms.

Firms	*Awards*	*(Expenditures)*
Electric Power Research Institute	$196,349	($248,493)
Woodward-Clyde Consultants and San Diego Gas and Electricity	—0—	(32,497)
Lockheed Center for Marine Research	50,000	(26,317)
Battelle Northwest Laboratories	137,000	(82,000)
General Atomics	14,000	(—0—)
General Dynamics Convair	12,000	(—0—)
VERAC Inc.	4,405	
Research Corporation	7,000	
Research Corporation	15,400	
California Avocado Society	1,212	

California State, Fullerton: An "instant college," founded after Sputnik in 1958, with about 15—16,000 current FTE and over 700 full-time faculty. Located in the rapidly growing southeastern sector of the Los Angeles megalopolis, the campus is close to a wide range of medium- and high-technology firms.

Firms	*Awards*	*(Expenditures)*
Science Eng'r. Association	$28,358	($21,033)
Global Computer Systems	26,016	(20,783)
Southern California Edison Co.	10,[illegible]26	(—0—)
Teletronix Inc.	562	
Research Corporation	11,250	
Research Corporation	1,400	
Research Corporation	5,000	
Research Corporation	12,000	
Woodfool Labs, Inc.	3,000	
McDonnell-Douglas Astronautics	14,000	
Rockwell International	6,000	
Rockwell International	6,000	
Rand McNally Inc.	2,000	

California State Polytechnic, Pomona: Originally an agricultural school, with a well-known center for the study of horses, it emphasizes engineering and applied programs. With about 12,000 FTE and 550 full-time faculty, it graduates approximately 450 engineers at the bachelor's level and 50 at the master's, per year. Pomona is located in the northeast corner of Los Angeles County, in one of the most rapidly industrializing parts of California.

Firms	*Awards*	*(Expenditures)*
Gas Producers Association	$ 39,980	($ 869)
Lockheed Aircraft Corporation	12,000	(5,066)
Southern California Edison Co.	27,000	
Southern California Edison Co.	81,000	
Organon Corporation	2,300	
Oak Turf Racing Association	300,000	

California State, Fresno: One of the original normal schools, with about 13—14,000 current FTE and under 600 full-time faculty. It is located in a small but substantial city about 200 miles north of Los Angeles, which is often referred to as the "capital" of the agri-business-dominated San Joaquin Valley.

Firms	*Awards*	*(Expenditures)*
Pacific Gas and Electric	$—0—	($112,986)
Southern California Edison Co.	40,000	(40,000)
Lilly Research Labs.	15,750	(14,340)
Lilly Research Labs.	11,175	(11,175)

San Jose State: San Jose, with 22,000 FTE and fewer than 1000 full-time faculty, is located at the southern end of the Santa Clara (or "Silicon") Valley, while Stanford University marks the northern end. Although San Jose's R&D records show a lot of activity in electronics and aerospace, much of this is funded by the federal government, through NASA's Ames Research Center. Most of the items listed below are linked to the Moss Landing Marine Laboratory, a state college facility operated by San Jose for all the northern campuses. It is clear from conversations on the campus that much of the consulting in the Silicon Valley by San Jose State faculty is done privately.

Firms	*Awards*	*(Expenditures)*
Kaiser Refractories	$ 41,437	($ 11,068)
Kaiser Refractories	—0—	(26,691)
CH2M Inc.	274,832	(188,248)
CH2M Inc.	35,000	(50,293)
Ocean Mineral Co.	122,202	(105,049)
Standard Oil Co., Indiana	27,921	(20,970)

California State, Sacramento: Located in the capital city, Sacramento has an FTE of about 15,000 and approximately 800 full-time faculty. While the total number of all grants and contracts is larger than at many campuses, there are relatively few of the R&D type. Again, most of that kind of work goes on under the cover of private consulting. Only one item in the foundations' annual report can be classified as private R&D—a contract from a local Procter and Gamble plant for $14,820, of which $1,788 was reported expended in fiscal 1979-80.

California State, Chico: One of the original normal schools, it is set in ranch and fruit-farming country about 100 miles north of Sacramento. Apart from various services that support agriculture there is little industry of any kind; the items from the private sector listed below confirm this. As will be seen in the next chapter, the Chico Computer Science Department has a great deal of interaction with the computer industry in the San Francisco Bay area, but again, this moves through private consulting channels.

[19] CSUC, *Reporting Activity in Research*.

Firms	*Awards*	*(Expenditures)*
Rice Growers Co-op	$17,400	($—0—)
Almond (Growers) Board	10,051	(10,051)
California Energy	—0—	(17,449)

Humboldt State At Arcata on the far northwestern coast, close to the Oregon border. It is the smallest campus of the eight with about 8,000 FTE and fewer than 500 full-time faculty. Although more isolated than Chico, the campus is surrounded by federal and state laboratories and experiment stations serving the area's lumber and fishing industries. Thus science and engineering faculty, especially the applied biological and physical scientists in the widely known School Natural Resources, have many opportunities to provide mutual services. But Humboldt presents one more case where most of the work for private industry is done off-campus. The foundation there reports processing only half a dozen or so small grants from commercial or industrial sources last year, each worth less than $10,000, for a total of about $60,000. However, the foundation director indicated that many faculty in fields related to area industries were doing private consulting.

G. An Intriguing Anomaly in the Data on Industrial Funding

Additional light on the dollar value of off-campus private consulting is revealed in two sets of figures reporting on the value of Industrial R&D expenditures at certain campuses. The first set deals with expenditures of private industrial funds through campus research foundations and is presented in Table 17. The second source of figures is *Engineering Education*, a publication of the American Association of Engineering Education of Washington, D.C., which surveys the nation's engineering schools each year.

The *Engineering Education* survey, covering the year 1979-1980, drew replies on amounts of R&D funding from only two of the California state colleges looked at here: San Jose State and California State, Sacramento. Table 19 contrasts the CSUC official figures on private industrial expenditures with the more limited, but still comparable, data from the *Engineering Education* survey. It will be noted that the two sets of figures for San Jose State are compatible. San Jose State Engineering School reports expenditures from private business or industrial sources which, as might be expected, amount to less than that officially reported for engineering and natural and physical science departments together. The figures for California State, Sacramento present an anomaly and, possibly, a clue to how much off-campus work is done there and at other campuses. According to the *Engineering Education* survey, the engineering faculty at California State, Sacramento, reported spending about 900% (i.e., more than 90 times) the amount of dollars from private business than was channelled through the campus research foundation! Discussion with the Sacramento engineering dean confirms the difference in, and the reason behind, the figures. According to him, he decided to gather data directly from his faculty for *Engineering Education's* annual questionnaire rather than simply submit figures available in existing campus records. He explained further that his questionnaire was meant only to elicit information on campus-related R&D. However, whatever the reasons, faculty reported on private work as well.

While this comparison may be somewhat tenuous, it is nevertheless suggestive—even indicative—of what might lie behind the official records of R&D activity of state college (and perhaps other kinds of) faculty. It certainly lends credence to the comments of various deans and vice-presidents at San Jose, Pomona and other places who suggested that work done as private practice off-campus by their faculties might well overshadow what is being done through campus administrative facilities. In the next chapter some projects of both kinds will be discussed in more detail.

Table 19

Private Industrial R&D Funds Expended by All Science and Engineering Departments Reported by CSUC, Year ending 6/30/80, and Engineering Departments Reported by *Engineering Education*, Year 1979-1980

	*CSUC Science & Engineering Depts. Official Foundation Reports, Year Ending 6/30/80**	*Engineering Education Engineering Schools Survey Covering 1979-80***
San Jose State	$502,346	$300,000
California State Sacramento	$ 1,788	$133,000

*CSUC: *Reporting Activity in Research etc.* ...Nov. 1980 (Derived).
***Engineering Education*, March 1981.[20]

[20]*Engineering Education*, March 1981, Vol. 71, No. 6, p. 426. And *CSUC Reporting Activity in Research, Workshops, Institutes, and Other Special Educational Projects for Fiscal Year Ended June 30, 1980* (Long Beach: 1980).

CHAPTER V

CALIFORNIA: SOME EXAMPLES OF CAMPUS—INDUSTRY INTERACTION

This chapter presents some specific examples of productive interaction between industry and state college science and engineering faculty. Brodsky, *et al.*,[1] have developed a classification of university-industry interaction which subsumes most linking activities under two general categories: (1) collaborative research mechanisms, including actual problem-oriented joint R&D activity, and (2) knowledge transfer mechanisms involving continuing education, co-operative education, innovation centers and consulting. In the case of "consulting," no distinction seems to be made regarding the formal "on-campus" and "off-campus" kinds of activity. As some of the examples below illustrate, elements of both types of mechanisms, plus on- and off-campus work, can often be jointly involved in any one case. Further, the range and types of interaction vary widely within disciplines and between campuses. Nevertheless, some characteristic features or patterns may be discerned; and our discussion will revolve around these.

A. Student Participation

One of the most direct—and potentially most productive—connections between the campus and private industry revolves around engineering students who must complete senior or master's projects focused on problems encountered in engineering practice. Traditionally, state college engineering projects have been oriented toward immediate vocational interests rather than post-graduate research careers; as a result, such projects often lead to subsequent employment. Thus the availability of industry-based projects ensures that students are directed toward private industry, while particular firms are provided with personnel conversant with their specific technical needs. At a more abstract level, this process underscores the role of state colleges in providing industry with technically trained personnel. Useem[2] notes the importance of San Jose State in the industrial development of the Silicon Valley:

> San Jose State University supplies more engineers with bachelor's degrees to area firms than any other school. Long overshadowed by the engineering school of its eminent neighbor, Stanford, it enrolls approximately 4000 students in engineering. . . . A leading industry figure called the school the "unsung hero of the Valley" for turning out so many graduates. About 14 percent of the University's undergraduates . . . are enrolled in engineering, a typical percentage for a large state university.

Senior and master's projects are supervised by faculty, but in addition, they are often overseen by a joint committee of faculty and industry or agency technical personnel. In the case of state college master's students, many are *already* full-time employees in their various fields; and their thesis projects are often tailored to technical problems confronting their employers.

At California State, Sacramento, a civil engineering professor used the master's project to organize a seminar for dropouts from the graduate program; most of these were fully involved in jobs and had given up the idea of finishing their degrees. They met once a week and were encouraged to develop work-related projects. According to one of members, then an engineer at a chemical company:

> The thesis topic that I had—the school just didn't have the equipment for me to do it—and I sort of abandoned it and was going to give it up.

[1] Neal H. Brodsky, Harold G. Kaufman, and John D. Tooker, *University/Industry Cooperation: A Preliminary Analysis of Existing Mechanisms and Their Relationship to the Innovation Process* (New York: Graduate School of Public Administration, New York University, 1980).

[2] Useem, Elizabeth (Boston State College), "Education and High Technology Industry: The Case of Silicon Valley—Summary of Research Findings," August 1981.

Instead:

> We were doing some work on deep injection wells at the company. So I wrote my thesis on using deep injection wells as an ultimate means for disposing of toxic and refractory wastes.

The company—a large one with branches throughout the country—approved the project and even secured the services of an outside consultant for the student's project committee. Estimated cost of the research to the company was about a quarter of a million dollars, well beyond the support available from the Sacramento campus alone.

Interestingly enough, a few years later the chemical company found itself in trouble with environmental authorities at several levels of government for allegedly having contaminated groundwater in the vicinity of its property by dumping wastes in unlined surface ponds. (Whether this occurred prior or subsequent to the engineer's work on injection disposal is unclear.) But in the meantime, the engineer—with master's degree completed—is working for the company in a new capacity; he is now responsible for its environmental control system.

Also at Sacramento, another civil engineering professor is working with students to test an underground pipe developed by ARMCO Steel for drainage and sewage systems. ARMCO, a national firm which produces highway and drainage fixtures, among other things, requested assistance in testing the pipe which is made of cement and encased in an ABS plastic coating. The professor has put several engineering senior and master's students to work on the project in the campus testing lab. The students are not only getting their necessary graduation projects or theses out of the work, but several have found themselves in a position to negotiate for jobs with the company which has branches across the country.

B. Gifts, "Taking in Washing" and "Making Do"

It is a commonplace among state college science and engineering faculty that their relatively expensive programs have been chronically underfunded in a system designed to provide low-cost mass instruction to a non-elite and numerous clientele. These financial straits grown increasingly severe as fiscal pressures mount on state budgets, have led to some singular, if predictable, dependencies on industry. A dean at San Diego State noted that the most recent engineering building on campus was built in 1962, with all its equipment and instrumentation based on vacuum tubes. Accordingly: "We've had to put a lot of emphasis on scrounging newer equipment, especially from companies around town."

He noted further that one of the salaried technicians who had good connections with area firms had proved so successful in soliciting gifts of equipment that he was presently detailed to work half-time cultivating his contacts and "begging." The campus research foundations are, of course, able to receive such donations and provide tax-deduction documentation for the donors. The most recent gift of this kind at San Diego provided a much needed laboratory refrigerator for a biochemistry lab. Similarly when the physics department at San Diego found itself in need of one kilometer of optical fiber for experimental work, five local firms were asked if they could spare some. All five could, and did; and a total of five kilometers arrived at the physics building.

Interviews at Cal Poly, Pomona, revealed that faculty there also rely on a campus lab technician to keep the facilities more up-to-date than they otherwise would be. With informal ties to a number of firms where he had been employed, he is able to locate and solicit gifts of surplus equipment. And a San Jose State newsletter reported in 1980 that a physics department technician had

> . . .recently completed modifying a $150,000 low-energy electron scanning microscope donated to the Physics Department by IBM's General Products Division in San Jose.[3]

According to department faculty, the microscope had become "outmoded for IBM's current needs" but remained an extremely valuable teaching tool. Useem reports some disagreement among campus officials about the value of donated equipment;[4] nevertheless, such donations appear to be an important source of corporate support for campus science programs.

Apart from the obvious tax deductions there may in some cases be other benefits accruing to donor companies. At Sacramento where Hewlett-Packard has recently established a plant, the state college has received a late-model HP 1000 minicomputer with graphics capability. A key reason is to familiarize students not only with HP systems in particular, but also with something close to state-of-the-art systems in general. State government budget officials are unconvinced that state college students need late-model systems "to learn on"—a view regarded as appallingly inappropriate in a field that makes its current equipment obsolete every few years. Hence, the computer companies are compelled to provide this kind of assistance if they want to hire graduates familiar with contemporary equipment.

And of course, other benefits can arise from placing state-of-the-art instrumentation on state college campuses. For example, Sacramento computer science faculty and students are working to adapt a program—much used in structural engineering, but previously workable only on much larger systems—to the HP minicomputer. This adaptation, if successful, will presumably enhance the HP 1000's usefulness

[3] San Jose State University, *Campus Digest* (March 24, 1980).
[4] Useem, "Education and High Technology Industry," p. 24.

and its sales potential. Such innovation clearly translates into industrial productivity at several levels.

Another way of coping with the relative poverty afflicting science and engineering labs and equipment is reported by Cal Poly. There, although enough money had been found to purchase and install an electron microscope facility, funds to operate and maintain it were not forthcoming. According to campus officials, the department responsible at Pomona is actively seeking contract work from some of the many firms nearby to help pay such overhead costs.

Finally like most institutions of higher education, California state colleges must often restrict their activities in the face of scarce resources. For oceanography research at San Diego State, restricting the scope of the program has ultimately brought it closer to industry. While their oceanographers operate from a joint research site at the Scripps facility at La Jolla with more generously funded teams, they are restricted in their range of research problems. Because the cruise capability of their small research vessel does not allow them to do deep-sea work, they have specialized in nearshore and estuary studies. As a result they have become proficient in applied aquaculture, specifically the study of commercial production problems associated with lobsters, rock scallops and similar marketable inshore species. This brings them in contact with not only the private industrial sector, but also the various government agencies providing support services to the aquacultural industry; this, of course, puts the San Diego State program in a position to receive funding from both sources.

C. Inventions and Innovations

One of the factors in the ability of state college science and engineering programs to attract financial support from private industry lies in the inventive or innovative capacity of the faculty. ("Invention" is used here to mean the creation of a new device or method; "innovation" to mean the introduction of a new or previous invention into practical use.) The examples that follow are not offered as an exhaustive inventory, but rather as illustrations of the creativity that may occur in this setting.

1. *The Teacup Solids Separator*

A Sacramento engineering professor specializing in water supply and wastewater drainage systems has been involved in projects linking him and the engineering school with government agencies and private firms for almost twenty years. Recently, he has been working with an off-campus colleague who has invented a device called a Teacup Solids Separator which separates solid debris from storm wastewater and sewage. The colleague frequently teaches part-time in the engineering school, a typical arrangement involving practicing engineers in the teaching program. Working together, the private engineer (whose firm specializes in water treatment problems), the faculty member, and students—graduate and undergraduate—have tailored models of the separator to specific industrial situations. At present, they are testing a more sophisticated, larger-scale application designed to remove solids from domestic and storm runoff wastewaters at the main sewage treatment plant in the city of Sacramento. This project is being monitored by potential users—both public and private—and by private firms interested in manufacturing and installing such systems on a commercial basis.

2. *The Stratified Charge*

Also at Sacramento, a mechanical engineering professor and his students have developed a feasible add-on device for automobile engine combustion chambers that allows much more efficient gasoline consumption and a reduction of air-polluting emissions to very low levels. The original invention is that of an off-campus engineer, now retired; and the device is said to operate through a process similar to that used in some Japanese cars which have performed well on efficiency and emissions tests. One of the advantages of the system developed at the Sacramento campus is that it is retrofittable to existing automobiles; it has been successfully installed in two American cars for testing and demonstration purposes. A contract with a state government agency to retrofit a test group of state vehicles is currently pending.

3. *Computer Enhancements*

A number of computer manufacturing firms in the "Silicon Valley" south of San Francisco, have had what officials of one termed a long and productive relationship with Chico State College (now CSU, Chico), located about 200 miles northeast of the Bay Area. Such relationships apparently stem from the 1960's migration of scientists and engineers from the aerospace industry to Chico and other California state colleges where they began setting up computer science programs. Many brought with them continuing connections with former colleagues remaining in the aerospace and electronics industries. The development of state college computer science programs has been particularly important to the computer companies in California which are dependent on educational programs of this kind to provide a continuous supply of trained technical and sales personnel at all levels. The computer industry is extremely competitive, if not piratical, in terms of skilled labor; rapid turnover of qualified technical and sales staff is an ongoing fact of life.

One of the first computer science departments in the California state college system was established at Chico, and it remains one of the largest. The industry's link with that campus, however, has been strengthened by other bonds. A faculty member and master's student, working there in the early 1970's with a popular model of one company's minicomputer, made changes at the firmware level which company engineers had doubted were possible. As a result of this experimentation, the capacity of that particular model and system was increased by a factor of 28. Furthermore, the changes were easily retrofitted; and as a consequence, the manufacturer moved into a stronger market position for that size and kind of instrument. Over the years since, the grateful firm has sent a steady stream of donated equipment and company scientists to the Chico campus to supplement the faculty's work with students.

At San Diego State, an electrical engineering professor acts as a consultant to a small local firm specializing in design and fabrication of microprocessor-equipped instrumentation for physics research laboratories. This relationship originated when the company called the campus for trouble-shooting assistance on a particular microprocessor design which the faculty member reportedly "went out and fixed . . . in one day."

The firm is one of a number of small companies around San Diego that build specialized digital equipment using pre-manufactured integrated circuit chips as "building blocks." When the campus engineer was called, they had been trying to build an instrument around a standard microprocessor chip. Because the problem was resolved quickly, they were able to present an important demonstration at an out-of-town marketing show the following week. According to the engineer, he has now been retained by the company to assist in the development of another special instrument to be built around another chip.

At Cal Poly, Pomona, a biological sciences professor has "spunoff" a small private company to promote and sell a specific computer software he has developed. His system allows a group of experts who work together to pool their knowledge in a jointly usable data base, enabling one of them to react quickly to a given problem. So far, the market for the system seems to be small practicing groups such as medical, scientific and legal firms.

4. *Energy Applications*

As might be expected, the energy field is the focus of much contemporary R&D activity. *The State Directory of Energy Consulting Services*, mentioned in Chapter-IV[5], indicates a substantial degree of energy expertise among state college science and engineering faculty on virtually every campus within the system.

At both San Diego and San Jose, faculty are helping to develop plans for co-generation plants to recycle energy that would otherwise be wasted. On the latter campus, engineering faculty were involved in the conceptual design of the heating system for the new campus library, a combination of solar and co-generated heat. At San Diego, a physics professor has developed a special type of solar heat collector capable of producing high temperatures suitable for steam power generation.

At Sacramento a mechanical engineering professor is involved with government and industry in a "gasification" project intended to convert city wood waste (from tree clippings and other sources) into gas for possible use by the campus. Once a prototype has been perfected, the converters will be manufactured by a local firm.

Also at Sacramento, another professor of civil engineering has invented and holds patents for a dry-cast concrete, the properties of which include rapid set-up, superior strength, machinability and polishability. This last property has attracted the interest of internationally known sculptors who have used the concrete in public locations at several places throughout the world. He has also designed and developed instrumentation for measuring stress on the shells of underground transit tunnels and other subsurface structures as part of a method of building more cost-efficient subsurface structures.

5. *Physics Applications*

This section has stressed the work of engineering faculty, probably because the emphasis on design in engineering leads naturally to new devices or systems. But faculty within the basic sciences may also develop new products or methods which have industrial application. For instance, a San Diego physics professor has developed a method to "lock" lasers together so that they oscillate in step, preventing laser frequencies from drifting apart. Another member of the same department has developed a new way to conduct satellite surveys of land and mineral deposits (including hydrocarbons). This process has military, as well as industrial, application.

D. Faculty Accessibility

Both private and campus-based collaborative activities between state college faculty and local industry usually develop out of referrals from scientists and engineers who are familiar with one another, but who work in different settings. But the simple presence in a community of a state college, and its pool of faculty expertise, apparently attracts inquiries from people with serious scientific concerns but who lack access to professional advice. Office staff of science and engineering departments at these institutions report frequent telephone calls requesting expert advice on a broad range of topics. Many faculty informants—particularly those in basic sciences like physics—report that initial contacts with smaller and newly-forming businesses seeking scientific assistance for the first

[5] CSEC Statewide Energy Consortium, *State Directory*.

time have often been made this way. For instance, physicists at the Sacramento campus provided key advice on laser technology in response to a request from the owner of a small optics firm (14 employees) manufacturing special photographic filters. In another case, the off-campus promoters of a highly-rated, new type of high fidelity speaker contacted Sacramento physics and mathematics faculty for controlled testing assistance, using a special test chamber available in the physics lab. Both the optical filter and the speaker are now being manufactured in Sacramento, and marketed throughout the world.

E. Private vs. On-Campus Work: an Exemplary Campus

We have already mentioned above that while faculty routinely conduct a good deal of R&D activity in their capacity as private consultants, the actual extent of such activity is unknown. Nowhere is this more apparent than at San Jose State which—because it is particularly active in terms of R&D—we will focus on briefly here.

The discussion of Table 17, above, indicated that in comparison to the other campuses studied, San Jose had the highest official percentage of R&D expenditures from all sources, as well as R&D money from industry. The largest single source of San Jose's on-campus R&D contracts is the Ames Research Center, a NASA facility operated at nearby Moffatt Field. The work with Ames began in the 1960's, with a psychologist interested in the performance of human auditory functions under space travel conditions; in FY 1980/81, faculty and student research assistants were at work on 45 contracts there. Funding at the Ames Center is, of course, largely federal; but the Center does serve to tie together local industrial electronics and aerospace research, as researchers from private firms in the vicinity also get NASA contracts through it.

But the industrial R&D contracts channeled through the San Jose Research Office do not, for the most part, originate with Silicon Valley firms. Faculty work with the relatively new, high-technology firms in this area is usually carried out independently, and not officially recorded on campus. The following case illustrates a fairly widespread pattern where expertise developed in the course of campus-based sponsored research is subsequently used in private consulting practice.

A mechanical engineering professor participated in a study of the ignition and combustion processes of a number of materials used in aircraft and space vehicles. The study required test burns under many conditions, and resulted in the publication of reports sufficient to establish the San Jose engineer as an authority on certain kinds of fires and their control. Subsequently as an associate of a firm of scientific specialists, he has worked as a private consultant on related problems such as subway transit fires and resulting generation and control of lethal gas, and anaerobic explosions aboard ships in dry dock. He declined an offer from a world-famous oil well fire control firm, explaining:

> I didn't want to be on call to jump on a Lear jet on five minutes notice and find myself stuck out in the North Sea in the middle of winter.

As for the matter of faculty and graduate students who have become involved in companies "spun-off" from the campus to develop and produce new processes and products over the years, San Jose research officials say they have lost track of most of them because the pattern has been repeated so often. In a recent telephone conversation, a campus dean cited one faculty member who had just launched a new company with a process for dealing with nuclear waste; another, who with others had just patented an automated system for environmental control; and another who, having successfully floated a company with off-campus backing on the basis of an advanced method for reworking micro-chips, had unfortunately just resigned to devote his full time to the venture.

Most of the industrial R&D that *is* channeled through the campus revolves around the oceanographic and marine biological research station at Moss Landing, about an hour's drive from San Jose on the Pacific Coast. This station is operated by San Jose for a consortium of six northern CSUC campuses. Unlike its San Diego counterpart, the San Jose facility has a deep-sea research vessel. (It is on a long term loan from Oregon State University which obtained a newer and more versatile ship with the help of the National Science Foundation.) Further, the research station is located not only at the end of an estuary "teeming with fish and fowl", but also within a few miles of a narrow deep-sea canyon which comes in close to shore.

Moss Landing has become an important research facility, supplying data for marine industries from fisheries to mining and oil exploration. One way in which the research ship's operations are supported is through its temporary lease to private firms with commercial R&D projects offshore. All in all, Moss Landing appears to be one of San Jose State's primary attractors of industrial R&D money.

In its purely educational role San Jose State, particularly its engineering school, as Useem suggests above, is closely linked to local industry which includes branches and head offices of nationally known firms. On the engineering school's Engineering Advisory Council, which attempts to develop and maintain ties between campus and industry in the San Jose State service area, are executives from Bechtel Corporation of San Francisco, General Electric—San Jose, Hewlett-Packard—Palo Alto, IBM—San Jose, Intel Corporation—Santa Clara, Lockheed Missiles and Space Company—Sunnyvale, Owens-Corning Fiberglass Corporation—Santa Clara, Quadrex Corporation—Campbell and World Airways—Oakland.

F. Spin-Off and Program Development: an Exemplary Case

A striking example of the way in which interaction can be mutually beneficial to industry and campus is provided by the medically and commercially successful prosthetic heart valve developed during the 1960's at what was then called Sacramento State College. Campus scientists were brought into the heart valve field by the death of a popular engineering dean who had suffered from heart valve disease and had undergone surgical emplacement of an early form of artificial valve in 1962. With a personal interest at stake, he had organized a campus conference on the biological and engineering aspects of heart valve development; but died before the conference could meet. The mechanical engineering professor who subsequently chaired the conference, as well as other science and engineering faculty, were drawn into a preliminary investigation of the problems involved.

At about the same time, an established medical specialist in artificial heart valves moved his federally funded project from an eastern hospital to the private Sutter hospital and Medical Foundation in Sacramento. Before long the hospital research team was in contact with the state college heart valve study group. As our engineering informant explained:

> They were interested in us. They needed the engineering help. They had started already (but) they had no way of making valves. They had no engineers to work with.

The earliest valves were hand-made from a single slab of metal in the campus engineering design shop. Later they were made by a skilled technician-machinist employed by the engineering school (in his spare time at home). All through this period, senior and master's students enrolled in a developing biomedical engineering program were at work on problems associated with valve design. Through the early 1960's a succession of valves were made for experimental implantation by heart specialists at hospitals throughout the United States.

By the middle of the decade the design was stabilized, and the valve's acceptance brought international interest. Because the handicraft method of manufacture could no longer meet the demand, the professors and physicians explored the idea of an entrepreneurial venture to manufacture the valves with the help of a local machine shop. The business project fell through however, when, as the mechanical engineer noted: "The doctors wanted to be doctors and we wanted to be teachers." The fact that the device was subsequently manufactured and distributed throughout the world (approximately 24,000 implantations) by the Cutter Laboratories of Berkeley, California, came as somewhat of a surprise to the state college faculty involved.

It should be noted that an important factor in the success of the heart valve project at Sacramento was the special nature of the nonprofit, private medical research foundation at Sutter Hospital. The Sutter Foundation is a low-pressure operation which functions to permit physicians at the hospital to do research, as well as practice medicine. It presents a contrast with a typical university medical school hospital in terms of the amount and pace of research work carried on. Because they carry a typical medical-practice patient load, the Sutter physicians have less time for their research; and this fact, apparently, has made for a workable relationship with state college faculty who are similarly encumbered with high teaching loads. A mechanical engineer associated with Sutter Hospital from the start, put it this way:

> The fact that they were doctors *first*, and researchers second, made things fit perfectly with our problems as full-time college teachers. If they had been full-time med school research doctors, we couldn't have kept up with them!

Eventually, a fully accredited biomedical engineering program leading to a master's degree was developed out of the continuing relationship between Sutter Hospital and the state college in Sacramento. Since its inception, the program has graduated specialists who have gone into at least three lines of activity. Some have become supervisors of biomedical technology programs at hospitals and health facilities, including medical schools. Others, like their teachers, have become involved in R&D for biomedical technology firms; while a third group have formed their own innovative R&D ventures.

For example, a recently formed biomedical technology division at Aerojet-General, an aerospace industry firm with a plant a few miles from the campus, has recruited staff from graduates of the biomed program. Aerojet is developing a "heart assist" device for use during surgery. Personnel are continuously moving between the plant and the state college campus, with people from the company participating both as students and part-time faculty.

The biomed graduates who have become involved in new spin-off R&D firms have frequently combined their talents with those of their former teachers from the Sacramento campus. These combined efforts have resulted in the development of a number of innovative products and business ventures of varying degrees and kinds of success. Three selected examples follow:

The Electronic Blood Analyzer: Several biomed program graduates and a faculty member have developed a blood analyzer which is being manufactured and marketed by the independent firm they formed to develop and distribute it.

The Ultrasonic Diagnostic Instrument: A similar spin-off firm developed the instrument, but was bought out by the General Electric Company which added the device to its newly formed medical products division. G.E. did not transfer its new holdings away, incidentally, but acquired manufacturing space in the Sacramento area; thus, links with the state college biomedical engineering program have been maintained.

The Ventilator Project: Another group, including some of the original heart valve team, developed a breathing assistance device for operating room use. Unfortunately, it was not ready for the market soon enough, and the venture failed. Two competitive biomedical technology firms were able to get similar ventilators approved and into production, saturating a rather specialized market.

Because of the unique opportunity it provides for observing the development over time of a program involving campus and industry, we will comment further on the biomedical engineering case at Sacramento (see Chapter VII).

G. Fundamental and/or Applied Research on a Consulting Basis

The mix of research, even fundamental or "pure" research often involved in the consulting work done by faculty of state colleges for private industry, is well-illustrated by the ornithologist from the biology department at Cal Poly, Pomona, who is studying patterns of bird migration through mountain passes under a grant from a public utility company. Because little is known about the varieties and behavior of migrating birds through the southern Sierras where turbulent winds are prevalent, his findings will undoubtedly make a contribution to ornithological science. The utility company,which retained this faculty expert as a consultant, is considering the setting up of "wind farms" involving the construction of high efficiency wind-driven turbines in these same passes. For the company, knowledge of the daytime and nocturnal movement of migrating birds is an important piece of practical data which will be considered as a factor in their future plans for the wind farm.

The next chapter will provide a brief look at reports of R&D-based interaction between state colleges and private industry from other parts of the United States.

CHAPTER VI

OTHER STATES: A LIMITED SURVEY

Information about faculty research and consulting at state colleges outside California is sketchy, but not unavailable. A formal study of the subject is underway in New Jersey; Leonard Rubin, of Montclair State College, is studying natural, physical and social science faculty at the six campuses of the New Jersey state college system. Although the data are still being analyzed, Professor Rubin has provided some figures on faculty consulting from preliminary tabulations based on more than 200 personal interviews. Table 20 shows that 69.3% of the respondents reported providing consulting services.[1]

Table 20

Percent of New Jersey State College Science and Social Science Faculty Providing Consulting Services

Consulting	*Not Consulting*	*Total*
69.3% (138)	30.7% (61)	100% (199)

In addition, 12.4% of the respondents reported they were currently involved in consulting for industrial clients, while 24.4% reported working for industry at some time. While we have no figures yet on paid as opposed to voluntary work, it can probably be safely assumed that most industrial consulting involves fees.

The American Association of State Colleges and Universities (AASCU), made up of more than 340 "second-tier" institutions—similar to CSUC institutions—from every state and territory, recently surveyed its members. The survey was informal and voluntary; it requested members to provide data on examples of current involvement with business and industry. The results, although not suited to quantitative analysis, nevertheless were of interest for our purposes here. A report published in June, 1981,[2] claims that the data returned indicate ". . . an increasing number of 'partnerships' between higher education and business and industry" among Association member institutions. Further, the fact that

> . . . the relationships are spreading well beyond the boundaries of the traditional university research centers is a key factor in broadening the country's economic base.[3]

The report concluded that state colleges appear to be taking on new responsibilities as academic resource providers in "entrepreneurial pockets" around the United States. The accounts that follow are drawn from the AASCU survey report, augmented in some cases by follow-up contacts with campus officials.

A. Trenton State College, New Jersey

A Trenton State College biologist and a number of undergraduate and graduate students have been working on a project supported by the National Science Foundation designed to develop a local aquaculture industry, utilizing heated water discharged from power plant cooling towers. It began in the late 1970's, and brought Trenton State into a cooperative arrangement with Rutgers (the State University), the New Jersey State Department of Agriculture, Long Island Oyster Farms, Inc., and Seabrook Farms, Inc., all under the general leadership of a principal investigator from the Public Service Electric and Gas Company of Newark.

Project members are attempting to raise rainbow trout and freshwater shrimp in the heated water pumped from a power plant situated on the Delaware River. Special ponds and raceways have been built and stocked

[1]Data from a study of science and social science faculty at New Jersey state colleges still in progress. Conducted by Professor Leonard Rubin of the Department of Sociology at Montclair State College, Upper Montclair, New Jersey. Supported by the National Science Foundation.

[2]American Association of State Colleges and Universities, *Background* (June 1981), p. 1.

[3]Ibid.

with fingerlings and shrimp larvae supplied by private firms; additional stocks to be introduced are striped bass, American eel, and possibly others. An attempt is also being made to raise different kinds of stock during different seasons of the year, when the overall temperature varies. Trenton State is responsible for on-site field experiments, while Rutgers has charge of the laboratory work.

B. College of William and Mary, Virginia

The Virginia Institute of Marine Science at the state-supported College of William and Mary is cooperating with the campus law school on a research project investigating the legal status of title to underwater properties. Sub-aqueous lands and title to them are of interest to developers, governments and conservationists, not to mention the energy industry. According to a release from the college public affairs office, "Virginia is among the seacoast states that suffer from uncertainty of title to wetlands." The project is being funded by a $100,000 grant from Continental Financial Services, which is described as a "diversified financial company."

C. State University College at Buffalo, New York

The state college in Buffalo is the site of the Great Lakes Laboratory. The Laboratory is intended to serve business, industry and government in environmental projects. For instance after a study of local industrial waste-disposal problems, state college faculty associated with the Laboratory recommended a waste-blending process whereby Bethlehem Steel Corporation would convey its waste pickling liquors to the Buffalo sewer authority which, in turn, would use it to remove phosphorous from water during the sewage treatment process.

Other assignments taken by the Laboratory have involved research and development concerning a proposed coal transfer facility for the harbor, and a project in which scrap tires donated by Dunlop Tire Company were used for "landscape revetments" against erosion along the Great Lakes coastline in western New York State.

Also at Buffalo State, the Energy Advising System for Industry (EASI) unit, funded by a $36,000 grant from the state energy office, was expected to complete by the end of the year 80 energy audits of businesses with 500 or fewer employees in the college service area. The public affairs office reports that "more than 25 western New York firms that have acted on energy saving recommendations were spending an average of $20,000 less a year." One firm, a paper company, is said to have cut its fuel bills by $600 a month.

D. University of Toledo, Ohio

Toledo was founded as a private institution in 1872, but was later absorbed into the Ohio system of state colleges. This campus is involved in research on high-sulfur coal, which is plentiful in parts of Ohio. Thus, a faculty member in the chemistry department has received $40,000 from the Ohio Coal Research Laboratories Association to develop a system for removing the sulfur. In addition, the geology department recently received over $100,000 for coal research in the form of grants, contracts and equipment gifts from private industry and government.

The Eitel Institute for Silicate Research at Toledo is a regional center for basic and applied research on silicate and similar substances, and has a roster of more than two dozen scientists from the departments of biology, chemistry, geology and physics. Faculty from other institutions in the state are also affiliated with the Institute, and attempts are reportedly being made to widen the membership to include qualified scientists in industry. Generally, the Institute seeks to "carry on research activity for businesses and industries which do not maintain an internal research capacity." One example currently underway is a project to develop further "production use of industrial by-products now considered waste material." This project is supported by grants of more than $80,000, about half of it from N-Viro of Ohio, a subsidiary of a local concrete supply firm which developed, in consultation with EISR, an interest in using cement-kiln dust and coal fire fly-ash as substitutes for lime in the making of cement.

Other Toledo faculty working with local private industry include a mechanical engineering professor with $14,000 from Champion Spark Plug Company for a study of "The 'Apparent Octane' Rating of Hydrogen Enhanced Combustion in a Low-Burn Engine"; an electrical engineer with $74,379 from Toledo Edison Company for a "Computer-Aided Analysis of Electrical Distribution Systems"; and a chemistry professor with $1,327 from Dow Corning Corporation to study "Vapor Pressures and Fluxes of Dow Corning Compound".

E. Southwestern Louisiana University

This campus, situated in an active industrial area near the Gulf of Mexico, reports a number of special arrangements for campus-industry cooperation involving local and out-of-state firms. The Center for Greenhouse Research, covering both vegetables and ornamental plants, has been set up with state government funds following appeals to the state by the Louisiana Greenhouse Owners Association. Another smaller project in the Department of Horticulture is sponsored by the nearby McIlhenny Company which processes a well-known hot tabasco sauce sold throughout the world. This project involves development of a high-yield, easily harvested tabasco pepper. Southwestern's agriculture faculty also regularly perform tests on pesticides for Mobile Chemicals and Union Carbide, both of which have plants in the nearby oil-producing and refining areas.

One of the larger projects at Southwestern is a $192,000 sub-contract from Dow Chemical Company for physical and chemical analysis of brine brought up from a new geo-pressured geothermal well being drilled near New Iberia, Louisiana. The analysis will be done on campus laboratory equipment. This project is part of a more complex undertaking originally funded by the U.S. Department of Energy.

Finally, in a manner similar to—but considerably larger in scope and scale than similar projects on several California campuses described in Chapter V—Southwestern computer scientists are attempting to improve the operational capability of a well-known minicomputer. Texas Instruments, Inc., has granted the Southwestern Computer Science Department a total of about half-a-million dollars in funds and equipment, the latter consisting of three TI 990/10 model minicomputers with peripherals. Faculty and students are running this state-of-the-art equipment to devise a new operating system and related software for the three minicomputers which would ". . . (regulate) the resources of the computers as they work in tandem to optimize their performance."

It is apparent that the institutions discussed here—the second-tier public state colleges that belong to the American Association of State Colleges and Universities—form a kind of continuum in terms of their relationships with industry. Clearly, some appear to have developed well-established programs with a wide range of scientific expertise available to clients in the private sector; others responding to the survey but not described here appear to be in the early stages of cultivating such relationships, and are beginning with modest projects.

Overall, however, nationwide data on these kinds of institutions and their collaboration with industry is fragmentary. Neither the scope nor the depth of such activity is readily visible for science policy planners interested in including it in estimates of the nation's scientific resources. Obviously, this is a situation that could benefit from investigation beyond the limited scope of this report.

CONCLUDING COMMENTS

This report on interaction between science and engineering faculty at state colleges and science-oriented industry in California and elsewhere in the country tells us some things and alerts us to others that would benefit from further research. Our findings suggest a considerable amount of research and development and consulting activity carried on by faculty at California and other American state colleges. These we have described collectively as constituting a "second-tier" of public higher education. Many of these institutions were formerly teachers' colleges; most now belong to the American Association of State Colleges and Universities (AASCU), and are generally established and maintained by state governments to teach the masses of non-elite students seeking a full four-year college education. All of them have filled out their faculties with Ph.D.'s from the surpluses in all fields which became available in the late '60's and early '70's.

Our findings suggest that a sizeable portion of the R&D and/or consulting by science and engineering faculty at state colleges is linked with the private industrial sector. Industrial R&D involved faculty in all science disciplines studied in our California survey—the greater share of it reported in engineering, with its emphasis on problem solving and design work. However, the increasing importance of natural and physical science inputs into high technology is likely to strengthen the links between industry and science faculty as well.

While the data on interaction of science and engineering faculty with industry at state colleges outside California is fragmentary here, nevertheless it suggests that the California activity is not peculiar or unique when compared with similar campuses throughout the country.

A. The Mechanical Heart Valve R&D Process Seen as a Developmental Model

When examined in its various aspects and stages, the case of the mechanical heart valve at California State, Sacramento, cited above in Chapter V, can be viewed as a model of how initially modest and sporadic attempts to do consulting and joint R&D work can set off a chain of developments with benefits for faculty, students, campus, private industry, and ultimately—it might be said in this case—for the public at large. In other words, it was an unpredictable and serendipitous twenty-year off-campus cooperation between engineering and biological science faculty from the state college, medical practitioners working part-time in a local private, non-profit medical facility and, ultimately, a large medical products firm serving a world market. More recently, the initial activity has been followed by the emergence of small, innovative firms spun-off from the state college. Altogether, it offers an illustration and a method by which R&D talent in fringe areas of higher education in America is—and might be additionally—conserved & utilized.

The pattern or model presented by this R&D and its ultimate products, programs and spin-offs, may be seen as having gone through a number of sequential steps during its two decades of development:

Stage I: Faculty involvement in off-campus R&D on the heart valve takes place on a private consulting basis. This followed naturally from the fact that, for the first half-dozen or so years after the California State Colleges System was set up in 1961, there were no formal facilities for dealing with *research* grants. "Educational and training grants" had been received, but not research funds.

Stage II: Faculty feedback from off-campus work enriches the campus educational program which is manifested in establishment of a master's program in biomedical engineering.

Stage III: Placement of biomedical engineering graduates of new program in medical facilities and in firms established in medical technology. Formation of innovative spin-off firms involving both graduates and faculty of new program.

Stage IV: The continuing interaction between spin-off firms, established medical technology firms, and the state college program by means of continuous interchange of students and part- and full-time faculty, resulting in enrichment of both academic program and private industrial sector.

Thus, a "successful" sequence or model process of this kind—if it could be duplicated in similar settings—would involve off-campus consulting and R&D, and both informal and formal enrichment of the campus program, while spawning technological innovation for industry.

B. R&D as an Unintended Consequence of the State College Function

Overall, the research done so far at various state colleges in the California State University and Colleges system suggests a tendency for science and, particularly, engineering faculty with doctoral level expertise to seek out—or be sought out by—people in business, the professions and industries that happen to need their particular services. This seems to happen largely because of the simple presence, the accessibility and availability of clusters of experts at state college campuses, of which there are about 350 widely dispersed throughout the country. While the nature of some academic specialties may encourage certain faculty to offer private consulting services or organize small business ventures regardless of their location (e.g., software creation), for the most part we can surmise that faculty activity in industry is closely related to opportunities at hand. In other words, at any given campus the amount and kinds of private consulting is likely to depend on the amount and kinds of industrial activity in the local service area of the college.[1] (Certainly more in-depth investigation is needed for a better estimate of what, where and how much R&D work is done as part of private consulting practice. The questions to be asked would focus upon—among other things—quantitative and qualitative differences between campus based R&D and faculty private practice. Needless to say, there are difficulties in studying such activity, not the least of which might be faculty reluctance to discuss extra earnings.)

On the other hand, as the value of non-teaching professional work for these kinds of campuses becomes more clearly recognized, more grants and contracts from industry may come to be formally processed through campus research offices. Under such arrangements, overhead charges would revert to the campus, while faculty could be compensated by a reduction in teaching load—which, commonly set at 12 hours with little or no laboratory or teaching assistance, is considered heavy in academic circles. Paradoxically, administrators may be more sanguine about such arrangements than faculty. One professor at San Diego complained that overhead charges of his campus foundation were so high as to discourage local industry from even approaching the campus in an official way (a contention denied by state college foundation officials and also by others in a position to make comparisons). Obviously as long as this kind of work remains a source of *extra* income, some faculty will continue to provide consulting services to private industry "on-the side."[2]

But there is more to it than just that. As we have seen above, involvement in consulting or R&D can clearly have stimulating effects for faculty and campus as well, in terms of continuing professional development, updating of knowledge and experience, and enrichment of science and engineering programs for students.

[1]British polytechnics, which comprise the second-tier of higher education in the United Kingdom after the universities, not only provide an interesting analogy to state colleges but also demonstrate well-developed modes of relationship with the private (and public) industrial sector. In a separate report submitted to the chancellor of the California State University, we have described the "consultancy companies" utilized by a number of British polytechnics to facilitate linkages with business and government (including foreign business and governments). The report includes discussion of one of the more unusual forms of integration with extramural agencies, the "technopark" of London's South Bank Polytechnic, which is situated in a single building in a crowded urban factory and warehouse district, and operates on the model of a medical "teaching hospital" administering to the needs of nearby industry and commerce.

[2]An interesting comparative view of some of the problems associated with "consultancy" in British polytechnics, is provided in *Consultancy Practise in Polytechnics: A Commentary* (London: Committee of Directors of Polytechnics, 1980). British polytechnics grew out of mergers between technical colleges and teachers' training institutions rather than out of teacher training facilities alone, as was usually the case in America. Consequently, polytechnics absorbed from their technical college roots a long tradition of faculty association with business and industry. For this reason, perhaps the British second-tier institutions seem more integrated into business, industry and governmental spheres of activity than do American state colleges, which have usually been linked solely to state educational establishments.

UNIVERSITY-INDUSTRY CONNECTIONS AND CHEMICAL RESEARCH: AN HISTORICAL PERSPECTIVE

by

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Preface

Over the years an American system of university-industry connections has grown up that is without parallel in the developed world for its strength, diversity and vitality. The system is the result of no conscious plan. Its variegated structure flows from the slow patterning of a myriad of individual, institutional and corporate responses to perceived needs, opportunities and problems. The system is thus an historical phenomenon of considerable complexity. It has deep roots in our national culture—in America's pluralism, in the service ethic of higher education, and in the pervasiveness of business values in the nation's life.

The American system of university-industry connections bears powerfully on the conduct of scientific research. Efforts to modify that system in order to improve the translation of basic research into industrial innovation are now the subject of much proper concern. These efforts will proceed better if they are informed by a knowledge of the variety of the historical forces and the human achievements that underlie the present system. With that thought in mind this essay addresses one central case—that of the connections of academic chemistry and chemical engineering with the chemical industry.

The method used is that of historical analysis. The *prolegomena* sets the stage in its first section, by pointing to the dual nature of chemistry and by sketching certain salient aspects of the American chemical discipline a century ago. In a second section, the point is made that growth has been the dominating motif in every aspect of chemistry over the past one hundred years. Certain indicators of absolute growth are presented, and the phenomenon of a relative decline concealed within it is alluded to. The prolegomena ends with a discussion of some micro-indicators which reflect the texture of university-industry connections, and which thus provide a bridge to the main body of the paper. That main body provides a narrative history of the chosen subject, in five sections covering the period from 1890 to 1980. No conclusion is offered, for the purpose of this paper is not to provide any explicit moral. Instead, the aim is to display the depth, variety, and tenacity of those forces which have been—and are—shaping the American system of university-industry connections.

For their assistance in the preparation of this essay I would like to thank Lisa Robinson, James E. Capshew and Simon Baatz. Robert F. Bud, P. Thomas Carroll, and Jeffrey L. Sturchio contributed equally with me to the work from which the data used in this essay was drawn. That data will be published by D. Reidel (Dordrecht, Holland and Boston, Mass) as Robert F. Bud et. al, *Chemistry in America, 1876-1976.*

CONTENTS

PROLEGOMENA

A. The Historical Roots of Twentieth Century Chemistry

1. *The dual nature of chemical science*

Chemistry has always been pursued for its practical utility as well as for its intellectual fascination.

From at least the late-eighteenth century, spokesmen and practitioners have understood that chemical knowledge offers a key to agricultural improvement and industrial advance. Since the second half of the nineteenth century, the promise has been steadily fulfilled. Synthetic dyestuffs, artifical fertilizers, food additives, and wholly "man-made" industrial and household products have been familiar results of chemical science for over half a century.[1] The employment of, and provisions for the education of, chemists and chemical engineers have grown correspondingly and are a marked feature of the modern era, especially in the United States.

Another aspect of chemistry's utility lies in its links to medicine. Since the Renaissance at least, the healing power of chemical remedies has made theoretical knowledge of the science a necessary item in the training of the physician. When Joseph Priestley, the renowned discoverer of oxygen, emigrated from Britain to the United States in 1794, he was quickly offered a professorship of chemistry in the nation's first medical school.[2] Many of today's great centers of chemical research have sprung from the root of chemistry in iatrochemistry and pharmacy, as have the recent triumphs of biochemistry and molecular biology, and the present hope for spectacular developments in bioengineering and related fields.

Chemistry has also long been an important element in natural philosophy—the alchemist sought gold not only for its material wealth and its medical importance as an incorruptible or sign of immortality—he also sought to make gold because the ability to do so would symbolize his intellectual and spiritual unity with nature.[3]

The chemical discipline has thus been one of variety and complexity from its earliest beginnings. The discipline encompasses:

- —craft or utilitarian knowledge, as in the agricultural and industrial arts.
- —vocational or professional training, as in the medical field.
- —abstract or conceptual understanding, as in basic research.

Education, employment, knowledge advancement and academic style all reflect this variety and complexity in chemistry. The mixture of the intellectual with the utilitarian has made chemistry a subject well-suited to flourish in the United States, especially in the twentieth century as American universities and industries have taken on a particular national style.

[1] Maurice Crosland, "The Development of Chemistry in the Eighteenth Century," *Studies on Voltaire and the Eighteenth Century*, 1963, 24, 369-441; Archibald & Nan L. Clow, *The Chemical Revolution: A Contribution to Social Technology* (Batchworth, London, 1952); Alexander Findlay, *A Hundred Years of Chemistry*, 3rd ed. (G. Duckworth, London, 1965); Williams Haynes, *This Chemical Age: The Miracle of Man-Made Materials*, 2nd ed. (A. A. Knopf, New York, 1942).

[2] Edgar F. Smith, *Priestley in America: 1794-1804* (P. Blakiston's Son & Co., Philadelphia, 1920); Allen G. Debus *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries*, 2 vols. (Science History Publications, New York, 1977).

[3] F. Sherwood Taylor, *The Alchemists, Founders of Modern Chemistry* (H. Schuman, New York, 1949).

2. *Three early American adepts*

The emergence in America of major industries, of research universities, and of close linkages between the two, is a development of the past one hundred years. However intimations of what lay ahead may be seen in the way that American chemists of the later nineteenth century filled many roles at the same time. A glimpse of the careers of three Presidents of the American Chemical Society gives a sense of prevailing realities a century ago.

James Curtis Booth (ACS Pres. 1883-85) might be characterized as the first professional consulting chemist in the United States. The firm he founded in Philadelphia survives to this day. In addition to analyzing ores, minerals, fertilizers, sugar and other materials, Booth took out manufacturing patents. He ran his own school of practical chemistry, in which around 50 young men eventually served apprenticeships, and he held professorships successively in the Franklin Institute, the Central High School, and the University of Pennsylvania. At one time he directed the Geological Survey of Delaware. He was "melter and refiner" of the U.S. Mint for almost forty years, and he edited a standard *Encyclopedia of Chemistry* of his day.[4]

Samuel W. Johnson (ACS Pres. 1878) was appointed to the faculty of the Sheffield Scientific School of Yale University in 1855, despite his lack of earned academic degrees. Johnson remained at Yale for over forty years, adding to his professorship the roles of chemist to the Connecticut State Agricultural Society and director of the pioneering Connecticut Agricultural Experiment Station. He was a leading chemical consultant in legal cases, and he wrote a best-seller on *How Crops Grow* that was translated into German, Italian, Japanese, Russian and Swedish.[5]

Most protean of all was Charles F. Chandler (ACS Pres. 1881, 1889) who played major roles as industrial chemist, educator, editor, organizer and public servant. Chandler was simultaneously Dean of the School of Mines and Head of the Chemistry Department at Columbia, professor in New York's College of Physicians and Surgeons and President of the College of Pharmacy. His great influence as a teacher was reinforced by his major roles in several learned societies. He was President of the New York City Board of Health for a decade from 1873. At the same time he was editor and publisher of the *American Chemist* and one of the leading industrial chemists of his day. He provided expert testimony in numerous patent litigations. His technical range included sugar, petroleum, illuminating gas, electrochemistry and the commercial analysis of waters and minerals. In the early days of the petroleum industry he was the foremost consultant in America. The Society of Chemical Industry awarded him its Perkin Medal in 1920, in recognition of his contributions to applied chemistry.[6]

The careers of these three men display how academic, agricultural, industrial, and medical themes were intertwined in American chemistry in its infant days. Booth, Chandler and Johnson all received their advanced training in German universities. However none was able to replicate his foreign concentration on research when he returned to America. Instead their careers show how under the conditions of a sparsely-settled continent with new needs and novel opportunities, European academic knowledge was transmuted into the mixed styles of American chemistry.

3. *Ph.Ds and the research ethos*

The Ph.D degree first became recognized as a certificate of competence in chemical research in Germany in the second quarter of the nineteenth century. The major credit lies with Justus von Liebig, a leader in the development of quantitative organic analysis. Liebig was appointed extraordinary professor at Giessen in 1824. His main source of students and income derived initially from his additional post as licensor in pharmacy for the state of Hesse-Darmstadt. However Liebig quickly built up a reputation in organic analysis, and began to attract a following of students fired with 1½enthusiasm for chemical research. From the mid-1830s his German audience was increasingly supplemented by students from Britain, France, Russia and the United States (Samuel W. Johnson, for instance, studied under Liebig in 1854).[7]

Liebig's success is of great interest, for it illustrates not only the links between chemistry and a medical vocation (pharmacy), but also between research reputation and international influence. His success in attracting and training students was also a key to the industrial employment of Ph.Ds. That employment was itself initially a "supply-side" phenomenon, and as such, indicative of the ways in which university life is unpredictable and possessed of its own dynamics.

Already by the early 1840s, doctors of philosophy were emerging from Liebig's laboratory faster than the German academic world could absorb them. One favored pupil—A. W. von Hofmann—moved to England in 1845 to become a professor in London's new (and precarious) Royal College of Chemistry, financed by agriculturists and manufacturers. A decade later one of Hofmann's young pupils—W. H. Perkin—discovered

[4] Biographical information on Booth (1810-1888) may be found in the *Dictionary of American Biography* (cited hereafter as *DAB*), 1929, *2*, 447-448.

[5] Johnson (1830-1909): *DAB*, 1933, *10*, 120-121. For an extended account of Johnson's work see Margaret W. Rossiter, *The Emergence of Agricultural Science: Justus Liebig and the Americans, 1840-1880* (Yale University Press, New Haven, 1975), chapters 8-9.

[6] *Chandler (1836-1925): DAB*, 1929, *3*, 611-613.

[7] See J. B. Morrell, "The Chemist Breeders: The Research Schools of Liebig and Thomas Thomson," *Ambix*, 1972, *19* 1-47.

the first of the aniline dyestuffs and the synthetic dyestuffs industry was born.[8] Much of the (cotton and woolen) market for dyestuffs was in England. It was there that the first developments took place. However the center of gravity of the synthetic dyestuffs industry soon moved back to the German states.

Thanks to Liebig—and those professors in other German universities who competitively emulated him—the supply of Ph.D chemists far exceeded academic, or any other, demand. Researchers in organic chemistry had a powerful motive to find new employment for their trained talents. Some German dyestuffs manufacturers began to employ the occasional chemist, usually without deriving any enduring benefits from the association. Four things served to change this state of affairs and to produce what proved to be a fundamental social invention, the industrial research laboratory. First, theoretical knowledge of organic compounds progresssed rapidly in the 1860s and 70s; second, the changes in patent law and market structure consequent upon the unification of the German states in 1871 placed a premium upon continuous innovations in such a fashion-conscious field as dyestuffs, as markets became large and publics remained fickle; third, the growing size of dyestuffs companies allowed a greater division of labor; and fourth, prolonged trial-and-error attempts to find successful ways to harness the supply of Ph.Ds and their esoteric knowledge to industrial goals finally began to yield success. By the 1890s German chemical companies were committed to the idea of industrial research, undertaken by trained chemists employed in new purpose-built laboratories.[9]

While German Ph.Ds in organic chemistry found tentative, then secure, employment in industrial laboratories in Germany in the 1880s and 90s, things were far different for American Ph.Ds returning to the United States. Those Americans who journeyed to Giessen and other German centers faced a lonely, uphill battle as they sought to establish German-style research in American academic institutions. The idea of science as *Wissenschaft*, as pure moral truth unfolding through never-ceasing research, was not easily grafted onto the traditions of the American college. Instead the first German-trained American Ph.Ds in chemistry found their most natural opportunity in those service-oriented areas that related to private and entrepreneurial enterprise (as Chandler did) or to agricultural chemistry and to experiment stations (as did Johnson). Only slowly, in the 1880s, did the idea of research as a natural, indeed central, academic activity begin to penetrate the country's older institutions of higher education. The example of Johns Hopkins (f. 1876), where chemistry was by far the largest scientific discipline from the very earliest days, was one strong encouragement. By the 1890s, the stage was set for a science that would respond to—and, on occasion, create—American opportunities, with forms appropriate to America in the industrial era.

B. The Overall Pattern of Growth

In order to appreciate the rhythms and the particularities of the way connections between universities and industry have developed, it will be helpful if we first sketch some of the long-run trends in chemical industry and in academic chemistry in the United States. Those trends have mainly to do with growth—that extraordinary growth which has characterized American science, American industry and American life in the past one hundred years. It is in terms of this enduring trend of growth that we may best understand how elements in the academic-industrial system have first been invented to cope with new conditions, then rapidly copied and diffused as the system grew. At the same time, absolute growth has concealed inside itself a second set of trends, those of relative decline. Chemistry is not as important within academe as it once was, nor are the traditional chemical industries able to set the pace as they once did. Strategies for linking academic with industrial concerns have necessarily altered, and fortune has favored those able to sense and to articulate the changing opportunities.

The over-arching context has been set by the long run trends in chemistry as occupation and profession; in the supply of credentialled chemists; in academic employment; in jobs in chemical industry; and in the growth of special niches in industrial research. A natural point of entry is with chemistry considered both as an occupation and a profession.[10]

1. *Chemistry as occupation and profession*

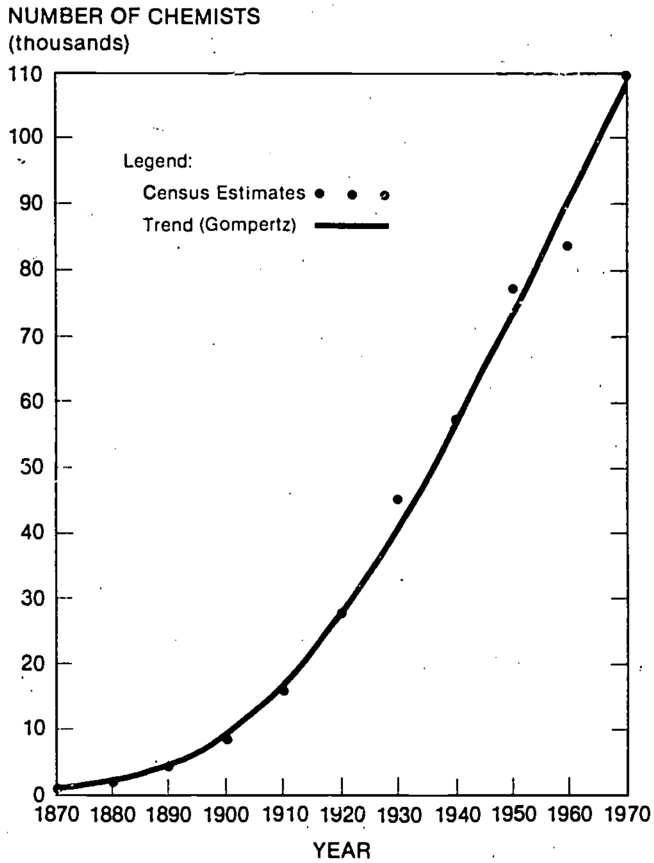
The available data reveal the dramatic growth in chemistry as an occupation over the last century. Figure 1 indicates that chemists in the labor force have increased more than a hundredfold over the period, starting at under 1,000 in 1870 and exceeding 100,000 by 1970. The graph gives a strong visual sense of the explosion of the chemical enterprise in one century's

[8]See Gerrylynn Kuszen Roberts, *The Royal College of Chemistry (1845-1853): A Social History of Chemistry in Early Victorian England* (Unpublished Ph.D dissertation, Johns Hopkins University, 1973); and *Perkin Centenary—London: 100 Years of Synthetic Dyestuffs* (Pergamon Press, London, 1958).

[9]John J. Beer, *The Emergence of the German Dye Industry* (University of Illinois Press, Urbana, 1959); George Meyer-Thurow, "Industrialization of Invention: A Case Study from German Chemical Industry," *Isis*, 1982, 73, 363-381.

[10]The analysis in the following section relies heavily upon the statistics and discussion presented in Robert F. Bud, P. Thomas Carroll, Jeffrey L. Sturchio, & Arnold Thackray, *Chemistry in America, 1876-1976: An Historical Application of Science Indicators* (Report to the National Science Foundation, Department of History and Sociology of Science, University of Pennsylvania, Philadelphia, 1978. Publication in book form by D. Reidel, Dordrecht, Holland is scheduled for 1984).

FIGURE 1. Gompertz Trend in the Number of Chemists, 1870-1970.



SOURCE: Bud *et al.*, *Chemistry in America*

time. A shift of this magnitude cannot but transform the very nature of the undertaking, influencing such things as patterns of organization and communication within chemistry.

The same conclusion follows from a *comparative* look at chemistry in relation to the rest of the U.S. labor force. Figure 2 shows the time series of chemists per 10,000 workers. The enduring trend is one in which chemists represent an increasing fraction of the labor force. But the rate of that increase is slowing, and past performance suggests a saturation around 15 chemists per 10,000 workers.

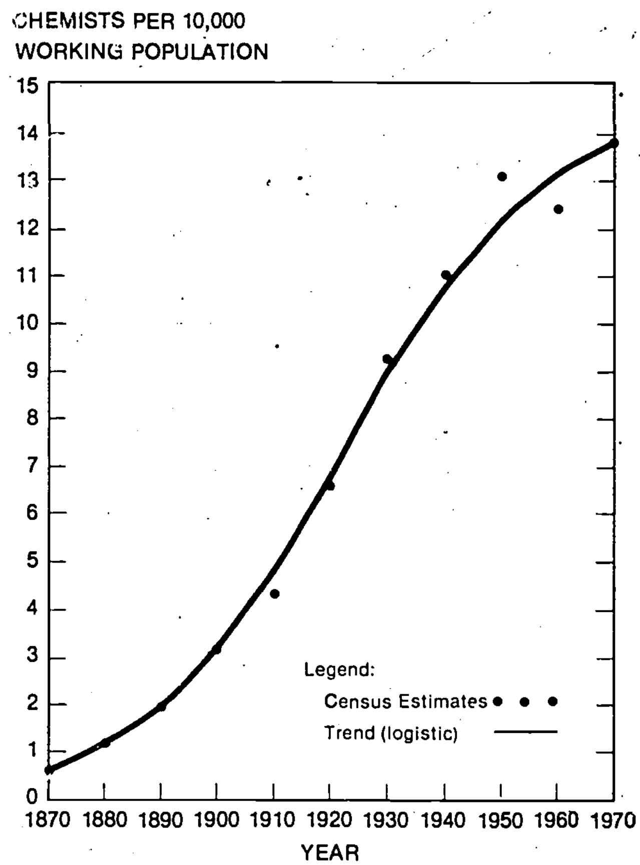
One final aspect of chemistry as occupation and profession deserves mention. It is instructive to consider the growth of chemistry as an occupational grouping in the wider context of what the Census calls "professional, technical, and kindred workers." This category includes accountants, engineers, and a considerable range of occupations comparable in skills to chemists. Figure 3 shows the number of chemists per 1,000 "professional, technical, and kindred workers." The steadily increasing importance of the chemist for the 80 years before 1950 is as dramatic as the subsequent quarter-century decline.

2. *The supply of credentialled chemists*

The United States is an increasingly academic nation. It is important to remember this when discussing the place of the sciences in American society. Chemistry has partaken of this education boom. For most of the past hundred years chemistry has been a steadily-growing academic activity (see Figures 4 and 5). At the same time chemistry has also suffered a sustained *relative decline* within academe and, more recently, an absolute decline in terms of degrees granted.

In 1890 some 600 baccalaureate degrees were conferred in chemistry; by 1910 the number was 2,100; by 1930 it was 4,400 and by 1950, 12,300. Since that time the number of degrees conferred has remained steady, or even declined a little. The pattern of rapid, absolute growth thus lasted for almost three quarters of a century (1880-1950). Growth on the doctorate level has been even more rapid, and more enduring. Thirty doctorates in chemistry were conferred in 1890; 80 in 1910; 330 in 1930; 970 in 1950; and 2,200 in 1970, since when the number of Ph.Ds has also declined somewhat.

FIGURE 2. Chemists per Ten Thousand Working Population, 1870-1970.

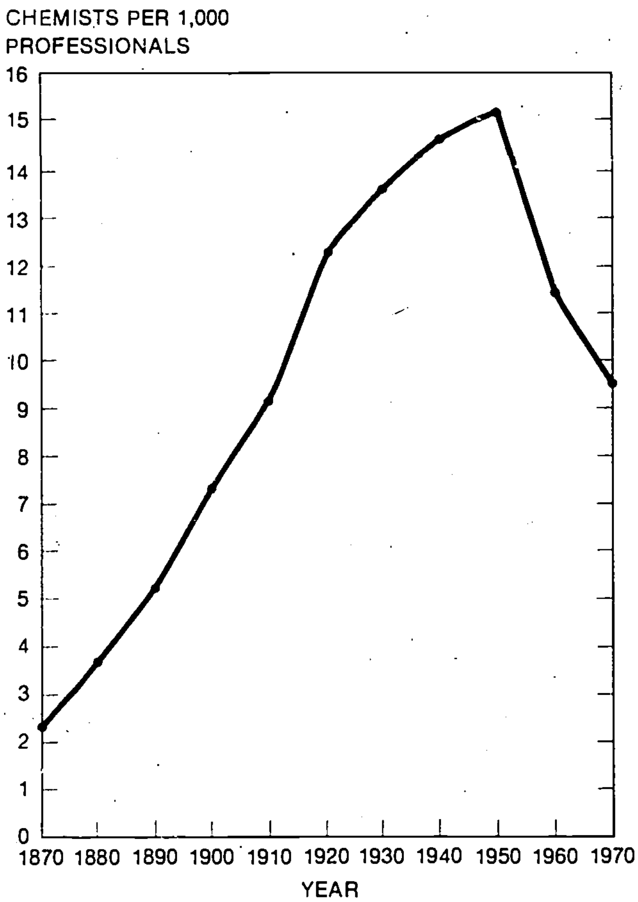


SOURCE: Bud *et al.*, *Chemistry in America*

While exponential increases characterize the American academic system, there are dangers in being transfixed by the dramatic phenomenon of absolute growth. In the case of chemistry, absolute growth overlays a second phenomenon—that of relative decline. In terms of its significance as a baccalaureate subject, chemistry has been subject to an *enduring trend of relative decline* for over half a century. In that time undergraduate chemistry degrees decreased in relative standing *by an order of magnitude*—from one in ten baccalaureates conferred to one in a hundred. A similar more modern trend is apparent on the doctoral level. As recently as 1940, chemistry departments conferred almost one fifth of all earned doctorates. By the early 1970s the proportion had declined to about one-fifteenth (see Figure 6).

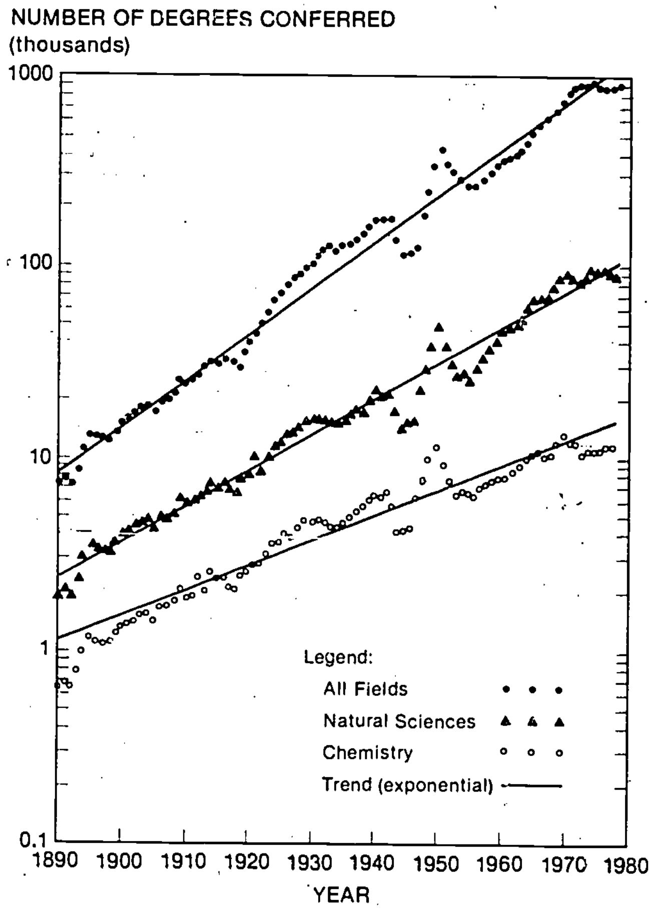
These relative declines were not caused by the rise of new chemistry-related disciplines. Adding the comparatively miniscule figures for biochemistry exacerbates the relative decline of chemistry on the doctoral level, and has no noticeable impact upon the trend

FIGURE 3. Chemists per Thousand Professional, Technical, and Kindred Workers, 1870-1970.



SOURCE: Bud *et al., Chemistry in America*

FIGURE 4. Trends in Bachelors Degrees Conferred in Selected Fields, 1890-1978.



SOURCE: Bud *et al., Chemistry in America*

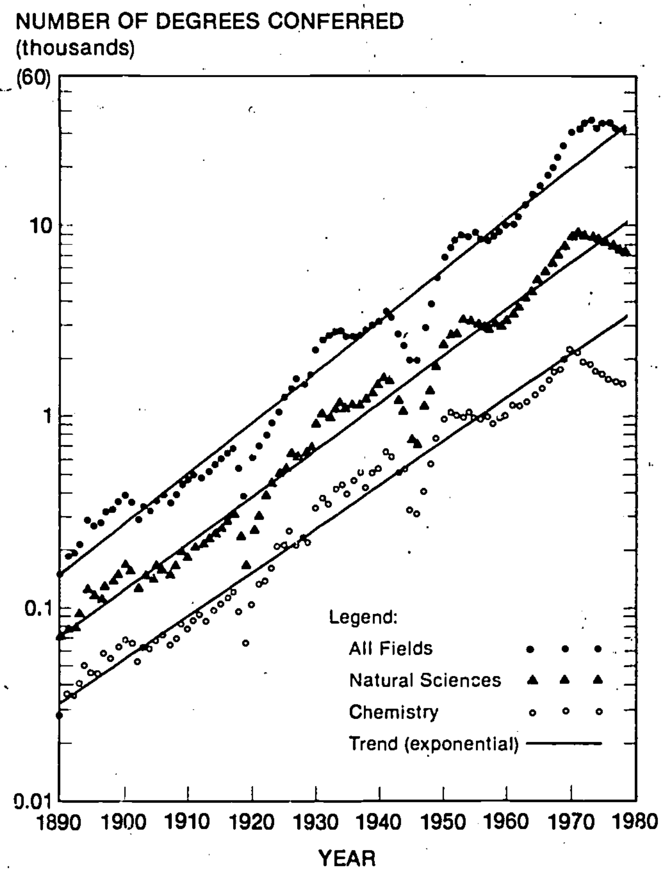
in bachelors degrees. Including chemical-materials engineering degrees (i.e., degrees in chemical engineering, metallurgical engineering, materials engineering, and ceramic engineering) alters the fraction of degrees attributable to chemistry, but it does not change the trend. The relative decline in degrees conferred is real, whether chemistry is broadly or narrowly defined.

This decline is not unique to chemistry, but characterizes the natural sciences as a whole. The enduring trend of relative decline of the natural sciences is as important to any adequate analysis as the more familiar concept of the absolute exponential growth of those sciences. Chemistry simply provides the most extreme example of a more widespread phenomenon. In this it pays the penalty of the pioneer that comes from its early dominant role among the academic sciences. On the one hand, *growth* has been the enduring context in which chemistry has functioned as academic discipline. That growth has had, and continues to have, important consequences with respect to scientists' expectations concerning available resources and proper procedures. In its early stages growth was sustained by direct, vocational linkage between higher education in chemistry and employment in the chemical profession. On the other hand, the same growth has concealed decline in the visibility of chemistry within higher education.

3. *Academic employment*

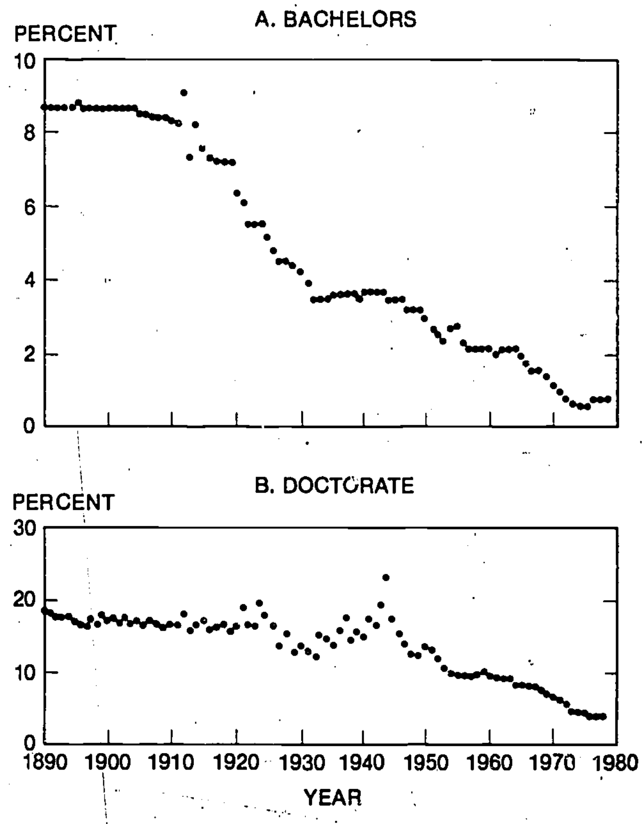
It is hard to obtain reliable historical information on the number of chemists in academic employment. Those concerned with counting *academics* have not seen fit to collect statistics upon academic *chemists*. For example, the Bureau of Census persisted until 1970 in lumping academic chemists in the heterogeneous group known as "college presidents, professors, and instructors." Only recently has it disaggregated this category by discipline for the 1970 returns and retroactively developed comparative data for the 1960 census.

FIGURE 5. Trends in Doctorate Degrees Conferred in Selected Fields, 1890-1978.



SOURCE: Bud *et al., Chemistry in America*

FIGURE 6. Chemistry as Percentage of All Degree Conferrals, by Level, 1890-1978.



SOURCE: Bud *et al., Chemistry in America*

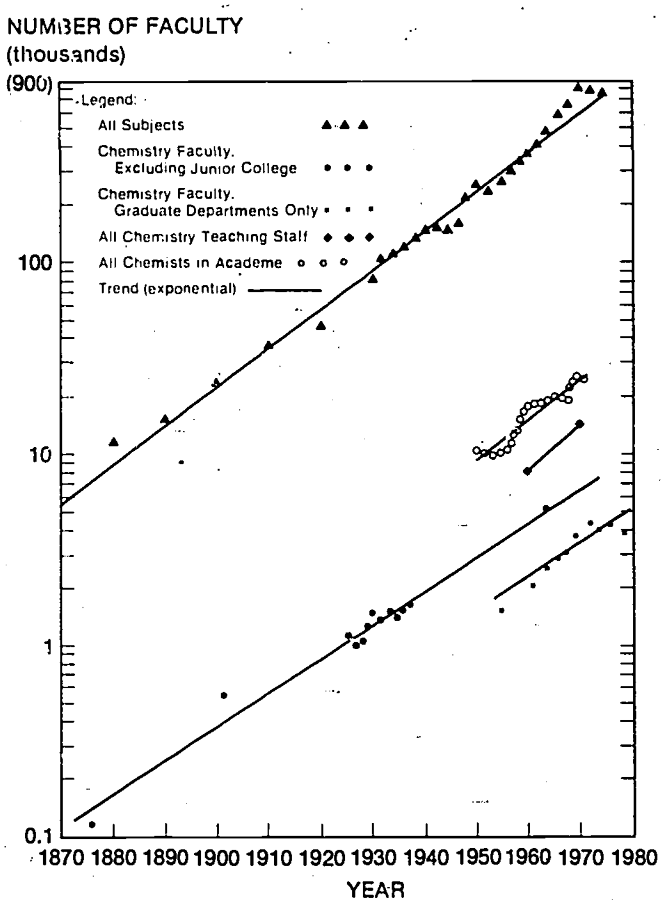
The disparities among the additional estimates highlight the softness of the data and the continuing ambiguities of terms like "faculty" and "college teacher." The disparities also provide an envelope for the employment of chemists in academe. From an estimated hundred or so in the 1870s, academic chemists have grown steadily until they now number in the neighborhood of 10,000 (see Figure 7). The century-long growth rate is 4.3 per cent per year. This rate of increase exceeds the 3.3 per cent per year rate of growth in the number of chemistry bachelors degrees conferred but it falls short of the 5.3 per cent annual rate of growth for chemistry doctorate conferrals. In all probability, there are today more chemistry faculty members per undergraduate student majoring in chemistry—and fewer per graduate student—than a hundred years ago.

The exponential increase in the absolute number of academic chemists is not so impressive as at first appears. Chemistry faculty have constituted between 1 and 2 percent of all teaching personnel at American colleges and universities during the past century. The data show a decline over the century but, given ambiguities in the estimates, it is not clear what to make of this trend. The employment of chemists in American higher education certainly does not show the precipitous relative decline that surfaced when degree conferrals were examined. Comparisons on the level of chemistry as profession also attest to the staying power of the academic side of chemical employment. The number of chemistry faculty in America, expressed as a fraction of the number of members of the American Chemical Society, has remained roughly constant (see Figure 8). Since World War I faculty have equalled between 5 and 10 per cent of ACS membership. Not all chemistry faculty have been ACS members, but the relationship between the size of the profession and the number of those charged with the training of new entrants to the profession has been stable.

4. *Chemists in industry*

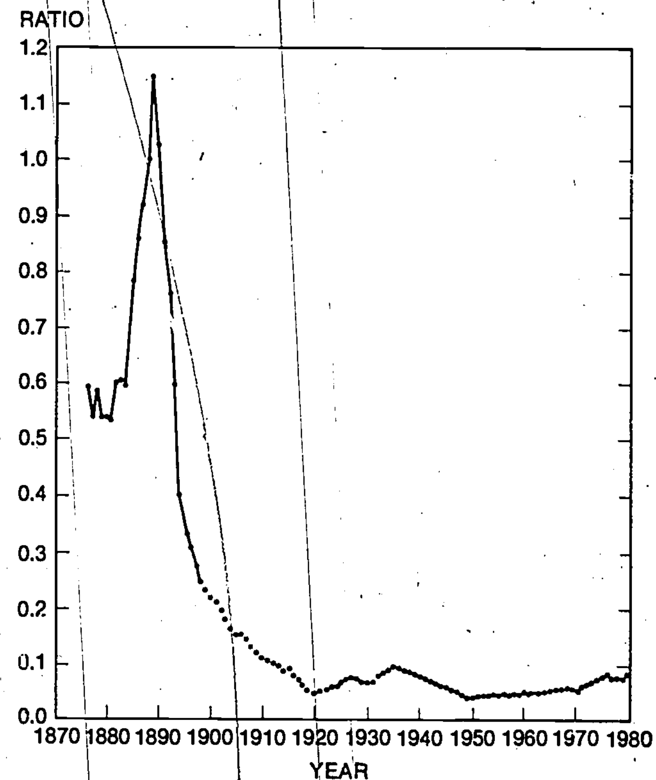
Throughout the twentieth century, the majority of American chemists and chemical engineers have worked

FIGURE 7. Faculty in Higher Education: All Subjects and Chemistry, 1870-1978.



SOURCE: Bud *et al.*, *Chemistry in America*

FIGURE 8. Ratio of Chemistry Faculty to ACS Membership, 1876-1979.

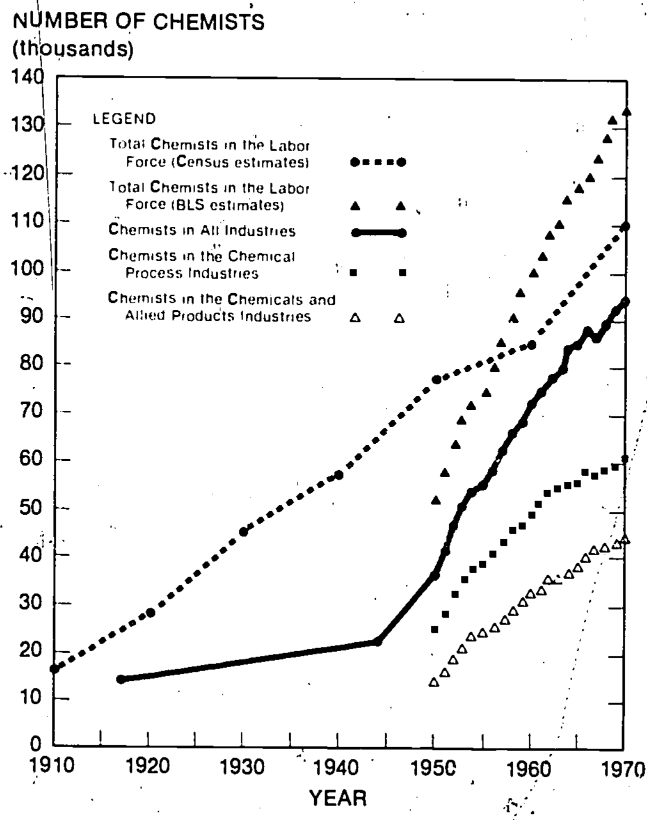


SOURCE: Bud *et al.*, *Chemistry in America*

in industry. However considerable difficulties attach to any attempt to construct indicators of that employment. It is not just "chemicals and allied products" industries or the chemical process industries that have hired chemists. Other manufacturing and even non-manufacturing industries have called upon their services. In 1950, for instance, two hundred chemists were employed by American railroads, one hundred by medical and dental laboratories, and two hundred in engineering and architectural services. There were even 96 members of the Association of Official Racing Chemists, who analyzed the urine and saliva of thoroughbreds to guard against the unauthorized use of drugs.

Considerable ambiguities thus attach to any attempt to specify the work in which chemists have been engaged. There are no clear points of demarcation between research, development, and routine analysis, nor between research and administration; nor is it possible to differentiate sharply between industrial chemistry and chemical engineering. These reservations should be borne in mind when looking at Figure 9, which displays the employment of chemists in American industry and shows an increase from roughly 12,700 persons in 1917 to over 93,000 in 1970. (Census and Bureau of Labor Statistics estimates of *all* chemists in the labor force—not just chemists in industry—are

FIGURE 9. Rough Estimates of the Number of Chemists in Industry, 1917-1970.



SOURCE: Bud *et al., Chemistry in America*

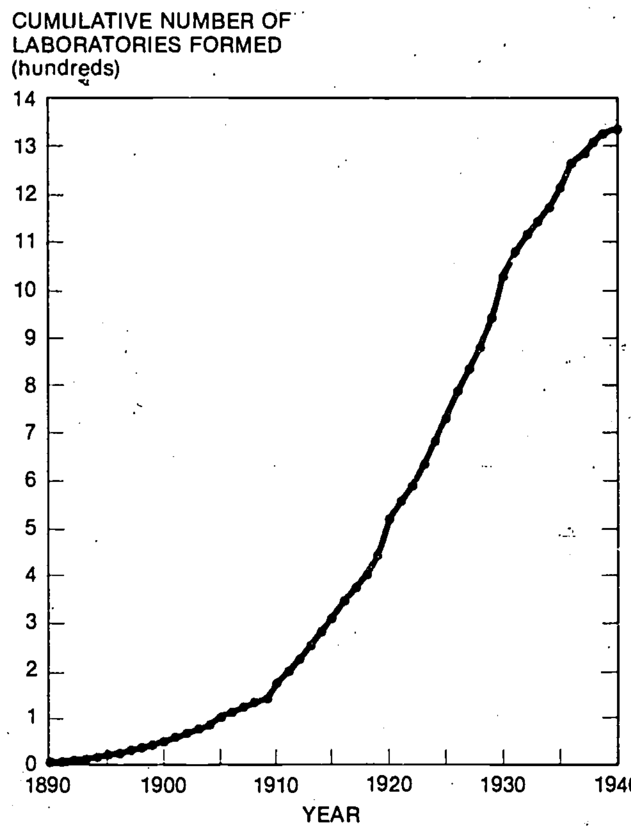
also provided for comparative purposes). The paucity of information prior to 1950 is apparent. So too is the long-term importance of industrial employment to the American chemical community. According to Bureau of Labor Statistics estimates, industry was the primary sector of employment for American chemists from at least 1950 to 1970, providing jobs for more than 70 per cent of the chemical community over that period. Evidence from earlier surveys suggests that this distribution of chemists has prevailed since World War I.

5. *Research laboratories and research workers*

The institutionalization of research in industry has been one of the most striking features of the social history of twentieth century American science and technology. The establishment of corporate research laboratories began around the turn of the century. Adopting a utilitarian rhetoric which resonated strongly with the Progressive era's faith in social progress through science, scientists appealed successfully to the captains of an expanding industrial community, who perceived continuous innovation as a new weapon in corporate strategy. Research would provide new products to compete with European imports, and produce patents to protect the ground thus gained. Research laboratories were first used in the electrical and chemical industries. The nascent industrial research movement gained impetus from the wartime experience of cooperative effort, and science became inextricably linked with industry during the boom years of Coolidge prosperity. The cumulative trend in the formation of laboratories from 1890 to 1940 is illustrated in Figure 10, which represents a 59 per cent sample of companies reporting laboratory activity to the National Research Council in 1940.

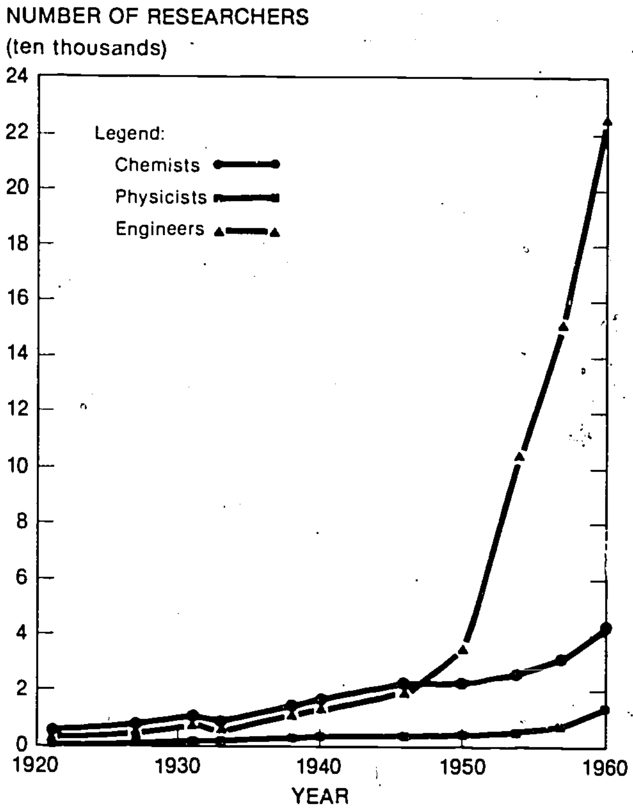
Industry-by-industry comparisons of the proportion of chemists among company research workers are not readily available. However aggregate data provide information on the disciplinary breakdown of scientists engaged in industrial research. Between 1921 and 1950, the increase in industrial researchers (9.6 per cent per annum) was more than four times that of all employees in U.S. manufacturing (2.3 per cent per annum). Figure 11 presents information on the employment of chemists in American industrial research

FIGURE 10. Cumulative Number of Industrial Research Laboratories Formed, 1890-1940.



SOURCE: Bud *et al., Chemistry in America*

FIGURE 11. Chemists, Physicists, and Engineers in Industrial Research, 1921-1960.



SOURCE: Bud *et al.*, *Chemistry in America*

from 1921 to 1960 (with physicists and engineers included for comparative purposes). During this period, the number of chemists in industrial research laboratories increased elevenfold, from about 3,800 to 43,000. Making no adjustment for the 11 per cent decline at the beginning of the Depression, this represents a doubling every 11 years. By comparison, the total number of chemists reported by the Census grew more slowly, from about 28,000 in 1920 to 77,000 in 1950. This is equivalent to a doubling every 21 years. The relatively rapid shift in the deployment of chemists transformed the contours of the chemical community, and industrial research gained in prominence.

6. *ACS Presidents: micro-indicators*

Large aggregates and long run trends can conceal the influence of particular individuals and institutions. At the same time individuals and institutions reflect, even while affecting aggregates and trends. Thus shifts in the educational background of American Chemical Society presidents over time display vividly the decline of German hegemony in the advanced training of American chemists. Before 1896, six out of ten ACS presidents spent time in German universities, while another three out of ten came to chemistry via medical training. By the turn of the century (1896-1905), ACS presidents were already as likely to have been trained in the United States as in Germany, and the proportion of American chemistry Ph.Ds among ACS presidents increased steadily thereafter (as shown in Figure 12).

Analysis of the institutional locations of ACS presidents during their tenure of office yields several interesting observations (Figure 13). First, academic chemists were the dominant group among ACS presidents, exerting an influence disproportionate to their size as a sector of the American chemical community. Second, although four of the first 25 individuals to become ACS president were employed by the federal or state governments when elected, no government chemist has been elected to the presidency of the American Chemical Society since 1906. Finally, chemists from the industrial sector were a major group among ACS presidents during the Society's first decade, but (except for a group of four industrially-connected presidents in the decade from 1926 to 1935) did not regain their position until after World War II.

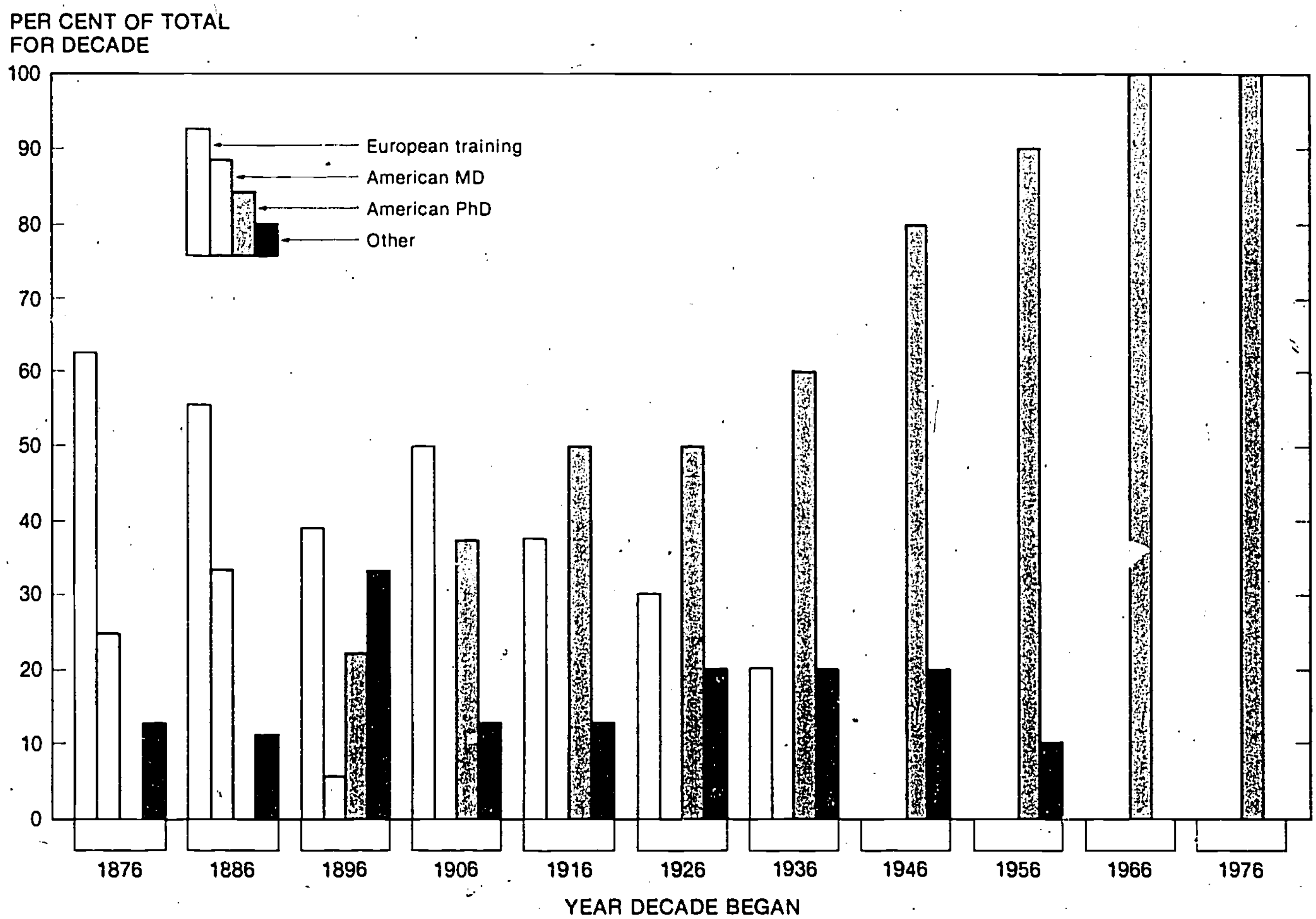
In the first few decades of the Society's existence, its presidents were employed in widely-varied pursuits. After the turn of the century, occupational backgrounds of ACS presidents became less diversified, a change related to the routinization of careers within the chemical community at large. Edgar Fahs Smith (President in 1895, 1921, 1922), Ira Remsen (1902), and Marston T. Bogert (1907, 1908)—Chandler's successor at Columbia—are three archetypal academic chemists of this period, just as Willis R. Whitney (1909) and William H. Nichols (1918, 1919) exemplify newly-available careers in industrial research and corporate chemical enterprise.[11] This shift was accompanied by a general decline in the importance of state or federal government positions as a route to the ACS elite, along with the long-term displacement of "chemist-entrepreneurs" and consulting chemists among ACS presidents, in favor of executives of chemical and other industrial corporations.

In a situation familiar to students of social stratification, high elites in science are maintained by selective processes of recruitment, socialization and allocation of resources.[12] Thus it is not surprising to find ACS presidents linked by social ties similar to those found among other groups in the aristocracy of Ameri-

[11] On the ACS and its presidents, see Herman Skolnik & Kenneth M. Reese, eds., *A Century of Chemistry: The Role of Chemists and the American Chemical Society* (American Chemical Society, Washington, D.C., 1976) and, for individuals, Wyndham Miles, ed., *American Chemists and Chemical Engineers* (American Chemical Society, Washington, D.C., 1976).

[12] See Harriet Zuckerman, *Scientific Elite: Nobel Laureates in the United States* (Free Press, New York, 1977), esp. chapter 8.

FIGURE 12. Educational Backgrounds of American Chemical Society Presidents, by Decade, 1876-1981.



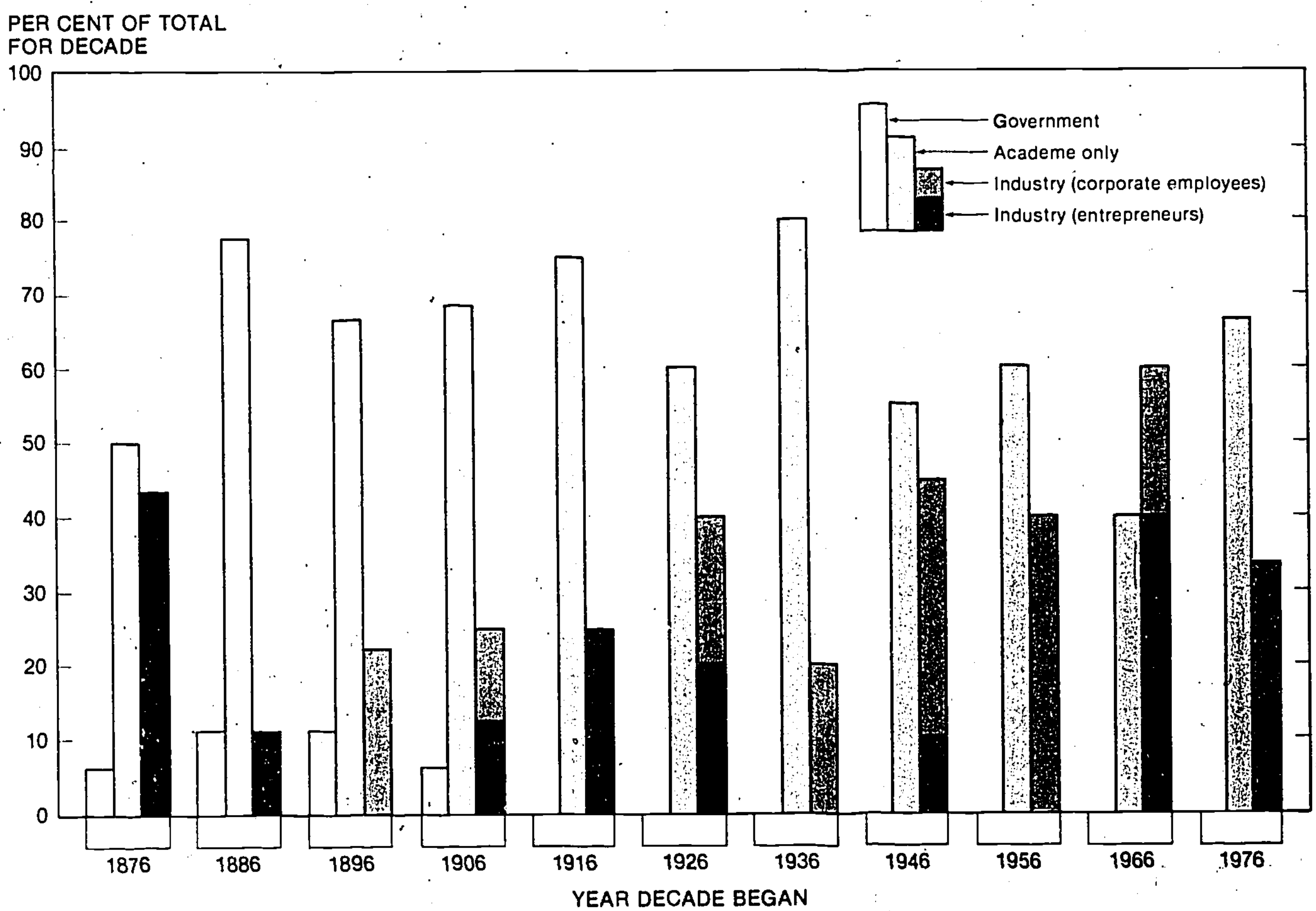
SOURCE: Bud *et al.*, *Chemistry in America*

can science, such as members of the National Academy of Sciences or Nobel laureates. The most striking case of such ties among a group of ACS presidents involves those chemists who obtained their training during the department chairmanships of T. W. Richards (1914) and Arthur B. Lamb (1933) at Harvard, and Roger Adams (1935) at Illinois (Figure 14). This "Harvard-Illinois axis" has accounted for approximately one in four ACS presidents elected since Theodore W. Richard's term of office in 1914. Illinois is even more important than the figure shows, since Karl A. Folkers (1962) obtained his baccalaureate there and Charles C. Price (1965) was on the faculty in the era of Adams' chairmanship.

As the example of Price suggests, many ACS presidents were colleagues of other members of the ACS high elite in particular chemistry departments or industrial laboratories. For instance, Penn's chemistry faculty in the late 1870s and '80s included F. A. Genth (1888), E. F. Smith (1895, 1921, 1922) and George Barker (1891), while Willis R. Whitney (1909), A. A. Noyes (1904) and James F. Norris (1925, 1926) were colleagues at MIT in the 1890s. After Whitney's move to the General Electric Research Laboratory in 1900, he recruited Irving Langmuir (1929) to the research staff. L. V. Redman (1932), Edward Weidlein (1937) and Leo Baekeland (1924) provide another example of colleagueship ties in industrial chemistry. Redman and Weidlein were two of the earliest recipients of industrial fellowships at the Mellon Institute for Industrial Research in 1913. Weidlein remained at the Institute, eventually assuming the directorship, but Redman left in 1914 to set up Redmanol Chemical Products. This entrepreneurial venture in marketing phenolic resins soon brought Redman into competition with Baekeland's General Bakelite Company, which manufactured similar plastics. After considerable litigation the two companies were merged into the Bakelite Corporation in 1922.

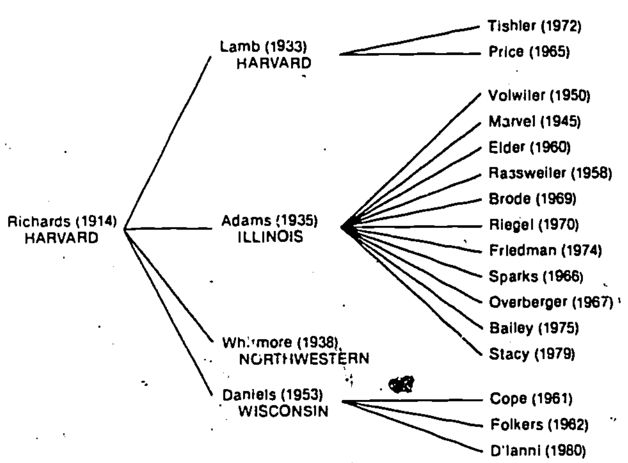
Micro-indicators of this kind hint at the subtle

FIGURE 13. Institutional Locations of American Chemical Society Presidents, 1876-1981.



SOURCE: Bud *et al.*, *Chemistry in America*

FIGURE 14. The "Harvard-Illinois Axis" among American Chemical Society Presidents.



SOURCE: Bud *et al.*, *Chemistry in America*

complexities of the American system of industry-university connections. These complexities are best displayed in terms of a narrative account of the development of that system.

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THE EVOLUTION OF THE AMERICAN SYSTEM

A. Division of Labor in a Growing Market, 1890-1920

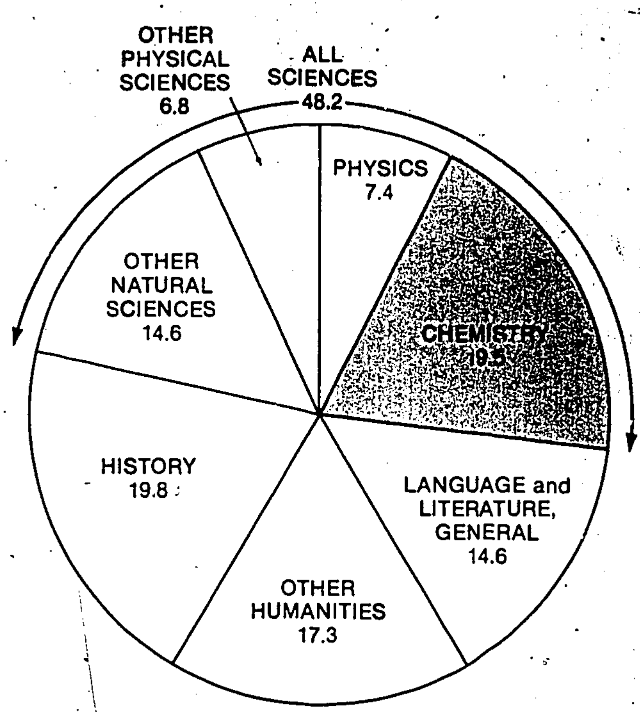
1. *The establishment of research universities*

The decades before World War I saw a surge in college enrollments. Demand for undergraduate courses in chemistry was particularly strong. On the one hand, the move to increase the standards of the leading medical schools meant a new emphasis on collegiate pre-medical courses. On the other hand, American industrial enterprise in basic and inorganic chemicals fostered a demand for college graduates with chemical knowledge and skills in chemical analysis. Bachelors degrees conferred in chemistry rose from 630 in 1890 to 2,570 in 1914.[1]

In chemistry as in other subjects, graduate training, faculty research and the entrenchment of departmental organization accompanied this growth. While total enrollment in all subjects at Harvard University doubled (from 2,270 to 4,120) between 1890 and 1910, enrollment in its graduate school increased more than threefold (130 to 440), while the number of non-professional teachers and research fellows grew almost fourfold (110 to 420).[2] Other major universities followed a similar pattern. University opportunities for, and supply of, research were thus powerfully influenced by demographic phenomena internal to academe. Chemists committed to research responded by building programs with an emphasis on basic science, in accord with their German heritage.

In the period up to 1900, chemistry was responsible for almost 20% of *all* doctorates awarded in the United States. The subject was correspondingly important in defining the style of the research university. John Hopkins, begun with a merchant's fortune in 1876, was the recognized pioneer of this new style of university, committed to academic excellence and the national and international reputation of its faculty. At Johns Hopkins, chemistry was the leading discipline in terms of Ph.Ds awarded, taking 19.5% of the total in the period to 1900 (see Figure 15). Ira Remsen (Ph.D Göttingen 1870; ACS Pres. 1902) took the opportunity his situation afforded; he personally trained 107 Ph.D

FIGURE 15. Subjects of Doctoral Dissertations at Johns Hopkins University before 1900.



NOTE: Diagram represents 514 PhDs. Numbers indicate percentages.
SOURCE: Bud *et al.*, *Chemistry in America*

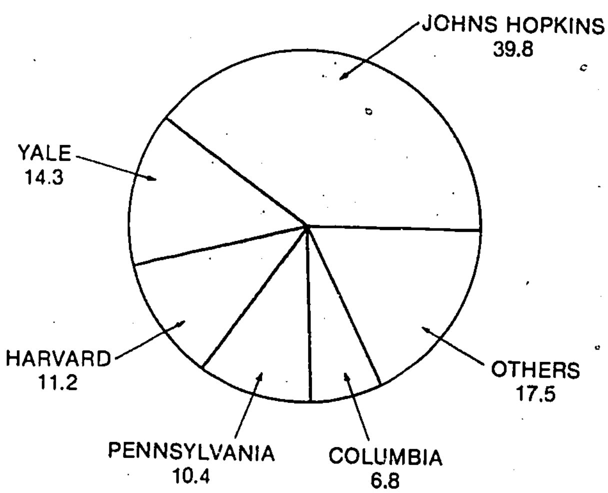
[1]Statistics taken from Bud et al., *Chemistry in America*, p. 282.
[2]Henry James, *Charles W. Eliot* (Houghton-Mifflin, Boston, 1930), vol 2, Appendices C and D.

chemists in the years before World War I; in the same era 97 of the 130 Hopkins doctors in organic chemistry (75%) went directly into college teaching. In 48 private and 17 state institutions Hopkins chemists rose to senior appointments, many as full professors and department chairman (9 became Deans, and 3 college presidents). Harvard, Stanford, Cornell, and MIT were among the major institutions with Hopkins appointees while liberal arts colleges were represented by Lafayette, Pomona, Bryn Mawr, Swarthmore, Antioch, Amherst and Oberlin among others.[3]

Four private universities in the East (Hopkins, Yale, Harvard and Pennsylvania) produced over 75% of all doctorates in chemistry, before 1900 (see Figure 16). These four institutions were correspondingly important in setting a style of research. Bequests from merchants and industrialists were vital to the financial prosperity of these institutions, and to their departments of chemistry. However, there was no direct link between Ph.D production and industrial needs. Instead these early departments found a focus in basic research, and in training teachers for other schools.

FIGURE 16. Institutions Granting Doctorates in Chemistry before 1900.

(251 PhDs, 19 schools)



Note: Top five schools are shaded.
Numbers indicate percentages.
SOURCE: Bud *et al.*, *Chemistry in America*

[3]On Remsen (1846-1927) see *Dictionary of Scientific Biography* (cited hereafter as *DSB*), 1975, *11*, 370-371. Statistics taken from Bud et al., *Chemistry in America*, pp. 167-170; and D. S. Tarbell, Ann T. Tarbell, & R. M. Joyce, "The Students of Ira Remsen and Roger Adams," *Isis*, 1980, 71, 620-626. See also Owen Hannaway, "The German Model of Chemical Education in America: Ira Remsen at Johns Hopkins (1876-1913)," *Ambix* 1976, 23, 145-164.

The industrially-relevant knowledge of the leaders of the first American research schools was drawn on in occasional consulting work, in accord with the promiscuous character of American chemistry. But the main academic-industrial connection lay in the teaching of those undergraduate chemists who on graduation would enter directly into industrial employment.

This early, Eastern, private model of research focused on the production of Ph.Ds able to pursue academic investigations while also teaching those less advanced chemists who would go into routine (mainly analytical) work in industry. What it did not do was to produce Ph.D-holding researchers qualified and properly disposed to make their careers in industry. That development was pioneered in the quite different but characteristically American context of the land-grant college.

2. *The land-grant model*

Transmuting private fortunes into academic and civic virtue was a special talent of the Eastern, private universities. However the pluralism of American academe meant that those universities enjoyed no monopoly in scientific life. Indeed an alternative model—more closely in accord with the promiscuous reality of American chemistry, if not with the academic ambitions of German-trained scholars—was available in the land-grant colleges, especially in the Midwest. That model was one of public service, and of close attention to the citizens—especially the farmers—of the state.

For instance at the University of Illinois, Arthur Palmer (chairman 1893-1904) specialized in analyses of the purity of municipal water supplies and, in 1895, succeeded in having the Illinois State Legislature establish a permanent State Water Survey, to be housed in the chemistry department and run by him. Palmer's colleague, Samuel W. Parr (ACS Pres. 1928) made his national reputation as an industrial chemist in this analytic "service" tradition. He developed novel means for testing bituminous Illinois coal and his Parr calorimeter—and the Parr Instrument Company—made him rich and famous.[4] Utility of this kind did not go unnoticed and, between 1872 and 1915, the Illinois chemistry "faculty and staff" increased from one to 62. In part this increase was fed by the growth in every part of the university, and by the need to teach chemistry to varied undergraduate audiences (total undergraduate enrollment in chemistry went from 70 to 2150 over the period). But the increase was also accompanied by a dramatic rise in graduate study. Illinois awarded its first Ph.D in 1903 to W. M. Dehn (who joined the faculty of the University of Washing-

[4]Parr (1857-1931): *DAB*, 1934, *14*, 252-253; Palmer (1861-1904): *Who Was Who in America* (cited hereafter as *WWW*), 1942, 1,931.

ton); by 1915 Illinois had 75 graduate students.[5]

Even though the university and the chemistry department had strong service orientations, the early Ph.Ds from Illinois tended to find employment in higher education itself. Students from Eastern institutions might command the leading academic positions, but there were many new and bouyantly-expanding Midwestern schools in which local Ph.Ds could find employment. Of 25 Illinois Ph.Ds from 1911-15, over half took academic positions.[6] Despite this characteristic tendency of academe to feed on itself during a period of growth, chemists in the universities were aware of the growing stature and possibilities of chemical industry, and of the need of that industry for men with new sorts of chemical skills. Yet a demand that was present in theory did not easily materialize in practice. It was one thing for industry to employ the skills in quantitative and qualitative analysis of baccalaureate chemists. It was something else again to find the students and the employers who together would justify an explicit concentration of Ph.D-holding chemists devoted to research in industrial chemistry, or applied chemistry, or the newly-invented subject of chemical engineering.

3. *Chemical engineering and industrial chemistry*

Courses in agricultural chemistry had long been familiar in nineteenth century America. Applied or industrial chemistry seemed a natural corollary, as industry developed. However such courses had a checkered career in the years before World War I, as did chemical engineering. If industrial chemistry too often seemed a collection of recipes, devoid of intellectual content, chemical engineering faced the problem that it was a hybrid discipline lacking unequivocal support from either chemists or traditional engineers.

Illinois, for instance, inaugurated a separate department of applied chemistry to teach a "course in applied chemistry with engineering subjects" in 1894, and thereby justified an increase from one to two professors of chemistry within the institution. The new department was returned to its home in chemistry, in 1904. At Pennsylvania, a four year program was inaugurated in the chemistry department, with chemical engineering as one division, in 1893. However the engineering division did not flourish—perhaps because the two Pennsylvania professors with developed interests in the Philadelphia area's extensive chemical industry both resigned from the university in favor of industrial and consulting careers, about this time (one of the two, Samuel P. Sadtler, went on to become founding President of the American Institute of Chemical Engineers, in 1908.[7]

It was at MIT—neither a straightforward land-grant university nor a straightforward private institution—that chemical engineering took firmest root. A curriculum in chemical engineering was first offered in 1888-89, and consisted of courses in applied chemistry, industrial chemistry, and mechanical engineering. During the 1890s the MIT faculty was strengthened by the addition of over half-a-dozen young German-trained chemists, including William H. Walker, William D. Coolidge, Willis R. Whitney and Warren K. Lewis. The popularity of MIT baccalaureates in chemical engineering grew slowly at first, but by 1916 the subject had far outstripped "pure" chemistry in its appeal (Table 1).

Table 1

Baccalaureates awarded in chemistry and chemical engineering at MIT by five-year periods, 1885-1934

Years	*S.B.s. in chemistry*	*S.B.s. in chemical engineering*
1885-1889	38	——
1890-1894	50	31
1895-1899	98	49
1900-1904	78	51
1905-1909	82	65
1910-1914	50	132
1915-1919	63	187
1920-1924	52	419
1925-1929	81	238
1930-1934	71	240

SOURCE: Servos, "Industrial Relations," p. 538.

The links between chemical theory, engineering knowledge and industrial practice were given further strength when, in 1916, William H. Walker and his younger colleague Warren K. Lewis established the School of Chemical Engineering Practice on the urging of Arthur D. Little. This cooperative extension program sent faculty and students to selected industrial plants for part of the year, and gave MIT chemical engineers access to costly facilities. The School was funded with $300,000 from George Eastman, and was a notable success that came to be widely emulated. Also important in the economy of academic-industrial interactions as pioneered at MIT was the Research Labora-

[5] S. W. Parr, "Historical Sketch of the Chemistry Department," pp. 16-29 in *University of Illinois, Department of Chemistry, Circular of Information of the Department of Chemistry: History, Equipment, Members of the Faculty, Students and Announcement of Courses for the Year 1916-1917*, University of Illinois *Bulletin*, 21 February 1916, vol. 13.

[6] For information on the Illinois chemistry department, here and below, see P. Thomas Carroll, *Perspectives on Academic Chemistry in America, 1876-1976: Diversification, Growth, and Change* (Unpublished Ph.D dissertation, University of Pennsylvania, 1982).

[7] J. W. Westwater, "The Beginnings of Chemical Engineering Education in the USA," pp. 141-152 in *History of Chemical Engineering*, William F. Furter, ed. (American Chemical Society, Washington, D.C., 1980); A. Norman Hixson & Alan L. Myers, "Four Score and Seven Years of Chemical Engineering at the University of Pennsylvania," in *A Century of Chemical Engineering*, edited by William F. Furter (Plenum Press, New York, 1982), pp. 127-138. Sadtler (1847-1923): *DAB*, 1935, *16*, 285-286.

tory of Applied Chemistry that Walker set up, in 1908. The hope was to apply scientific knowledge systematically, and to provide contract research facilities for industrialists reluctant to embark on staffing their own laboratories.

This willingness to be of service had its direct and indirect rewards. By 1921 the Research Laboratory of Applied Chemistry had handled almost $200,000 in mundane contracts of one kind and another. More interesting is the fact that Eastman and two other scions of chemical business (T. Coleman, and Pierre S., du Pont) so approved of the way the institution was responsive to business sensibilities that together they gave MIT over $11 million in building and endowment funds between 1911 and 1921.[8]

4. *The first growth of industrial research*

The chemical and chemical process industries began to experiment with research in this era. Companies such as General Chemical (1900), Dow (1900), Du Pont (1902), Standard Oil of Indiana (1906), Goodyear (1909), Eastman Kodak (1912), and American Cyanamid (1912) were among the early pioneers of central research and development laboratories. As with the German dyestuffs industry, progress was tentative and the future of the enterprise uncertain.

The employment of chemists was not limited to chemical companies, and the case of Willis R. Whitney and the General Electric Company is instructive.

On 15 December 1900 Whitney, then an assistant professor of chemistry at MIT, began devoting two days a week to research at General Electric's largest manufacturing works at Schenectady, New York. His employment was prompted by GE's sense that German inventions, and activities by their American rival Westinghouse, threatened GE's dominance in the electric lighting business. Whitney took to his work at GE and soon resigned his MIT position to become full-time director of the fledgling research laboratory (a position he held, with great success, until 1932), though he knew full well "that the company is not primarily a philanthropic asylum for indigent chemists." He recruited an able staff, including William D. Coolidge from the MIT physical chemistry laboratory (in 1905) and Irving Langmuir who, in 1909, was disappointed in his hopes for the chairmanship of the chemistry department at Stevens Institute of Technology.

Whitney, Coolidge and Langmuir together foreshadowed much about the course of industrial research in certain very large companies, and in the strong connections of that research with academic work. All three held (German) Ph.Ds and all three had multiple academic contacts, and prior academic careers. Coolidge's work on inventing and perfecting a process for making tungsten wire for use in incandescent lamps resulted in a 1913 patent that was fundamental to GE's continued prosperity. Whitney and Langmuir in their turns were Presidents of the American Chemical Society (1909 and 1929), and Langmuir's work in surface chemistry led to the award of the Nobel prize in 1932.[9] The example set by Whitney at GE was strongly to influence C.E.K. Mees, himself another leader in industrial research and director of the Eastman Kodak laboratory from 1912 to 1956, and also to inspire Charles F. Kettering, General Motors research director for a period of twenty-seven years. On another level it is interesting to note how the Harvard graduate student and chemist James B. Conant was to retain a lasting memory of a 1913 lecture by Whitney extolling the opportunities for scientists in industry.[10]

The eventual strong success and widespread influence of the GE laboratory should not obscure how *tentative* was its role and its future in the early days. While major innovation, and associated patents, was one obvious goal, that goal was not reached quickly, easily or often. A second main line of usefulness instead emerged in minor improvements of products and processes, and in building an essentially defensive network of patents to ensure continuing dominance in traditional techniques and market areas.

The pattern was similar at Du Pont. In the late nineteenth century laboratories for routine testing and analysis grew and prospered along with the company's new dynamite works and its older black powder facility. Small clusters of academically-trained chemists began to be employed in these laboratories in the 1890s: Oscar Jackson, superintendent of the Repauno dynamite works—a graduate of Harvard and a student of Adolph von Baeyer in Munich—was the key figure in this development. The plant laboratories were mainly occupied with routine testing, but responding to the problems of clients, elucidating the value of patents offered to Du Pont, and development work of various kinds also began to be important.

In 1902 Du Pont took the formal step of differentiating chemical research from production responsibilities, and the Eastern Laboratory was inaugurated with an explicitly advisory role within the company. However the Eastern Laboratory was close to the dynamite works, and its staff included several chemists with

[8]This account draws heavily on John W. Servos, "The Industrial Relations of Science: Chemistry at MIT, 1900-1939," *Isis*, 1980, *71*, 531-549 which contains an extended discussion of the factors involved in the rise and decline of contract research during the period. Walker (1869-1934): *WWW*, 1942, *1*, 1291; Lewis (1882-1975): *WWW*, 1976, *6*, 246; Little (1863-1935): *DAB*, 1944, 21, 500-501.

[9]George Wise, "A New Role for Professional Scientists in Industry: Industrial Research at General Electric, 1900-1916," *Technology and Culture*, 1980, *21*, 408-429. Whitney (1868-1958): *DAB*, 1980, *26*, 694-695; Langmuir (1881-1957): *DSB*, 1973, 8, 22-25; Coolidge (1873-1975): *WWW*, 1976, *6*, 89.

[10]Mees (1882-1960): *DAB*, 1980, *26*, 441-443; Kettering (1876-1958): *DAB*, 1980, *26*, 332-333.

extensive plant experience. One of them was the laboratory's Director, Charles Lee Reese (ACS Pres. 1934; AIChE Pres. 1924, 1925). Reese was a graduate of the University of Virginia, who took his Ph.D under Robert Bunsen at Heidelberg in 1886. Uncertain about his academic future, Reese left his position in the Johns Hopkins chemistry department in 1900, in favor of an industrial career. Under Reese,and in accord with tradition,process improvements and waste product recovery were the two main concerns of the early Eastern Laboratory, as Du Pont management sought to rationalize the company. In 1903 a new Development Department was formed, which included an Experiment Station. A further reorganization in 1911 consolidated the Experiment Station and the Eastern Laboratory into a Chemical Department with Reese at its head, and a staff of 120. Process development and problems with products still formed the staple of this enlarged central staff, but attention began to turn to new products as the company adopted a conscious strategy of diversification away from explosives. New uses for nitrocellulose was one obvious concern: in 1913 97% of Du Pont's business was in explosives, but over one third of all research expenditures went to seeking new products in nitrocellulose chemistry. A second concern was to improve the products of certain existing companies like the artificial leather of the Fabrikoid Company and the celluloid of the Arlington Company, acquired in 1915.

By 1917, the importance of research and innovation to Du Pont was unarguable. In a move pregnant with implications for the future, Du Pont then became the first chemical company to recognize the industrial value of advanced academic knowledge through appointment of a Ph.D to its Board of Directors, in the person of Reese. Reese of course had a German doctorate—an interesting footnote on a year most often remembered for the outbreak of war between America and Germany.[11]

5. *The idea of contract research*

Obviously, few companies were of the size of General Electric, Eastman Kodak or Du Pont. However academic chemists were familiar with consulting and industrial problems, and as the example of William H. Walker at MIT indicates, some at least were anxious to tap industry as a source of funds and as an employer of their growing number of Ph.Ds.

Another such individual was Robert K. Duncan, who after a mixed career in teaching and journalism became professor of industrial chemistry at the University of Kansas in 1906. There he pioneered the idea of having students undertake specific pieces of work paid for by companies interested in the results. The first industrial fellowship was supported by a laundering company in Boston (and led, eventually, to the foundation of the American Institute of Laundering). Duncan was able to interest Andrew W. and Richard B. Mellon in his ideas. The Mellons encouraged Duncan to set up a department of industrial research at the University of Pittsburgh, in 1910. Three years later the department became an institute named after the Mellon family, who commissioned a building and undertook to support the venture for five years: by 1915 the Institute employed 23 fellows. Though nominally a part of the University of Pittsburgh, the Mellon Institute operated in an independent way. The Institute pioneered many contract research procedures, notably the limited-tenure fellowship through which a new Ph.D might work on a specific problem for a particular company. The power of this technique for harnessing academic knowledge to industrial concerns was soon apparent; by 1936 annual fellowship donations had reached $1M, with a total of $11M contributed over the preceding quarter-century. And by the Institute's fiftieth anniversary in 1963 some 229 Mellon fellows had gone on to management positions in industry, including 16 presidents of companies.[12]

Though the Mellon Institute was not formally limited to chemical concerns, the majority of its early fellows and of its research problems lay in the field of chemistry. One especially dramatic example of the Institute's effect may be seen in the work of George Curme.

Curme, one of four Ph.D graduates of the University of Chicago in 1913, undertook postdoctoral work in Germany. He considered his prospects of finding academic employment to be bleak and, in 1914, accepted the Prestolite fellowship at the Mellon Institute. His initial task was to find a cheaper source of acetylene than calcium carbide (Prestolite made the lamps for bicycles and cars). The train of research thus initiated led to the discovery that by using organic liquids in exothermic reactions he could produce not only acetylene but ethylene. By 1920 he was convinced of the possibility that, starting with petroleum, it would be possible to create an organic chemical industry of almost unlimited proportions, based on ethylene, acetylene and their by-products. His sponsor—by now combined as the Union Carbide and Carbon Corpora-

[11]For information on Du Pont, here and below, see Jeffrey L. Sturchio, *Chemists and Industry in Modern America: Studies in the Historical Application of Science Indicators* (Unpublished Ph.D dissertation, University of Pennsylvania, 1981), pp. 125-138. Reese (1862-1940): *DAB*, 1958, *22*, 550-551.

[12]Duncan (1868-1914): *DAB*, 1930, *5*, 511-512. For a sketch of the Institute by its director from 1921-56, see Edward R. Weidlein, "A Thumbnail History of Mellon Institute," pp. 19-25 in *Science and Human Progress: Addresses at the Celebration of the Fiftieth Anniversary of Mellon Institute*, H. P. Klug, ed. (Mellon Institute, Pittsburgh, 1964). Figures are taken from Edward R. Weidlein & William A. Hamor, *Glances at Industrial Research During Walks and Talks in Mellon Institute* (Reinhold, New York, 1936), p. 30.

tion—agreed, and over the next three decades Curme played a primary role in the development of petrochemicals, including the manufacture of such products as bottled gas (propane) for domestic use, Prestone antifreeze, and synthetic rubber. He was eventually to become vice-president for research of the Union Carbide Company (1951).[13]

Equally striking was the work of L. V. Redman (ACS Pres. 1932) who accepted one of the original industrial fellowships under Duncan at Kansas in 1910. Redman transferred to the Mellon Institute in 1913, continuing his work on phenol-aldehyde condensation resins of the type recently discovered by Leo Baekeland (ACS Pres. 1924; AIChE Pres. 1912). The hope of Redman's sponsors was a superior furniture polish. However, by the time of its 1922 merger with Baekeland's competing company, the Redmanol Chemical Products Company was already producing a wide range of phenolic resins with uses in such things as aircraft propellors and automobile ignition systems. Redman became Director of Research for the Bakelite Corporation, and presided over the rapid early growth of the plastic industry.[14]

The Mellon Institute exemplifies a developing pattern: it relied on the vision of an academic entrepreneur familiar with industrial problems; it profited from the philanthropy of a family whose fortune came from chemically-linked endeavors; it had loose but real connections with an academic institution; and its members saw no great barriers between academic knowledge and manufacturing concerns, or between careers in industry and activity in learned societies.

These last characteristics were also true of Arthur D. Little (ACS Pres. 1912, 1913; AIChE Pres. 1919), who studied chemistry at MIT in the early 1880s, but who did not stay to graduate. Instead, Little went to work in the paper-pulping industry, took out patents, and prospered as a consulting chemist. In 1900 he formed a partnership with William H. Walker of MIT. Walker withdrew in 1905 because the demands on his time were too great. However Little continued to prosper (and began to be an influential adviser at MIT). By 1909, "Arthur D. Little Inc., Chemists, Engineers, and Managers" was a thriving organization undertaking research on contracts for profit. Extensive new buildings, with well-equipped laboratories and library were opened in 1917. Little's experience, his enthusiasm and his entrepreneurial genius prompted many other developments in industrial research, and a variety of links between academe and industry. For instance, Walker's Research Laboratory of Applied Chemistry at MIT owed much to Little's example and advice, as did the formation of the first central laboratory at the General Motors Corporation.[15]

The successes of Little's organization and of the Mellon Institute prompted numerous imitators. In 1916, for example, the University of Washington organized a Bureau of Industrial Research to which the industries of that state were encouraged to bring their problems. In the following year the University of Oklahoma established a special Industrial Research Department concerned with oil, gas and gasoline, and in 1918 Julius Stieglitz (ACS Pres. 1917) at the University of Chicago "invited industrial fellowships the expenses of which were to be met by manufacturing companies", while promising chemical courses shaped to bring about closer cooperation between scientists and businessmen.[16]

6. *Individual philanthropy and basic research*

As the examples of the Mellons, the Du Ponts and George Eastman suggest, creators and inheritors of the giant fortunes that were coming into being on the basis of such chemically-oriented industries as oil (Rockefeller), steel (Carnegie), explosives (Du Pont) and photography (Eastman) were not slow to endorse scientific research on a wide and inclusive basis.

Such endorsement might take the form of buildings or capital resources for a particular style of activity (the Mellon Institute) or for a particular academic institution (MIT). It also encompassed the endowment of whole institutes devoted to basic research outside the traditional university setting (the Carnegie Institution), and a slow groping toward the idea of operating foundations willing to fund particular programs of research in diverse institutions (Rockefeller).[17]

On the eve of American entry into World War I, a certain division of labor was thus apparent within a confused and tentative situation. Universities and colleges were educating increasing numbers of chemists, and developing strengths in pure research. A growing trickle of Ph.Ds was finding its way into industrial research. Most of that research—whether conducted within the companies or subcontracted to the Mellon Institute, the MIT Research Laboratory of Applied Chemistry, or similar organizations—was aimed at immediate problems, and funded on a lowly level. Where massive philanthropy existed—as with the Du Ponts or Andrew Mellon or John D. Rockefeller—it strongly influenced academic behavior, but its aims

[13]Augustus B. Kinzel, "George Oliver Curme, Jr. (1888-1976)," *National Academy of Sciences Biographical Memoirs*, 1980, 52, 120-137.

[14]Redman (1880-1946): Miles, *American Chemists*, pp. 400-401; Baekeland (1863-1944): *DSB*, 1970, *1*, 385.

[15]Williams Haynes, ed., *American Chemical Industry*, vol. 6 (Van Nostrand, New York, 1949), p. 250. See also Haynes, "Arthur D. Little," pp. 1192-1201 in *Great Chemists*, Eduard Farber, ed. (Interscience, New York/London, 1961).

[16]Haynes, *American Chemical Industry*, vol. 3 (1945), pp. 392-394. On Stieglitz (1867-1937): *DAB*, 1958, 22, 630-631.

[17]On foundations in general see Eduard C. Lindeman, *Wealth and Culture* (Harcourt, Brace and Co., New York, 1936); and Robert H. Bremner, *American Philanthropy* (University of Chicago Press, Chicago, 1960), chapters 7-10.

were broadly cultural rather than narrowly economic. However universities and industry were already closely linked on many levels from the employment of baccalaureate students to the practice of industrial consulting by professors, and from the work of businessmen as trustees and benefactors of academic institutions to the existence of important common ground between academe and industry in the American Chemical Society, the American Institute of Chemical Engineers and other comparable organizations.

B. Consolidating the System, 1920-1940

World War I was sometimes called "the chemists war." In the United States the Chemical Warfare Service was the result of an extraordinary mobilization. Its ranks included many talented individuals who were later to serve together in other common causes—individuals like Roger Adams, James B. Conant, Arthur D. Little and Warren K. Lewis.

The war affected American chemistry and chemical industry in various ways. It made vivid the independence of American universities from German academic domination, that was already apparent by 1910. It created contexts in which academics and industrialists forged new personal relationships as they worked on common problems. It made explicit and urgent the need to replace the German sources of many industrial and fine chemicals. More than that, the subsequent defeat of Germany, and the seizure of German patents, opened the way to an effloresence of domestic chemical manufacturers, under an appropriate tariff policy.[18]

Chemical industry and academic chemistry both boomed in the Coolidge years. The further growth of higher education led to the development and routinization of many of those patterns of academic-industrial interaction that were already apparent in 1915. Industrial research laboratories grew in number, scale and success; new, independent research institutes came into existence; and foundation and company support of academic research became familiar and widespread. The years of the Depression took the edge off some of these developments. At the same time Depression realities fostered the desire of leading chemical spokesmen to rationalize and improve the system, and to fill in some "missing pieces." Though federal and state governments were becoming important as partners in the evolving system, academic and industrial leaders were agreed on seeing them as junior partners whose role it was to serve corporate interests, for the public good. If the aim was to consolidate a national system, it was also agreed that the system properly belonged under private control.

1. *Independent research institutes*

In the period between the wars the Mellon Institute became wholly independent. Under its own board of trustees it continued its focus on individual fellowships and on contract research in chemistry. Even in the difficult year of 1933 it had some 85 fellows at work. Chemistry was also a continuing mainstay of the Arthur D. Little organization, where much attention was devoted to the new field of petrochemicals. Twenty-seven research chemists and seven analytical chemists formed the core of its endeavors in 1933.[19] The links of Little's enterprise to MIT were further strengthened by his will (1935) which stipulated that the profits from a controlling interest in Arthur D. Little Inc. were to go to MIT, where he had been a Member of the Corporation for over twenty years.

The Mellon and Little institutions were both in older industrial areas, as was the Battelle Memorial Institute, founded in 1929 as a memorial to the heir of the Columbus Iron and Steel Works in Ohio. An endowment of almost $4M was devoted to "education in connection with the encouragement of creative and research work, and the making of discoveries and inventions in connection with the metallurgy of coal, iron, steel, zinc and their allied industries." These terms show how common was the acceptance of an equation between education, research, and industrial progress. In practice the Battelle Memorial Institute pioneered contracts for research on short-term problems, that research being undertaken by staff teams assembled from requisite disciplines, among which chemistry and metallurgy were the most prominent. Another research institute of this kind was the Armour Research Foundation of Chicago, founded in 1936 by several faculty members of Chicago's Armour (later, Illinois) Institute of Technology.[20] Also of interest is the Institute of Paper Chemistry, which was organized in 1929 in close association with Lawrence College in Appleton, Wisconsin. Support came from graduated dues levied on "member companies" to support a small faculty committed to interdisciplinary research and to the teaching of students already possessed of a bachelors degree in chemistry or chemical engineering.[21]

[18]Daniel P. Jones, *The Role of Chemists in War Gas Research in the United States during World War I* (Unpublished Ph.D dissertation, University of Wisconsin, Madison, 1969); Haynes, *American Chemical Industry*, vol. 2 (1945).

[19]Clarence J. West and Callie Hull, comps., "Industrial Research Laboratories of the United States," *Bulletin of the National Research Council*, 1933, August, 91, pp. 115, 123.

[20]An excellent source concerning independent research institutes is Richard L. Lesher, *Independent Research Institutes and Industrial Application of Aerospace Research* (Unpublished Ph.D dissertation, Indiana University, 1963), chapter 3. For a more general overview see Harold Orlans, *The Nonprofit Research Institute* (McGraw-Hill, New York, 1972), quotation from page 33.

[21]Roy P. Whitney and Harry T. Cullinan, Jr., "The Graduate Program at the Institute of Paper Chemistry," *Chemical Engineering Education*, 1978, *12*, 56-59.

2. *Industrial research laboratories as a genre*

During the twenties both the number of companies maintaining research laboratories and the number of people employed in industrial research tripled. The increase in industrial researchers is dramatic when considered against the 28 per cent increase in all persons employed in U.S. manufacturing between 1921 and the onset of the Depression. The rate of growth of industrial research laboratories slowed during the early 1930s, but the number of research workers still doubled during each of the next two decades. Among those engaged in industrial research, chemists were the predominant group during the interwar years. As Table 2 also shows, one of every three persons in industrial research in 1921 was a chemist. By the late 1920s, as a variety of industries jumped on the research bandwagon, the proportion of chemists dropped slightly, to one in four. But chemists maintained their central position throughout the 1930s and 1940s.

By the late 1920s over half of the industrial laboratories reporting to the National Research Council were located in the chemical process industries. Between 1927 and 1938 the proportion of all research personnel employed in this group increased from 41.0 to 52.2 per cent. Within the chemical process industries, companies in chemicals and allied products, petroleum, primary metals, and rubber employed the largest research staffs, accounting for nearly 85 per cent of the research workers in the group by the late 1930s. The chemicals and allied products industry had more researchers than any other industry in the late 1920s and 1930s, employing one in five research workers (see Table 3). Figures 17 and 18 present detailed employment information for three components of the chemical process industries—industrial chemicals (the largest subgroup of chemicals and allied products), petroleum, and rubber. These figures reveal the expanding opportunities for chemists and other scientists.

In industrial chemicals and rubber, research was directed mainly toward the improvement of manufacturing processes and the exploration of new applications for products. In petroleum, breakthroughs in catalytic cracking and polymerization technology, along with early movement into the field of synthetic organic chemicals, help to explain the growth in the 1920s and 1930s of both the number of laboratories and the number of researchers in the industry. Research workers in the petroleum industry increased from a few hundred in the 1920s to more than 5,000 in 1938, accounting for one in nine industrial research personnel and placing the industry second only to chemicals and allied products in the extent of its research activity.[22]

Much of the growth after the late 1920s can be attributed to the expansion of existing laboratories, especially in industrial chemicals. For example, between 1928 and 1938 the number of research workers employed at Dow Chemical increased from about 100 to more than 500; at Du Pont, from about 850 to over 2,500 persons. Once again, the particular case of Du Pont reveals the shifting style of industrial research as a genre, away from an occasional concern with product innovation toward a strategy of fundamental research as a deliberately-employed weapon (though testing and development work remained central to the chemist's role in the research laboratory, as throughout industry).

By the early 1920s, Du Pont was producing pyralin plastics, paints and related chemicals, fabrikoid, and dyestuffs in addition to its traditional array of military, industrial, and sporting explosives. Coordination of activity in industries as diverse as heavy chemicals,

[22]Bud et al., *Chemistry in America*, pp. 130-133.

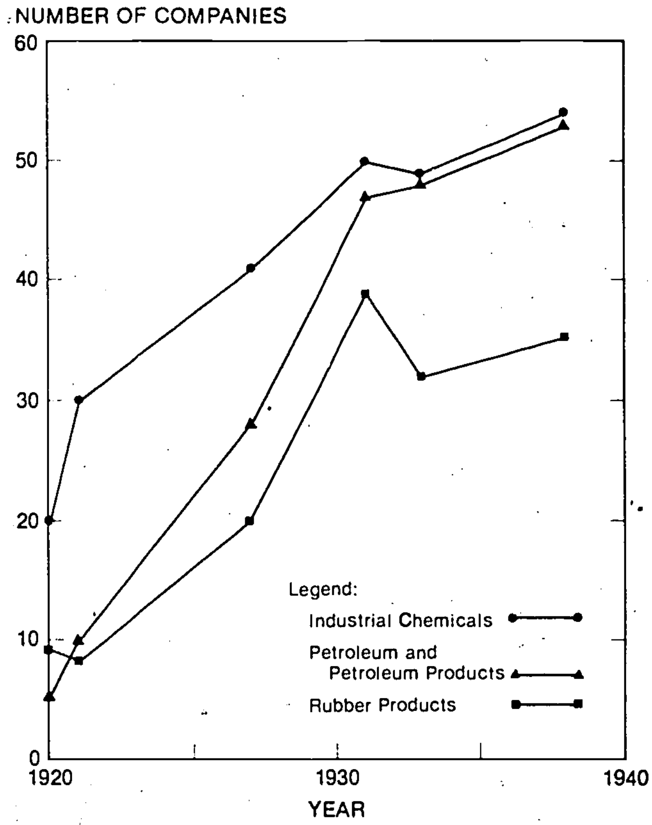
Table 2

Industrial Research Personnel, by Selected Field, 1921-1950

Year	*Corporate units surveyed*	*Research personnel*				
					Chemists	
		Total	*Physicists*	*Engineers*	*Number*	*As percentage of total*
	(1)	(2)	(3)	(4)	(5)	(6)
1921	568	11,500	150	1,898	3,830	33.3
1927	926	18,982	437	3,018	5,163	27.2
1931	1,520	32,830	689	6,993	8,470	25.8
1933	1,462	27,567	414	5,541	7,526	27.3
1938	1,722	44,292	1,550	10,276	12,623	28.5
1940	2,210	70,033	2,031	14,9[illegible]7	15,687	22.4
1946	2,443	133,515	2,660	20,6[illegible]7	21,095	15.8
1950	2,795	165,032	2,969	35,601	23,159	14.0

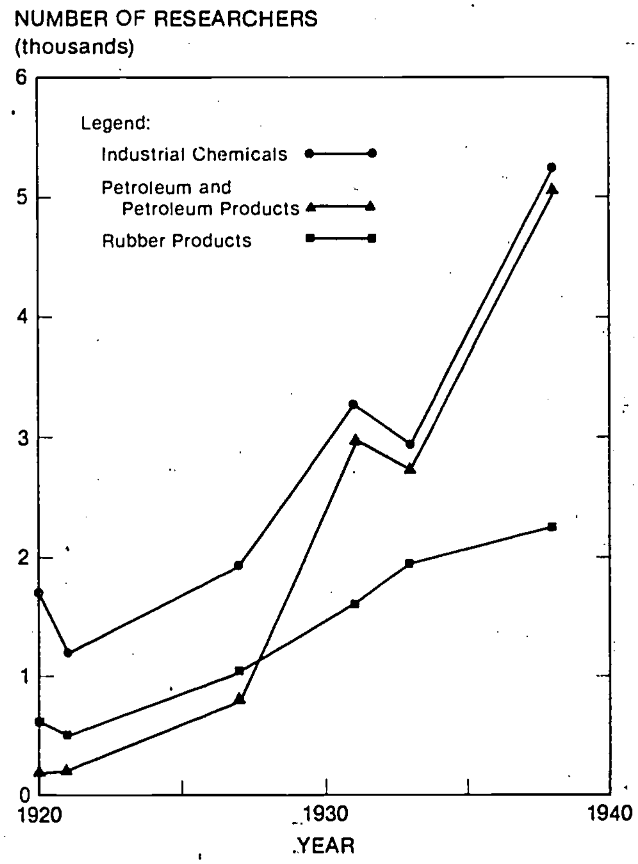
SOURCE: Bud et al., *Chemistry in America.*

FIGURE 17. Number of Companies Maintaining Research Laboratories in Selected Industrial Groups, 1920-1938.



SOURCE: Bud *et al., Chemistry in America*

FIGURE 18. Research Personnel in Selected Industrial Groups, 1920-1938.



SOURCE: Bud *et al., Chemistry in America*

organic dyestuffs, and paints proved difficult. In 1921 a decentralized, multi-divisional structure was adopted (a solution that has since come to characterize the modern business corporation). Research organization was remodelled accordingly, with each division having its own technical staff concerned with short and long-run problems related to the division's product line. A new Central Chemical Department coordinated the growing number of research laboratories, control laboratories, and technical services to manufacturing plants, while also undertaking work on subjects not connected with existing Du Pont products and processes.

In 1927 the Central Chemical Department alone had a staff of 850 people and a budget of $2.2M. It was at this juncture that its new head, C.M.A. Stine (AIChE Pres. 1947), successfully argued that "applied research is facing a shortage of its principal raw materials" in new ideas. Du Pont had already pioneered the marketing of rayon (1920), Duco lacquers (1923), synthetic ammonia (1924) and cellophane (1927). However the policy of capitalizing on the technology acquired from other companies or inventors seemed too limited: Du Pont should perform its own fundamental investigations in colloids, catalysis, and synthetic organic chemistry. Stine backed up his case by reference to the examples of German chemical industry, and the General Electric Company. His request was granted, with a subvention of $20,000 for 1927 to undertake the deliberate search for new scientific facts. The idea of fundamental research as an industrial strategy was thus blessed, belatedly. Its future was secured when, within a decade, the brilliant work of W. H. Carothers and his associates gave rise to neoprene and nylon. By 1940 the fundamental research program at Du Pont accounted for nearly one third of the Central Chemical Department's research budget, and employed 152 people. That number was barely 5% of the total of "research workers" employed by the company. However, those 152 people formed a crucial link between a vastly expanded industrial enterprise and its basis in an equally transformed academe.[23]

[23]Sturchio, *Chemists and Industry in Modern America*, pp. 138-145. Stine (1882-1954): *DAB*, 1977, *25*, 662-663; Carothers (1896-1937): *DAB*, 1958, *22*, 96-97.

Table 3

Distribution of Research Personnel in the Chemical Process Industries, 1927 and 1938

Industrial group	Companies				Employees			
	1927		1938		1927		1938	
	Number	As percentage of total	Number	As percentage of total	Number	As percentage of total	Number	As percentage of total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Food and kindred products	62	6.7	108	6.3	401	2.1	1,424	3.2
Paper and allied products	28	3.0	57	3.3	271	1.4	752	1.7
Chemical and allied products	231	24.9	395	22.9	3,463	18.2	9,542	21.5
Petroleum and its products	28	3.0	53	3.1	788	4.2	5,033	11.4
Rubber products	20	2.2	35	2.0	1,115	5.9	2,250	5.1
Stone, clay, and glass products	45	4.9	99	5.7	527	2.8	1,404	3.2
Primary metals	97	10.5	144	8.4	1,222	6.4	2,728	6.2
Total, chemical process industries	511	55.2	891	51.7	7,787	41.0	23,133	52.2
Total, all industries	926	100.0	1,722	100.0	18,982	100.0	44,292	100.0

SOURCE: Bud et al., *Chemistry in America*.

A different, but equally vital, link lay with the chemical engineers. The Du Pont company did not hire its first chemical engineering graduate until 1920. In 1929 a chemical engineering group was added to the fundamental research program. That group flourished as it focused on the improvement of the "unit operations" of chemical industry, and as it pioneered in retaining as consultants professors from a number of leading universities. Contacts and individual careers in chemical engineering also vividly exemplified the developing two-way street between fundamental chemical science and industrial production, and between academic employment and commercial careers. Among the chemical engineers who later moved from the company to academe were Allen P. Coulborn (to the University of Delaware, 1939), Thomas B. Drew (Columbia, 1941), James O. Maloney (Kansas, 1946) and W. Robert Marshall (Wisconsin, 1947).[24]

3. *Corporate and institutionalized philanthropy*

If the emergence of fundamental research inside large corporations was one trend of the twenties and thirties, efforts by corporations to nourish fundamental research inside the universities was another. Almost by definition that effort was never sufficient to the demands and opportunities of academic research. But it was real, serious, and sustained. The effort depended on many different individuals, corporations, foundations and institutions and—like so much else in the relations between the universities and industry—it awaits its historian. Here it is only possible to cast episodic light on the rich network of graduate scholarships, faculty consultantships, research grants, equipment awards, and other incentives by which academic—industrial linkages were developed and sustained, and research and innovation fostered.

Most important in their long-run implications were the growing number of fellowships for graduate students. For instance the Du Pont Company inaugurated in 1918 a cluster of 18 fellowships and 33 scholarships at selected universities throughout the country, in line with its new stress on research and innovation. Other companies undertook similar efforts and chemistry was by no means the only subject favored. By 1928 it seems that a minimum of 95 fellowships and scholarships were supported by at least 56 companies. The variety of chemically-linked endeavors may be seen from some information for 1934. In that year the John Hopkins Chemistry Department enjoyed $1,000 fellowships "for the study of chemistry" from the Carbide and Carbon Chemicals Corp. (New York), the Cuhady Packing Co. (Chicago), the General Motors Corp. (Detroit), Eli Lilly and Co. (Indianapolis), Westinghouse Electric and Manufacturing Co. (Pittsburgh) and U.S. Industrial Alcohol Co., William R. Warner and Co. Inc., and John Wiley and Sons Inc. (all of New York). By 1940—despite the Depression—a national total of at least 721 awards in all subjects were underwritten by 200 companies. In chemistry, the California Institute of Technology had 8 fellowships, while MIT had 13, and various land-grant universities even more (Illi-

[24] Vance E. Senecal, "Du Pont and Chemical Engineering in the Twentieth Century," in Furter, *History of Chemical Engineering*, pp. 283-301.

nois, 15; Michigan, 10; Ohio State, 24; Penn State, 12; Wisconsin, 9).[25]

Harder to trace, yet equally important, was the growing practice in companies of donating specialized pieces of research equipment to particular universities and departments, or to individual professors for their research. On occasion such corporate philanthropy might be extended by an individual businessman, in donating a whole building to house a new or extended department of chemistry or chemical engineering. As early as 1917 C. W. and P. G. Gates, two lumber operators, financed the Gates Chemical Laboratory at the California Institute of Technology, while a decade later William Henry Nichols, Chairman of the Board of Allied Chemical and Dye Corporation, gave $3/4M for the Nichols Building for Chemistry at New York University.[26] Such examples could be multiplied.

Scholarships, buildings and equipment given to educational institutions underlined the growing belief that "the industry of producing the chemist is the most fundamental industry of all."[27] Another mechanism that was of great use in acquainting industrial researchers with academic findings, in making academics sensitive to industrial problems, and in channelling recruits to selected companies, was the industrial consultantship. Thus the Standard Oil Company of New Jersey decided to form "a thoroughly organized and competent research department" in 1919. To advise and assist in this venture, Standard Oil called not only on Ira Remsen of Johns Hopkins, but on Warren K. Lewis of MIT and Robert A. Millikan of the California Institute of Technology. The services of these consultants—and especially of Lewis—were to prove invaluable, when the company became urgently interested in coal hydrogenation in 1927, as part of a synthetic fuel program to meet a feared petroleum shortage. Robert P. Russell, assistant professor of chemical engineering at MIT, became manager of the necessary research laboratory and "recruited a staff composed largely of young MIT faculty members and graduate students."[28]

If consultantships represented one way in which faculty gave of their skills to industrial concerns, positions as trustees of academic institutions were a mode in which leading industrialists could bring their knowledge and concerns to bear on academic life. More subtle but no less pervasive was the influence brought into play by those industrially-related foundations which came to dispense philanthropy on a previously undreamt of scale in the 1920s and 1930s. The various Rockefeller-related charities derived their assets from the booming of the oil industry, and the Rockefeller Foundation powerfully affected the development of scientific—especially medical—research in the United States, in the period up to 1940. As master strategist of Rockefeller programs in the natural sciences, Warren Weaver institutionalized a pattern of project grants for specific pieces of research by leading academic scientists that was to be widely imitated in the fifties and sixties; he was also the catalyst for that fundamental research in biochemistry and molecular biology which was to underlie the subsequent exfoliation of genetic engineering. In keeping with widening American awareness, the Rockefeller-sponsored International Education Board vigorously promoted foreign scholars and institutions (as, for instance, in the 1927 grant of $131,455 for constructing and equipping of J. N. Brønsted's Institute of Physical Chemistry, in Copenhagen).[29]

The steel fortune of Andrew Carnegie was the other dominant force in the philanthropic support of scientific research, principally through the vehicle of the Carnegie Institution of Washington, D.C. Another far more modest research institute was the Bartol Research Foundation, inaugurated in 1924 at the Franklin Institute of Philadelphia. This institute derived its endowment of nearly $1M from the sugar refining ventures of George E. Bartol.[30] Quite different in style, but more immediately powerful in its effects, was the Chemical Foundation established in 1919 to administer the licensing of seized German chemical patents, and to distribute the proceeds so as to advance chemistry in America. This foundation favored popularizations and publicity, but it also provided needed funds for a multiplicity of academic projects from the *Journal of Chemical Education* to Wilder D. Bancroft's *Journal of Physical Chemistry* (which by 1931 received no less than $17,000 a year). In the years from 1919 to 1938 the Chemical Foundation distributed over $8M, of

[25] P. Thomas Carroll, "Industrial Fellowships and Scholarships for Academic Research in American Chemistry and Chemical Engineering, Selected Years, 1920-1940," (Unpublished paper, Department of History and Sociology of Science, University of Pennsylvania, June, 1977).

[26] Robert H. Kargon, "Temple to Science: Cooperative Research and the Birth of the California Institute of Technology," *Historical Studies in the Physical Sciences*, 1977, *8*, 3-31; "The Nichols Building for Chemistry. The Formal Opening, December Third, Nineteen twenty-seven, at University Heights in the City of New York" (New York University, New York, n.d.).

[27] M. T. Bogert in 1915 quoted in Haynes, *American Chemical Industry*, vol. 3, p. 394.

[28] Edward J. Gornowski, "The History of Chemical Engineering at Exxon," in Furter, *History of Chemical Engineering*, pp 303-311. Quote appears on page 307.

[29] On Rockefeller programs in the natural sciences, see Robert E. Kohler, "The Management of Science: The Experience of Warren Weaver and the Rockefeller Foundation Programme in Molecular Biology," *Minerva*, 1976, 14, 279-306; and Raymond B. Fosdick, *The Story of the Rockefeller Foundation* (Harper & Bros., New York, 1952), chapters 12-13. Among the International Education Board's projects in chemistry described in George W. Gray, *Education on an International Scale* (Harcourt, Brace & Co., New York, 1941) is an appropriation of $35,000 made to the American Chemical Society for the publication of the second decennial index of *Chemical Abstracts* (pp. 32-34). See also Ernest Victor Hollis, *Philanthropic Foundations and Higher Education* (Columbia University Press, New York, 1938).

[30] Lesher, *Independent Research Institutes*, p. 73.

which almost three quarters went to educational and research activities.[31] Altogether, it has been estimated, 100 philanthropic foundations contributed over $22M to higher education in the natural sciences in the decade from 1921 to 1930, with the great bulk (c.$20M) going to academic research.[32]

4. *The academic use of industrial opportunity*

The uses to which the developing academic-industrial system could be put stand out most sharply in the career-patterns of certain individuals. Outstanding among them was Roger Adams, who by 1940 had become the leading organic chemist in the United States, had built the University of Illinois Chemistry Department into the world's greatest producer of Ph.Ds in any discipline and had forged an unrivalled network of connections in industry.[33] His life exemplifies the shrewd use of industrial opportunity, without compromising academic tradition.

Roger Adams (ACS Pres. 1935) majored in chemistry and took his Ph.D at Harvard (1912) before spending a year in German laboratories. In 1913 he returned to Harvard to teach elementary organic chemistry (a position in which he was succeeded by J. B. Conant) and in 1916 he moved to the University of Illinois as an assistant professor. At Illinois he quickly found an unusual "industrial" opportunity. World War I had led to an embargo on German goods, and American universities and fine chemical users faced immediate, serious shortages of numerous organic chemicals traditionally imported from Germany. Adams turned an Illinois summer course in "organic preps" into "Organic Chemical Manufactures"—a year round activity producing some fifty or so rare organic chemicals for Illinois and other universities, and for industrial concerns, while incidentally providing financial support for graduate students. The chief corporate buyer of the organic chemicals produced was Eastman Kodak. Initially, the university provided a fund of $5,000 to cover the start up expenses of what proved to be a highly successful if modest venture, and one that still endured three decades later.

Organic Chemical Manufactures had many utilities. It provided good contacts for Adams and made him visible in the industrial world. It gave his students practical experience in scaling up laboratory processes to industrial quantities. It led to the creation of two serials, *Organic Syntheses* and *Organic Reactions*, which Adams edited. And it gave him exposure to creative administrative arrangements borrowed from the business world; the two serials, for instance, were each owned by private corporations which sold stock to patrons. Adams' key aide in creating Organic Chemical Manufactures was E. H. Volwiler (ACS Pres. 1950), his first Ph.D (1918). In a portent of things to come, Volwiler took employment with a burgeoning Illinois drug company, Abbott Laboratories, where Adams was already (1917) a highly-valued consultant; eventually Volwiler became Chairman of the Board, and Adams' long association with the company culminated in his own election to the Board (1953).

From 1918 to 1926 Adams published 73 scientific papers and trained 45 Ph.Ds, setting the style of a lifetime of creative endeavor. Between 1918 and 1958 he trained 184 Ph.Ds in all. Whereas only 8% of Ira Remsen's students at Johns Hopkins had gone directly into industry, 65% of Adams' students did so. Half of this latter group attained a position of director of research or equivalent, and 14 eventually became members of higher management. Pre-eminent as a chemist was Wallace Carothers (Ph.D 1924) who went first to Harvard, then to Du Pont in 1928 to participate in their new venture into fundamental research. Noteworthy among Adams' pre-World War II students were G. D. Graves (Ph.D 1923) who also had a distinguished career with Du Pont, E. E. Dreyer (Ph.D 1924; eventually vice-President for Research, Colgate, Palmolive, Peet Co.), C. F. Rassweiler (Ph.D 1924; eventually vice-Chairman, Johns Manville Co., ACS Pres. 1958), William H. Lycan (Ph.D 1929; eventually with Johnson & Johnson as vice-Chairman, J&J International), W. E. Hanford (Ph.D 1935; eventually vice-President, Olin Corp.), E. E. Gruber (Ph.D 1937; eventually vice-President, General Tire & Rubber Co.), and T. L. Cairns (Ph.D 1939, eventually Director, Central Research & Development Dept., Du Pont).

Adams himself was convinced that "graduate study is becoming more and more essential as the industries learn to recognize the potentialities of men with this training." In 1941 he emphasized that "the constant flow of new applications of chemistry into almost every industry and the enormous increase in the number of important chemical discoveries in recent years have brought about a rapid development of chemistry and chemical engineering in the United States." The Illinois department—which embraced both chemistry and chemical engineering—exemplified that rapid development. In 1940 it had 38 faculty members and graduated 46 Ph.Ds, 30 of whom took positions in industries ranging from pharmaceuticals to photography, and from steel to textiles. Through his Ph.Ds Adams nourished a network of links with industrialists and industrial concerns, while he him-

[31] John W. Servos, "A Disciplinary Program That Failed: Wilder D. Bancroft and *The Journal of Physical Chemistry*, 1896-1933," *Isis*, 1982, 73, 207-232; Williams Haynes and Edward L. Gordy, eds., *Chemical Industry's Contribution to the Nation: 1635-1935* (Chemical Markets, New York, 1935), pp. 139-143; Skolnik and Reese, *A Century of Chemistry*, pp. 17, 264-265. Bancroft (1867-1953): *DAB*, 1977, 25, 35-37.

[32] Lindeman, *Wealth and Culture*, pp. 72-83.

[33] An excellent biography of Adams (1889-1971) is now available: D. Stanley Tarbell and Ann Tracy Tarbell, *Roger Adams: Scientist and Statesman* (American Chemical Society, Washington, D.C., 1982).

self demonstrated by his actions the potentialities of "men with this training." He consulted on a regular basis for A. E. Staley Co., M. W. Kellogg Co., Coca Cola, Abbott Laboratories, Johnson and Johnson, and Du Pont. Indeed he was instrumental in helping shape Du Pont's effort in basic research, both through his advice and through his supply not only of outstanding leaders (Carothers, Cairns) but also of rank-and-file researchers (for example, in 1940 alone, 3 of his Ph.Ds went to Du Pont).[34]

If, on Adams' definition the duty and one of the primary responsibilities of the university was to train chemists for industry, then industry too had its obligations. One small but important one was to assist in the supply of necessary apparatus and chemicals to the university as when, in 1925, F. W. Willard, the Assistant Superintendent of Development at the Western Electric Company, had 50 gallons of castor oil distillate shipped to the Illinois department "without charge as it is intended for student instruction." More important, indeed central, was industry's role in providing grants for fundamental research, and in supporting students. Adams' success in persuading industrial companies to support graduate work is strikingly displayed in his Department's roster for 1940: aside from 14 post-doctoral fellows supported by Du Pont, the Rockefeller Foundation and the National Research Council, among others, some 28 graduate students enjoyed support from industrial sources that included the Continental Oil Company, Rohm and Haas, and the National Lime Association.

Roger Adams at Illinois found a harmonious way of combining the growing interdependence of academic research and chemical manufacturing in the 1920s and 1930s. Other institutions were not necessarily as convinced of the virtues of such interdependence, nor as imaginative in grappling with problems that inevitably arose when academic and industrial interests found themselves in competition rather than cooperation.

At MIT, a conflict developed between William H. Walker with his Research Laboratory of Applied Chemistry (RLAC), and A. A. Noyes (ACS Pres. 1904) whose own more fundamental Research Laboratory of Physical Chemistry was much less successful in attracting financial support. Walker, Arthur D. Little and Warren K. Lewis pioneered in developing a chemical engineering curriculum ("unit operations", the School of Chemical Engineering Practice) well suited to the practical demands of chemical industry, and MIT baccalaureates in chemical engineering rose from 132 in the period of 1910-1914 to 240 in the Depression years of 1930-1934. Chemical research was correspondingly closely tied to the programs and funding of the RLAC, and its search for narrow answers to specific questions (the leakage from oil barrels, for Vacuum Oil Co.; better greaseproof paper, for the Papercan Corp.). When fundamental research was undertaken, sponsors sometimes refused to allow the publication of results (as when the Humble Oil Company vetoed publication of work on methods for vacuum distillation of lubricating oils). The practical success of chemical engineers and applied research militated against attention to fundamental chemistry: baccalaureates granted in chemistry in 1930-1934 (71) were less than granted in 1900-1904 (78). Leading workers in basic science found MIT unattractive—A. A. Noyes' own migration to Caltech is indicative. Only when the Depression years brought a dramatic decrease in the funding of RLAC ($171,000 in 1926-27, $55,000 in 1931-32) was MIT able to re-chart its course toward emphasizing fundamental research once again, in a way attractive to the best academic minds.[35]

If MIT invested heavily in direct industrial links in the 1920s, the California Institute of Technology took 0½the opposite road, emphasizing "cooperative research" on problems of fundamental scientific importance that crossed disciplinary lines. A. A. Noyes was attracted from MIT to Caltech in part by the existence of the new Gates Chemical Laboratory, one of several laboratories built for the Institute by wealthy Californians. In the 1920s and 30s Noyes, George Ellery Hale and R. A. Millikan built up the resources and prestige of Caltech by emphasizing cooperative research, and by drawing on a *troika* of patrons: the large, private foundations (Carnegie, Rockefeller), local Los Angeles and Pasadena wealth (Gates, Bridge, Robinson), and private industry. The student body was kept small and the Institute emphasized graduate work and a clear focus on research. Noyes was thus able to nourish a preeminent school of research in physical chemistry with students and collaborators like G. N. Lewis, R. C. Tolman, W. D. Coolidge, L. A. Kraus, and Linus Pauling.[36]

The experiences of Illinois, MIT and Caltech suggest something of the vitality and diversity of the system of academic-industrial contacts that had emerged by the 1920s. The California Institute of Technology was supreme in the art of translating private, industrially-derived wealth (Carnegie, Rockefeller, and California locals) into the culturally-applauded triumphs of abstract research. In contrast, Roger Adams found a more direct, harmonious *modus vivendi* between academic ambition and industrial needs, while the

[34]University of Illinois, *Department of Chemistry (University of Illinois Press, Urbana, 1941)*, pp. 10-20, 160-161. Quote appears on page 7.

[35]Servos, "Industrial Relations," pp. 536-549. Noyes (1866-1936): *DSB*, 1974, *10*, 156-157.

[36]John W. Servos, "The Knowledge Corporation: A. A. Noyes and Chemistry at Cal-Tech, 1915-1930," *Ambix* 1976, *23*, 175-186; Linus Pauling, "Fifty Years of Physical Chemistry in the California Institute of Technology," *Annual Review of Physical Chemistry*, 1965, *16*, 1-14; Kargon, "Temple to Science."

experiences of MIT served to underline just how difficult was the sort of balancing act that Adams apparently performed with ease.

Where Adams, Noyes, Hale and their peers at other institutions were in close agreement was in the shared belief that developments in science required a new set of national agencies to coordinate and facilitate the growing venture. However it was to be a national enterprise firmly under private control. As R. A. Millikan put it as early as 1922: "One of the most dangerous tendencies which confronts America today is the apparently growing tendency of her people to get into the habit of calling upon the state to meet all their wants. The genius of the Anglo-Saxon race has in the past lain in the development of individual initiative.[37]

5. *National enterprise and private control*

The experience of World War I fostered a heightened sense of national awareness in the scientific community. Chemists were especially active. Shared experience in the Chemical Warfare Service drew leading young men together, as did the industrial need to manufacture on an emergency basis many chemicals previously imported from Germany. Of particular importance in laying the basis for future scientific cooperation was the National Research Council (NRC), which was jointly supported during the war by private foundations, industry and the federal government. With the war ended, the need for government involvement was over but the desire lived on for private mechanisms to harness national enterprise. The Carnegie Corporation appropriated $1.45M for a permanent building for the NRC, in Washington, and $3.55M for an endowment fund. By 1938 an additional $1.45M had been granted for the Council's operations.

In practice the NRC was largely composed of university professors, and its primary thrust was support of research in the natural sciences. Over the period 1919-38 the Council administered $4.02M in fellowships, and an equal amount in research grants in physics, chemistry, mathematics, and biological and natural sciences. About three-quarters of this money came from Carnegie and Rockefeller funds, with the balance equally divided between other foundations and industrial sources. Once again private, industrially-derived monies were used as a major support of fundamental research. The distinction however was that the funds were under national direction, and distributed on a national basis by mechanisms of peer review.

The jewel in the NRC's crown was its system of National Research Fellowships. These fellowships—financed by $4.8M from the Rockefeller Foundation during the years of their existence, from 1919 to 1951—began with the broad purpose of promoting "fundamental research in physics and chemistry in educational institutions" through the support for one or two years of postdoctoral fellows "who have already demonstrated a high order of ability in research." A. A. Noyes, Wilder D. Bancroft, and Roger Adams were among those influential in directing the award of fellowships in chemistry. Their aim was unabashedly elitist—the use of private funds, on a national basis, to support extraordinary talent and to build a world-reputation for American science. The fellows (between 20 and 88 a year in all sciences, in the era 1920-40, with 1931 as the peak year) tended to cluster at certain favored institutions—the chemists at Berkeley, Harvard, and Caltech—thus reinforcing the values the scheme's sponsors wished to promote.[38]

The NRC also created an Industrial Advisory Commission, including George Eastman, Andrew W. Mellon, and Pierre S. du Pont, which, it was hoped, would solicit funds from industry for the support of academic research in a way that would reinforce the scheme of National Research Fellowships. However the Commission was not a success. Undeterred, George Ellery Hale set to work in the early 1920s to create a National Research Fund, based on the conviction that without pure science the whole system of industrial progress would dry up. That belief was endorsed by the trustees of the proposed fund, including its secretary, Herbert Hoover. Their aim was to raise $20M from industry for the support of research, to be distributed in grants modelled after the system of National Research Fellowships. The campaign began in earnest in 1926, but the pledges never amounted to the $20M hoped for and, with the onset of the Depression, the whole scheme collapsed.[39]

The ambition for a National Research Fund financed by industry reveals how strong was the sense of the need for *national* enterprise transcending the desires of particular individuals and institutions, and the sense of the possibilities and appropriateness of industrial support of academic science. The failure of that ambition in turn underlines the limitations of industrial patronage. In this same era of the 1920s and 30s MIT was finding that individual companies preferred research that was specifically harnessed to their own concerns (better grease-proof paper) and that if the research possessed an industry-wide utility (vacuum distillation techniques for lubricating oils), the sponsoring company had no wish to see publication of results, and destruction of its competitive advantage. To put it differently, no sponsoring company wished to finance those "externalities of benefit" which would accrue to its competitors through the

[37]Quoted in Kargon, "Temple to Science," p. 15.

[38]For an informal history of the fellowships, see Myron J. Rand, "The National Research Fellowships," *Scientific Monthly*, 1951, *73*, 71-80.

[39]See Lance E. Davis and Daniel J. Kevles, "The National Research Fund: A Case Study in the Industrial Support of Academic Science," *Minerva*, 1974, *12*, 207-220.

open publication of research for which it had paid. This fact of economic life meant that industrial leaders might applaud the idea of a National Research Fund and agree that science was the mother of invention, but they were unwilling to commit the resources of their individual firms to an activity that would not yield them exclusive or privileged benefit. Support of particular academic institutions for reasons of sentiment via endowment or recurrent gifts from private individuals (Eastman, Du Pont, Nichols, etc.) was one thing. Commitment of company money to a National Research Fund was something else. For it did not promise any exclusive or special privilege of the kind that could be gained through direct support of individual universities and departments, through, say, fellowships with their promise of a competitive edge in recruitment. The problem of externalities of benefit set one sharp limit on the extent and character of industrial monies for academic research.

If a voluntary National Research Fund could only fully work when all firms contributed in some proportionate way, such a voluntary fund was not the only way of raising the necessary funds on a national basis. National fund raising was of course well entrenched even in the 1920s, via the taxing power of the federal government. And, already in the 1920s, and 1930s, the government was funding basic research in a number of areas, and thereby allowing industrial and commercial firms at work in those areas a means of internalizing the externalities of benefit. Those areas of government interest, and the whole idea of federal funding of research, took on a new saliency in the 1930s as the Depression sharply limited all but the most essential corporate expenditures, and "New Dealers" experimented with remedies for what seemed to be glaring defects in the American way of doing business.

The Department of Agriculture for one, had a long tradition of supporting scientific research—its budget for this activity already stood at $11.2M in 1929. By 1939 that figure had increased to nearly $20M and, thanks to the Bankhead-Jones Act of 1935, $4M of that sum was for the first time specifically allocated to basic research. One aim of that research was to find new industrial (chemical) uses for surplus farm products—a program also vigorously urged by the Farm Chemurgic Council, which included luminaries like Roger Adams. In 1938 the Department of Agriculture also began to extablish regional research laboratories.[40]

More contentious was the effort to establish basic research within the National Bureau of Standards. Between 1935 and 1941 its Director, Lyman J. Briggs, pressed the argument that there was "an *essential place* in Government for basic research in physics and chemistry in order to provide the foundations for new industries." The sort of research Briggs had in mind lay between the fundamental research undertaken in the universities and the applied research carried out by industries seeking answers to their immediate problems. The research "must be quite fundamental in character" but have "some distant practical objective", and the National Bureau of Standards was its proper home. Briggs' plan drew on the earlier "Recovery Plan of Science Progress" presented in 1933 by Roosevelt's Science Advisory Board. That plan—never implemented—proposed that the federal government spend $16M over six years "in support of research in the natural sciences and their applications." The funds were to be assigned as far as possible to university laboratories, through a special committee of the National Research Council: national enterprise under private control, once again.

Briggs proposed an annual Congressional appropriation that would grow to $5M after five years, with half to be spent in the Bureau of Standards, and half dispersed through contracts. The Bankhead-Jones Act offered an encouraging precedent, and the failure of the National Research Fund indicated the need for action by the government. However Briggs was unable to win Congressional support for his ideas, in part because of infighting between the Bureau of Standards and other agencies that felt their interests threatened by his proposal (Agriculture, Labor). Also troubling were questions as to how political control and the desire for geographical equity might influence the distribution of contracts, and why such research should not be supported by a fresh, direct tax on the industries that would benefit. The Agriculture Secretary, Henry A. Wallace, might announce in 1936 that "today one of the major functions of government" was to support basic research "wherever it may lead, for the ultimate good of all the people." However in the 1930s that belief seemed rather to threaten traditional American values and an academic-industrial system with many triumphs to its credit, than to point to new worlds of opportunity. It was only through the experience of World War II that those opportunities were plainly revealed.[41]

C. The Influence of War

1. *World War I and the return to normalcy*

The First World War had a profound effect on the nation's science. The 1914 award of the Nobel prize to Harvard scientist Theodore W. Richards—the first Nobel award to an American chemist—was one early indicator of the changing position of America in relation to Euro-

[40]Carroll W. Pursell, Jr., "The Administration of Science in the Department of Agriculture, 1933-1940." *Agricultural History*, 1968, 42, 231-240.

[41]Carroll W. Pursell, Jr., "A Preface to Government Support of Research and Development: Research Legislation and the National Bureau of Standards, 1935-41," *Technology and Culture*, 1968, 9, 145-164. Quotes appear on pages 145 and 148.

pean research.[42] The war laid waste to areas of Europe, bled her resources, and delivered damaging blows from which Germany, her leading scientific nation, was never fully to recover. In contrast, American involvement in the war was distant, and comparatively brief. Mobilization of the nation's scientists and especially its chemists was more of an adventure than a sustained enterprise with profound results or compelling practical implications. Recruitment of chemists under military auspices in 1918, to man the Chemical Warfare Service, worked surprisingly well. The government's own emergency program to build nitrogen fixation plants also set an interesting precedent. The nitrogen program cost $107M and delivered only one plant, operating on an experimental basis, when the Armistice intervened. However the program hinted at what might be achieved if scientific knowledge, industrial skills and government money were to be applied to difficult but technically feasible problems.[43]

It was to take a far longer war, in which American interests were more obviously at stake and scientific knowledge was a more familiar key, before the union of science, industry and government would take hold on a lasting basis. Instead the scientific legacy of World War I lay with those individuals who were newly aware of the national character of their work, and newly convinced that American science in the twentieth century was destined to take on the world leadership that had lain in Europe for over three hundred years. The National Research Council was the most obvious symbol of this awareness. The NRC advocated national enterprise under private control, in keeping with the common desire for "normalcy" which followed the experience of World War I. The federal role was seen as properly one of very modest support in certain areas (notably, agriculture) and coordination rather than direction of private initiatives (as in the National Advisory Committee for Aeronautics, founded in 1915 and continued in peacetime). In the 1920s and 30s the NRC reinforced rather than disturbed the belief that the American system of academic-industrial relations, and indeed the health of the whole of American science, was a question best left in private hands. At the same time the NRC fostered that sense of national community which provided the basis for massive, rapid, and efficient government direction of academic and industrial aspects of science when the outbreak of World War II rendered such direction a matter of overriding national importance.

2. *Science and government in World War II*

World War II brought about a fusion of academic research, industrial production, and government finance on a hitherto unprecedented scale. The atomic bomb, radar, napalm, and buna-S rubber were some of the more obvious outcomes. It turned out that the ends fully justified the means, but those means were initially regarded with surprise. J. B. Conant recorded how—recalling his 1918 work in the Chemical Warfare Service—"I had imagined, as war drew near, that many of my scientific friends and perhaps, I myself would once again put on a uniform."[44] Instead, in June 1940, under the leadership of Vannevar Bush, a convinced Republican and president of the Carnegie Institution of Washington, a National Defense Research Committee (NDRC) was formed by President Roosevelt.[45] And—in a way symbolic of the previous era—the Committee's first, and for many months sole salaried staff member (its executive secretary) was financed by the Carnegie Corporation.

Conant well summarized one view of the realities that the NDRC came to express:

> Forgetting (if one can) the contribution of the NDRC to the winning of the war, it is clear that the creation of the committee marked the beginning of a revolution. The mode of the committee's operation. . .has had a transforming effect on the relation of the universities to the federal government. The pattern set has made the postwar world of American science entirely different from that of the prewar years. The essence of the revolution was the shift in 1940 from expanding research in government laboratories, to private enterprise and the use of federal money to support work in universities and scientific institutes through contractual agreements.

Bush insisted from the start that, rather than building and staffing government laboratories, the NDRC would "write contracts with universities, research institutes and industrial laboratories." In this way the theme of dispersed, privately controlled activity was carried over from the prewar era. In some ways the NDRC fulfilled the functions of the hoped-for National Research Fund of the 1920s, or of the 1933 "Recovery Plan of Science Progress." In other ways it built on Bush's experience as a member of the National Advisory Committee for Aeronautics. But the size and scale of the problems confronted by the NDRC, and the speed with which it pushed toward solutions, were wholly without precedent.

The inner core of the NDRC consisted of a physicist (Karl Compton, MIT President), a chemist (Conant, Harvard President), and an engineer (Frank Jewett, Director of the Bell Telephone Laboratories, NAS President), together with Bush and Dr. Richard Tolman of

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[42] Richards (1868-1928): *DSB*, 1975, *11*, 416-418.

[43] Skolnik & Reese, *A Century of Chemistry*, pp. 146-147.

[44] James B. Conant, *My Several Lives: Memoirs of a Social Inventor* (Harper & Row, New York, 1970), p. 236. Conant (1893-1978): *WWW*, 1981, 7, 121.

[45] Some of Bush's personal views may be found in his memoirs, entitled *Pieces of the Action* (William Morrow & Co., New York, 1970). Bush (1890-1974): *WWW*, 1976, 6, 63.

Caltech.[46] Conant himself had charge of the Chemical Division—Division B (Bombs, Fuels, Gases, Chemical Problems). He found it quite natural to enlist as his first two colleagues in supervising the work of the Division, Warren K. Lewis and Roger Adams. They in turn recruited scores of their influential colleagues and students in key institutions.[47] The result was that, over the years from 1940 to 1945, hundreds and thousands of chemists, chemical engineers and other scientists became intimately familiar with the idea of research in universities and independent institutes being funded by the government, and of priorities in research being set by those most scientifically equipped to judge the outcome. The NDRC was joined in July 1941 by a Committee on Medical Research (CMR). NDRC and CMR together formed a new Office of Scientific Research and Development (OSRD), charged not only with necessary research but also with the development of new weapons. The result was a vast increase in the scale of activity, and in the number and intensity of contacts between academics and industrialists.

In the period to June 1945 OSRD was responsible for over seven hundred contracts with non-industrial organizations, ranging from 75 contracts with a value of $116M channelled through MIT and 48 contracts for $83M at Caltech to 9 contracts ($1.1M) at the University of New Mexico and 15 contracts ($1.1M) at Battelle Memorial Institute.[48] The CMR wing of the organization alone wrote contracts for $2.3M of chemical research in universities and other institutions, as part of the overall $25M it committed between 1941 and 1947. And CMR could point with pride to the results of its wartime work—in the development and wide use of penicillin, sulfonamides, gamma globulin, adrenal steroids and cortisone, among other drugs and techniques.[49]

The success of the Manhattan Project, of work on the production of synthetic rubber, of the development of new drugs, and of a host of lesser schemes made plain for all to see that science was an essential key both to national defense and to economic prosperity in the modern state. The question faced in 1945, and argued out explicitly before Congress and elsewhere in the period up to 1950, was to define the proper modes by which the state might secure its interests in these areas, given the realities of America's pluralistic system of academic-industrial relations. The answers were not arrived at easily, nor did they command complete consensus. However those answers were built out of wartime experience with the funding of research by government, and they were answers that underwrote a new era of unparalleled intellectual achievement in the basic sciences.

3. *The new social contract*

Just as Vannevar Bush was central to OSRD, and shaped its style, so he set out a widely-influential program for postwar research in his *Science—the Endless Frontier*.[50] The elitist style of OSRD had already aroused Congressional criticism when, in the fall of 1942, Senator Harley M. Kilgore introduced a "Technology Mobilization Bill." The critics wanted several disparate things—a fairer deal for small business and the lone inventor, and a more professional "Office of Technological Mobilization" to curb the alleged waste of scientific manpower and the unhealthy concentration of research and development contracts, together with the "giveaway" of patents to private companies. By the summer of 1943 Senator Kilgore was focusing on an Office of Scientific and Technological Mobilization (OSTM) which would coordinate the scientific and technical agencies of the federal government. The intention was, *inter alia*, for OSTM to finance through grants and loans scientific and technical education and the advancement of pure and applied research. Kilgore believed that the prevailing system of academic-industrial relations had reduced much university research to "the status of handmaiden for corporate or industrial research, and has resulted in corporate control of many of our schools."[51]

In contrast, the National Association of Manufacturers saw Kilgore's ideas as an attempt to "socialize" all of science in the United States. The Army and Navy also greatly disliked the idea of a civilian-dominated agency being in control of the development of military technology. Most scientists also disliked the Kilgore bill, though few went as far as Frank Jewett, president of the National Academy of Sciences, who claimed that scientists were unalterably opposed "to being made

[46] Conant, *My Several Lives*, pp. 234-238; Carroll Pursell, "Science Agencies in World War II: the OSRD and its Challengers" in Nathan Reingold, ed., *The Sciences in the American Context: New Perspectives* (Smithsonian Institution Press, Washington, D.C. 1979), pp. 359-378.

[47] See W. A. Noyes, ed., *Chemistry: A History of the Chemistry Components of the National Defense Research Committee, 1940-1946* (Little, Brown & Co., Boston, 1948).

[48] James Phinney Baxter 3rd, *Scientists Against Time* (Little, Brown & Co., Boston, 1946), p. 456. See also Irvin Stewart, *Organizing Scientific Research for War: The Administrative History of the Office of Scientific Research and Development* (Little, Brown & Co., Boston, 1948).

[49] Stephen P. Strickland, *Politics, Science, and Dread Disease: A Short History of United States Medical Research Policy* (Harvard University Press, Cambridge, Mass., 1965), p. 16.

[50] Vannevar Bush, *Science—The Endless Frontier* (Government Printing Office, Washington, D.C., 1945). The paragraphs that follow draw heavily on Daniel J. Kevles, "The National Science Foundation and the Debate over Postwar Research Policy, 1942-1945," *Isis*, 1977, 68, 5-26. See also J. Merton England, *A Patron for Pure Science, The National Science Foundation's Formative Years, 1945-57.* (National Science Foundation, Washington, D.C. 1982), Strickland, *Politics, Science, and Dread Disease*, and Skolnik & Reese, *A Century of Chemistry*, pp. 149-150.

[51] Quoted in Kevles, "The National Science Foundation," p. 10.

the intellectual slaves of the state" and considered federal aid to academic research a threat to the freedom of science. What most scientists rather feared was, in the words of J. B. Conant, "coordinating agencies with dictatorial powers. . .a peacetime scientific general staff."[52] As events were to prove, they had far less objection to federal funding itself.

Late in 1943 Vannevar Bush wrote to Kilgore, setting out his own ideas about postwar needs—needs centered on coordinating rather than controlling the federal agencies concerned with science; on having a scientific advisory system in the federal government, but one staffed by the best—and hence most disinterested—scientists rather than by representatives of labor, small business or consumers; and on federal support for academic research and training, to advance the work of the intellectually most talented. The new bill for a National Science Foundation that Kilgore drafted early in 1944 conceded much ground to Bush and other critics. However there was still one fundamental disagreement—Kilgore wanted a foundation responsive to lay control and directly interested in research that would advance the general welfare; Bush and his allies wanted an agency run by scientists mainly for the purpose of advancing science, for they believed that such an agency would best serve the public good as talented and disinterested individuals created new knowledge available to all. It was in this context, and with a deliberate eye to its political utilities, that on 20 November 1944 President Roosevelt released a letter drafted by Bush which invited the latter's ideas on the peacetime implications of OSRD. Bush responded by commissioning carefully constructed task forces of scientists and industrialists, and with his own tract on *Science—The Endless Frontier* which was published to widespread applause in July 1945. By then, Bush and his friends were deeply convinced that federal support of basic research was a necessity, that universities were the proper home of that research, that a foundation insulated from geographic and populist pressures was the appropriate agent of federal largesse, and that peer review mechanisms would support the pursuit of academic excellence.

In practice, political contention meant that it was not until May 1950 that the National Science Foundation became a reality. By then, quite separate initiatives had split off both medical and military research, which were to be sponsored and pursued by other federal agencies. The immediate postwar period of confusion about proper peacetime practices thus gave rise to a pluralism in the federal means of support of academic research which nicely matched the pluralism of private patronage. By the early 1950s academic scientists were able to seek support from an array of federal agencies—including Agriculture, Commerce, Defense, and the Atomic Energy Commission—as well as from the National Science Foundation and the National Institutes of Health. This pluralism was soon combined with Cold-War demands for scientific strength, consumerist wishes for better health, and baby-boom desires for improved educational facilities. The result was an escalation of federal support for science in a way not foreseen by even the most farsighted visionary in 1940. The result was also to downgrade the importance of industrial support of academic work, even as that support continued to grow in absolute amount and in the variety of its forms.

The change in scale and in priorities may be seen by contrasting the state of affairs in the late 1950s with that of 1930. In 1930, the national budget from all sources for scientific research and development of all kinds was roughly $166M. Industry provided 70 percent of the funds, while the federal government underwrote only 15 percent. Ten years later, industry still provided two thirds of the money. The government share had increased slightly to one-fifth, but the total was still only about $345M. Wartime mobilization changed this radically, as government research expenditures climbed to $720M in 1944. By the late 1950s, U.S. expenditures on research and development reached ten billion dollars (over twenty times greater than prewar levels, in constant dollars) and government supplied two thirds of the money.[53]

A change of such magnitude was equivalent to the ratification of a new social contract for basic science. That contract still involved academics, industrialists and the federal government. But all parties were now agreed that government (through taxation) was the major internalizer of the "externalities of benefit" deriving from basic research. And it was to be the direct defense- and education-related needs of government which would dominate the contract for almost three decades after World War II.

D. The Era of Growing Federal Support, 1950-1965

1. *The expansion of academe*

It was anticipated that, following World War II, there would be a short-lived surge in undergraduate enrollments as those who had deferred attendance sought necessary credentials for civilian, peacetime careers. Thanks to the G.I. Bill, the surge duly occurred. However what had not been anticipated was the way in which postwar prosperity would encourage marriage and with it the childbearing that had also been deferred from the Depression years. A rising birthrate (with peaks of 3,817,000 births in 1947 and 4,208,000 in

[52] Quotations from Kevles, "The National Science Foundation," pp. 11-12.

[53] The argument of this paragraph depends on Sturchio, *Chemists and Industry*, p. 216.

1957) brought with it a heightened demand for teachers—initially on the nursery and elementary levels but, from the late 1950s, on the high school and college levels too.

Demand for teachers (that is, college graduates) implied an increased need of those who in their turn would teach the teachers. Ph.Ds in the sciences and in engineering subjects we're among those required to staff the expanding universities, and in a familiar process, the academic expension on this more advanced level also fed on itself in the years of postwar prosperity. The National Defense Education Act that followed the 1957 launching of the Soviet *Sputnik* was but one of the many mechanisms by which college and graduate school were made more accessible to thousands of students, and the supply of Ph.D.s boosted to meet an escalating demand. At the same time, the expansion of high technology industries and the needs of the Cold War increased still further the demand for scientists and engineers. Doctorates granted in chemistry had averaged under 500 a year in the late 1920s: by 1960 the figure was 1,062 and rising strongly.[54]

The 1950s and early 1960s were years of relatively untroubled expansion for the nation's research universities. With both new Ph.Ds and senior professors being keenly competed for by rival academic institutions, the research ethos was emphasized heavily. It was not only that many of the best scientists valued fundamental research more highly than anything else. It was also that, because of the peer review system and the growth of federal support, individual scientists brought funds and overhead with them if they moved from institution to institution. Buying scientific "stars" might help rather than hurt a university's budget while also serving to enhance the institution's reputation.

2. *NSF, NIH and basic research*

The change in the scale, and the modes of financing, of university work between 1940 and the mid-sixties was nothing short of extraordinary. While the total educational and general income of colleges and universities trebled between 1940 and 1950, the federal contribution multiplied more than thirteenfold (from $39M to $524M). By 1950, government on all levels (and principally the federal government) was estimated to be meeting 60 percent of the total cost of higher education, and far surpassing private philanthropy or industrial giving as a source of support.

In the 1950s and early 60s federal support for research grew rapidly. One estimate suggests that total federal support for basic research increased from $201M in 1956 to $1,782M in 1964. In the latter year, federal funds for basic research in chemistry were estimated at $100M. By way of contrast the *whole chemical industry of the United States* was estimated to be spending only $110-$115M of its own money on basic research that year (though industry itself also obtained at least 25% of the funds that the federal government committed to chemical research).

It seems that, of the $100M the federal government spent on basic research in chemistry, about half went to universities, principally in research grants distributed by the system of peer review. The pluralism of the system, and the variety of federal agencies involved, may be seen from Table 4. That table shows how, in 1964, nine federal agencies each contributed $1M or more to basic research in university chemistry, with the National Institutes of Health and the National Science Foundation providing more than $10M each. In contrast, the universities themselves contributed a maximum of $8.3M to chemical research, while private foundations provided $4.7M, and industrial support of basic chemical research on campus amounted to $2.5M, just 5% of the federal total.[55]

The rapid growth of federal support helped to underwrite a major flowering of chemical research in which, by 1960, the United States was the dominating world power. It also fed two contradictory moods. On the one hand, certain observers understood that an era of such rapid growth must have its terminus. On the other hand, scientists engaged in academic work saw mainly the need for still further funds to exploit ramifying opportunities.

Early in 1965, Harvey Brooks pointed out that "as a fraction of the gross national product, research and

Table 4

Sources of Explicit Research Funds (in millions), 1964

Federal Agencies		*University*	$ 8.3
NIH	$13.8	*Industry*	$ 2.3
NSF	11.3	(Hidden Support)	0.2
AEC off-site	9.4		
AEC on-site	3.5		
AFOSR	3.5	Total	$ 2.5
NASA	1.8		
ARO (D)	2.0	*Other*	
ONR	1.4		
ARPA	1.0	PRF	$ 1.9
Other	1.6	Other foundations	2.4
Overhead	0.9	Other	0.3
(Hidden Support)	2.1	(Hidden Support)	0.1
Total	$51.3	Total	$ 4.7
		Grand Total	$66.8

SOURCE: Adapted from Table F1, *Chemistry: Opportunities and Needs*, p. 217.

[54]Bud et al., *Chemistry in America*, p. 289.

[55]Frank H. Westheimer, ed., *Chemistry: Opportunities and Needs: A Report on Basic Research in U.S. Chemistry* (National Academy of Sciences-National Research Council, Washington, D.C., 1965). See pp. 164, 217, etc.

development activities are nearly three times what they were during the peak of effort toward the end of World War II. . .federal expenditures have been doubling in about six years. It is obvious to ask whether there is any natural or logical limit to this trend. It is hard to see what it is, or should be. . ." However, "the slowed growth of federal funds for general science, the kind on which most graduate students are trained" ("little science") was coming into collision with "rapidly rising aspirations and expectations on the part of universities. . .Typically, institutions plan to expand faculty by 50 percent, and graduate students by 30 percent. . .in the next five years."[56]

The NRC Committee on Science and Public Policy, a group composed of leading university professors with one lone representative from industry, concurred in the belief that the federal government was the patron who should meet the growing needs of "little science." Its 1965 "Westheimer report" on *Chemistry: Opportunities and Needs* pointed out that only 33.2% of grant requests in chemistry were fully or partly funded by NSF in 1963, and argued that "the careers of young investigators are stifled for lack of funds." The Committee felt that "chemistry. . .has outgrown its resources." Looking back over 10 years of extraordinary growth in federal support with a compounded annual growth rate of 16%, the report concluded: "the Committee feels strongly that even a 16 percent rate of increase will prove inadequate to achieve the proper growth of U S chemistry."[57]

The sentiments of the Westheimer report provide an interesting indicator of academic hopes in 1965, if not of political realities in a nation beginning to face campus unrest and about to confront the strains of the Vietnam War. The report also indicates the changed position of industrial support of academic research, for that support was simply not a matter that the committee pursued in any detail.

3. *Industrial research*

In the 1950s and 60s the chemical process industries continued to play a major role in the still-growing employment of industrial chemists. Within the chemical process industries, the chemicals and allied products group became increasingly important: the proportion of *all* industrial chemists employed in the latter group increased from one-third to one-half in the years from 1950 to 1970. Chemicals and allied products accounted for 52 percent of the growth in industrial employment of chemists over the twenty-year period, and for 81 percent of the increase in chemists employed in the chemical process industries (see Table 5).

The growing importance of chemists within the chemicals and allied products group is confirmed by an examination of total employment in the industry. Chemists constituted a growing fraction of a growing labor force, increasing from about 208 per ten thousand employees in 1950 to over 480 in the mid-1960s. This indicator displays in microcosm the increasing importance of chemical skills and knowledge within the industrial economy and hints at the steadily growing importance of all varieties of industrial research. Another indicator that points to the same phenomenon is company funds committed to research and development activity In 1957, firms in chemical and allied products spent $616M; by 1964 the figure was $1,082M.[58]

Whereas industrial employers in the Depression years had found it comparatively straightforward to recruit able PhD chemists, they faced a changed competitive position in the postwar era, even as they possessed convincing evidence of the worth of basic research. One result was that major employers—firms like Exxon, General Electric and Du Pont—chose to emphasize how like academic research their own work was. Extensive new research laboratories were built, often in campus-like settings remote from actual industrial plants, and "blue sky research" aimed at unspecified, distant targets was much in vogue. From the early 1960s a reaction set in, as much of that research failed to yield economically valuable discoveries. The consequence was disillusionment, and a widening gulf between academic and industrial preoccupations.

Even so, about 8 percent of industrial chemists were employed in basic research in 1964, according to one estimate. And these chemists contributed about 30 percent of American publications on chemical research.[59] Some of this basic research was financed by the federal government (perhaps 25%), for just as federal grants to universities were one outcome of World War II so too were government contracts to industrial firms with the capacity to undertake basic research in areas of interest to such agencies as the Atomic Energy Commission, the armed services, and the National Aeronautics and Space Administration. The new social contract thus involved changed forms of interaction among academe, industry and government. These forms were strengthened and routinized as university professors not only acted as consultants to industrial firms on the concerns of these firms but participated in federally funded industrial research, and sat on appropriate government advisory panels. However industrial and academic interests moved further apart in certain ways, as the availability of federal funds to both academic and industrial researchers served to

[56] Harvey Brooks, "Effects of Current Trends on the Support of Research," in *Effects of Current Trends on the Support of Research*, (National Research Council, Washington, D.C., 1965), p. 4.

[57] *Chemistry: Opportunities and Needs*, pp. 185, 188.

[58] Sturchio, *Chemists and Industry*, p. 311.

[59] *Chemistry: Opportunities and Needs*, pp. 157-159.

Table 5

Chemists in the Chemical Process Industries, 1950-1970

Year	*Food and kindred products*	*Paper and allied products*	*Chemicals and allied products*	*Petroleum refining*	*Rubber and products*	*Stone clay and glass*	*Primary metals*	*Total*[a]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Number (Thousands)								
1950	2.9	1.5	13.4	2.3	1.6	0.9	2.0	24.6
1955	3.6	2.1	23.7	3.5	2.0	1.2	2.3	38.4
1960	4.4	2.8	32.0	3.9	2.2	1.5	2.7	49.5
1965	4.5	2.9	37.8	3.4	2.8	1.5	2.2	55.1
1970	4.5	3.6	42.8	3.2	3.0	1.5	2.4	61.0
B. As percentage of total chemists in industry								
1950	7.9	4.1	36.6	6.3	4.4	2.5	5.5	67.2
1955	6.5	3.8	43.0	6.4	3.6	2.2	4.2	69.7
1960	6.1	3.9	44.4	5.4	3.1	2.1	3.7	68.7
1965	5.3	3.4	44.7	4.0	3.3	1.8	2.6	65.2
1970	4.8	3.9	45.8	3.4	3.2	1.6	2.6	65.2

[a] Detail may not add to total because of rounding adjustments.

SOURCE: *Bud et al., Chemistry in America.*

insulate the two groups from an anxious concern with each other's agendas.

4. *Research associations and technological research institutes*

A comparatively small but not unimportant quantity of basic research in chemistry, as in the other sciences, continued to be conducted in a growing variety of private institutions. By 1964, seventeen major non-profit research institutions estimated their annual expenditure for basic research in chemistry to total $10M. These seventeen institutions employed about 1000 chemists, with over 40% engaged in basic research.[60]

The research institutes in question included such older, industrially-oriented organizations as the Battelle Memorial Institute, the Franklin Institute (where the Laboratories for Research and Development began contract research in 1946) and the Mellon Institute. All enjoyed substantial growth in the 1950s and 60s—Battelle for instance increased its research space from 500,000 to 900,000 square feet between 1950 and 1960 while establishing European branches in Geneva and Frankfurt, each with several hundred staff members. By 1958 Battelle had moved sufficiently beyond its original concern with metallurgy to begin work on chemotherapy for the cancer research program of NIH. The somewhat newer Armour Research Foundation had $11.0M of "research volume" and 445 staff members by 1956; by 1961 its income had grown to $16M and its research contracts were undertaken by a staff of 1,250 organized into six divisions, including chemistry, and metals and ceramics research. Though quite separate from the Illinois Institute of Technology, the Armour Research Foundation answered to the same board of trustees and in 1963 it was renamed the IIT Research Institute: yet another illustration of the varieties of linkage in the academic-government-industrial system.[61]

The most successful of the campus-linked institutes was the Stanford Research Institute (SRI), which was founded in 1946 by the trustees of Stanford University at the request, and with the support of a group of industrial leaders. Initially it was governed by a board of directors elected by the Stanford trustees, with the university president as chairman. The aim of SRI was "to promote and foster the application of science in the development of commerce, trade, and industry." The institute began life with a $1/2M loan from the university, and a staff of three. Funds for buildings and facilities were provided for by the SRI Associates Plan (itself a variant of the Technology Plan introduced by MIT almost fifty years earlier), through which companies and individuals provide $15,000 for membership. By 1960 over $2.7M had been contributed, and the list of corporate members contained names of many large companies. By 1960 too, SRI had 1800 permanent employees and had handled over $100M in assignments. The success of SRI testified to the continuing vitality of academic-industrial connections. At the same time the Institute depended heavily on the

[60] *Chemistry: Opportunities and Needs*, p. 162.

[61] Harold Vagtborg, *Research and American Industrial Development* (Pergamon Press, New York, 1976), p. 219.

availability of government contracts. That reality, and the fact that Stanford University chose to sever its links with SRI in 1970, indicate how direct links between the universities and industrial concerns were no longer a high-priority matter in the 1960s.[62]

Other research institutes with a specific geographical locus rather than an explicit university connection also appeared in this era. The Midwest Research Institute began in July 1944, in Kansas City, Missouri, close by the Kansas City University. By 1960 it had 273 employees and a "research volume" of $2.3M. Contracts from the armed services and other government agencies were especially important to its growth. The Southern Research Institute of Birmingham, Alabama, was organized in 1941 but did not begin operations until 1945. Its capital fund—contributed primarily by area industries—exceeded $4M by 1960, while its almost 400 employees worked on some $3 1/2M of contracts in eight divisions including metallurgy, biochemistry, organic chemistry, chemotherapy, and applied chemistry. Finally, the Southwest Research Institute, organized in San Antonio, Texas, in 1947, had over 500 employees by 1960. Approximately 45 percent of its income came from industry and other non-government sources, while the remainder came from military and civilian agencies of government. Characteristically, its staff members published actively, held office in a variety of learned and professional societies, and offered numerous courses both in local universities and as far away as the University of California and the Massachusetts Institute of Technology.[63]

Technological research institutes connected with a particular academic institute (Armour, SRI, Mellon) flourished in this era, as did those with a specific regional concern (Franklin, Battelle, Southern, Midwest, Southwest). A third form of organization of growing importance was the institute with ties to an industrial trade association, and devoted to a particular industry or technology, as the Institute of Paper Chemistry, the Institute of Rubber Research, or the Textile Research Institute. One final group of considerable interest to science in general—though not so much to chemistry in particular—was that group of institutes like the Jet Propulsion Laboratory (Caltech), the Lawrence Radiation Laboratory (University of California), the Institute for Atomic Research (Iowa State University), and the Cornell Aeronautical Laboratory (Cornell University). These latter institutes depended primarily on government funds and undertook work of immediate interest to the defense of the nation. While of great importance to the evolving academic-government-industrial system, they lie outside the scope of this history.[64]

5. *Old themes and new variations*

The essential continuities that linked the new social contract to its prewar roots, and the reality of the changes in the relations of academe, industry and government may be seen refracted in the later career of Roger Adams.

Adams has been a member of Roosevelt's Science Advisory Board in 1934-35, and had played a key role in the NDRC from its earliest days. He was thus familiar with the theories and the realities of the links between government and the research universities, and able to help in shaping early NSF policy toward both science and industry from his position as a member of the National Science Board (1954-1960). The fact that he also joined the board of the Battelle Memorial Institute in 1953 meant that he was cognizant of the opportunities that faced the nonprofit research institutes. For instance, he was able to prevail against opposing views in NSF and to guard the tax-free status of these institutes.[65]

Adams believed wholeheartedly in the virtues of private enterprise, and of the necessity to seek out, reward and nurture scientific talent. It was therefore natural for him to play a major role in helping to shape three philanthropic ventures which were to be major supports of postwar chemistry in academe and which—but for federal largesse—would have loomed even larger in the consciousness of chemists committed to basic research.

As a member of the American Chemical Society Board of Directors from 1940 to 1950, Adams was intimately involved in the negotiations that led to the creation of the Petroleum Research Fund (PRF) to support "advanced scientific education and fundamental research in the 'petroleum field'." The monies in the fund derived from successful innovations in the petroleum industry, and were administered as an endowment by the ACS: by 1976 the PRF had given more than $60M for chemical research.[66] Adams was also appointed a trustee of the Robert A. Welch Foundation. This foundation—established in 1954 with the fortune of a Texas oilman—was to devote itself to fundamental research in chemistry. By 1976 it was to report assets of $123.5M and expenses of $7.5M or "approximately forty percent of all private foundation funds devoted to the direct pursuit of non-mission oriented basic

[62] Lesher, *Independent Research Institutes*, pp. 79-86, 95-99. See also Weldon B. Gibson, *SRI, The Founding Years* (Publishing Services Center, Los Altos, CA 1980).

[63] Lesher, *Independent Research Institutes*, pp. 86-93, 100-102.

[64] For a discussion of federal research and development centers see Orlans, *The Nonprofit Research Institute*.

[65] Tarbell and Tarbell, *Roger Adams*, p. 188.

[66] Skolnik and Reese, *A Century of Chemistry*, pp. 34-35.

chemical research in colleges and universities."[67] Finally we should note Adams' key role in shaping the program of post-doctoral fellowships offered by the Sloan Foundation. In keeping with Adams' vision, these highly-regarded fellowships allow their recipients unfettered freedom to pursue their own basic research.[68]

The examples of the PRF, the Welch Foundation, and the Sloan fellowships indicate how older forms of private philanthropy continued a flow of funds from industrial fortunes into academic research. If such philanthropy did not enjoy the limelight afforded to earlier ventures associated with Carnegie and Rockefeller, it was nonetheless important to the continued health of chemical research and to the pluralistic character that informed the American system even in the days of greatest growth in government support of academic science.

E. A New Consolidation, 1965-1980

1. *Academic steady state*

By the late 1960s it was apparent that the boom days were over for federal financing of academic research. The rapid buildup in enrollments and in political support for all forms of higher education were coming to an end. In 1970 the numbers of Ph.Ds in chemistry (2208) and chemical engineering (438) reached a peak; by 1979 the figures had fallen back some twenty-five percent. However the number of baccalaureates awarded in chemistry remained steady (11,617 in 1970; 11,643 in 1979) and in chemical engineering it rose significantly (3,720 in 1970; 5,655 in 1979).[69] As these statistics suggest, what had changed was not so much the overall size or the teaching mission of the university but its relative attractiveness as a site for research.

Overall federal spending for basic research in all fields had reached a record $2415M by 1965, from only $1030M as late as 1960. After 1965, further growth was painfully slow—a peak of $2837M in 1968 was not surpassed until 1978, with $2921M. However in every year federal spending dwarfed all other sources combined (1965, $2415M to $1001M; 1978, $2921M to $1090M). As the major recipients of federal monies for basic research, universities were acutely aware of the slowdown in the growth of *largesse* from their main patron. It is estimated that total university expenditures from all sources for basic research in all fields went from $2003M in 1968 to $2,110M a decade later: steady state indeed.[70]

Given this context, it is not surprising that academics began to show new interest in nonfederal sources for the support of basic research, from the early 1970s onward.

One obvious, familiar source lay in industry. If industrial ability to finance basic research—in house, or in universities and other centers—was small compared with federal sources (25% of the latter, in 1965), it was not subject to the same political constraints.

2. *The federal government as bearer of externalities*

Academic spokesmen and others committed to the basic research mission of the universities came to a gradual consensus in the 1970s. On the one hand they realized that growth in federal funds for that mission could no longer be taken for granted. On the other hand, they had no desire to return to the world as it was in the heydey of Roger Adams and Frank Jewett. Instead, they believed that the pluralistic modes of federal support which had developed in the 1940s and 50s, together with project selection by peer review, meant the danger had been avoided that academic scientists would become the "intellectual slaves" of the state. At the same time, the extraordinary record of American success in Nobel prize and other international comparisons indicated that federal support could be compatible with the loftiest of intellectual criteria. Academic spokesmen felt comfortable with the twin ideas that the university was "the home of research" and that the federal government was the proper bearer of the externalities of cost of that research.

What was less clear to academic or other spokesmen was the appropriate scale on which those externalities should be financed; or when considerations of national security took over from prospects of civilian application as an appropriate ground for economic choice; or where the correct boundaries lay between federal support of basic research and private, industrial responsibility for financing innovation and development. All three areas provoked continuing discussions through the 1970s. What was new within those discussions was the increasing attention focused on the possible roles of industry, and the reaching out for fresh cooperative modes that would embrace industry, academe and—possibly—government.

[67]W. O. Milligan, "Preface," in *Proceedings of the Robert A. Welch Foundation Conferences on Chemical Research: XX. American Chemistry—Bicentennial* (Robert A. Welch Foundation, Houston, 1977), p. viii. Financial data is included in "The Robert A. Welch Foundation," in *The International Foundation Directory*, H. V. Hodson, ed. (Gale Research Co., Detroit, 1974), p. 321.

[68]Adams was chairman of the committee that recommended the fellowships. The program was approved in 1954, and the initial awards were made in 1955 to 24 individuals, totaling $235,000. By 1975 the program had disbursed $25M to 1,220 scientists; about 40% of the awards have been for chemistry. For further details see the Annual Reports of the *Alfred P. Sloan Foundation*.

[69]*Chemical and Engineering News*, 1981 59 (27 July), 69.

[70]*Science Indicators, 1980. Report of the National Science Board 1981* (U.S. Government Printing Office, Washington, D.C., 1981), tables 2-13 and 3-10. (All figures in constant 1972 dollars).

3. *Old and new forms of academic-industrial interaction*

Many older forms of academic-industrial cooperation returned to prominence in the 1970s, in chemistry as in other sciences. The benefits of consultancies were stressed, with the addition that this was one good way of bringing the industrial client abreast of government-financed work in university laboratories. Industrial grants were also stressed, though as late as 1972 it was reported that "universities which have been 'too well' funded from federal sources. . .tend to stop looking for industrial research support, which is harder to get." Industrial fellowships were re-emphasized, and more academic institutions began to experiment with "industrial associates" on the MIT model. Connections between industrial research associations and universities also gained a new prominence.

At the same time, many individuals and institutions began to cast about for new models of academic-industrial interaction. Not surprisingly in view of their prominence as supporters of academic research, federal agencies were involved in this experimentation. Already in the mid-1960s, the Advanced Research Projects Agency funded three goal-oriented projects in the field of materials science, each linking one university and one company in a team effort. This form of venture was an obvious modification of the (industrial) contractor—(university) subcontractor model familiar to some Department of Defense and NASA ventures.[71]

By early 1972, national concern over perceived "failures" to innovate as successfully as some foreign countries led the President of the United States to announce an "Experimental R and D Incentives Program" within the National Science Foundation. Within this program one development was the creation of industry-wide "university-industry centers", as in the MIT-Industry Polymer Processing Program. Seed funds from NSF allowed MIT staff to identify industry-wide problems, define research needs and select projects to be supported. By 1980 some twelve member companies were paying $560,000 (the full cost) to support 25 projects, with all patent rights accruing to MIT. In this period NSF also introduced the deliberate, partial funding of cooperative research projects between academic and industrial researchers.[72]

The later 1970s also saw a revival, on a new scale, of the older model of direct agreements between a particular academic institution and a particular industrial company to cooperate on basic research in an area of common interest. Thus in 1974 Harvard Medical School and the Monsanto Company entered into a twelve year, $23M commitment to basic research on the biochemistry and biology of organogenesis. MIT and the Exxon Corporation have launched a comparable ten year, $8M agreement for a combustion science program.[73] Similar arrangements in the bioengineering field have been concentrated at West Coast universities.[74] Most spectacular of all is the $100M endowment promised for the molecular genetics and developmental biology to be undertaken at the new Whitehead Institute of MIT.[75] While all these ventures involve chemistry to some degree, they operate in novel scientific areas and on a previously unknown scale as to duration and financial commitment.

4. *Unstable equilibrium*

The most optimistic of industrial spokesmen do not expect that industrial financing will underwrite more than ten to fifteen percent of academic research in the decade ahead. Whether funding on even that scale will be forthcoming on a sustained basis remains to be discovered. Equally uncertain is whether industrial companies will find such investment as financially rewarding as they hope. It is also not yet clear what long-run role federal agencies will play in facilitating new forms of academic-industrial cooperation. However what is clear is that the new interest in academic-industrial ventures, which has been growing rapidly for several years, marks the end of one stage in the story of basic research in America. The next chapter remains to be written.

[71] Rustum Roy, "University-Industry Interaction Patterns," *Science*, 1972, *178*, 955-960. Quotation from p. 956.

[72] "Technology Incentives: NSF Gropes for Relevance," *Science*, 1973, *180*, 1105-1107, and Denis J. Prager and Gilbert S. Omenn, "Research, Innovation, and University-Industry Linkages," *Science*, 1980, *207*, 379-384.

[73] Prager and Omenn, "Research," and Wayne Biddle, "A Patent on Knowledge," *Harper's*, 1981, *263* (July) 22-26.

[74] See *New York Times*, 12 September 1981, p. 32.

[75] "Academic Values Tested by MIT's New Center," *Chemical and Engineering News*, 1982, 60 (15 March) 7-12.

UNIVERSITY INDUSTRY COOPERATION IN MICROELECTRONICS AND COMPUTERS

I. Some Perspectives from the Field

by

Erich Bloch
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and

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Stanford University

II. Seven Case Studies

by

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Council for the Advancement of Science Writing

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CHAPTER I

SOME PERSPECTIVES FROM THE FIELD

A. Introduction

The last two years have seen an increasing trend for cooperation between industry and academia in the microelectronics area and those high technology industry sectors that depend on microelectronics as its base technology: computer manufacturers, instrument makers, telecommunication companies.

The following two accounts describe aspects of this new relationship and the underlying reasons for a change between these two sectors of U.S. society.

This description is meant to stimulate others into action, or at least stimulate new thinking in this important relationship.

B. Semiconductor Research Cooperative (SRC)

1. *Semiconductors and Computers: Basic Industries*

The 1980's will see an increasing penetration of high technology into industry, business, and the everyday life of people across the globe. The technologies of semiconductors and computers are predominant contributors to these developments.

The reasons are not difficult to perceive:

a. Semiconductors and computers are productivity tools that have a strong positive influence on cost and quality in manufacturing and on the effectiveness of the engineer, scientist, and administrator.

b. Because semiconductors and computers are new developments and products themselves, they represent growing industry sectors contributing to the wealth of nations and taking the place of declining industries.

c. They are basic industries—similar to steel and automobile in the early part of this century. Their developments are used as building blocks for novel products and have resulted in the establishment of new industry sectors.

2. *Increase in Worldwide Competition*

Because of the pervasiveness of semiconductors and computers, worldwide competition in the two industries is increasing. Through government initiatives, especially in Japan, France, Germany, and England, the knowledge base of these technologies is spreading worldwide and is augmented by the contributions in research, development, and manufacturing that these nations are making.

The United States no longer has an undisputed lead. In fact, in specific sectors of these industries, such as memory devices, calculators, and displays, the U.S.A. has lost its preeminence. It is important to elaborate on this point with specific data:

— While the U.S. semiconductor industry supplied 100% of worldwide memory chip production in the early 1970's and over 90% in 1975, the U.S. production of 16K memory chips had fallen by 1980 to 60%. The production of 64K chips in 1982 is estimated to be 30% for the United States and 70% for Japan.

— The number of papers presented by U.S.A.-based authors in the prestigious yearly ISSC (International Solid State Circuit Conference) has decreased from 78% in 1971 to 55% in 1981. Japan's participation in turn has increased from 5% to 30%.

— The worldwide sales of semiconductors by the three major world industrial centers has also undergone a change. The percentage U.S. contribution to worldwide semiconductor production in 1981 has dropped to 60% from a high of 70% ten years ago; Japan's has increased to 26%.

3. *The World Environment*

The economic and political stresses that U.S. companies are experiencing make the prospect of world competition even more ominous.

The inflation rate in the U.S. since 1978 has been higher than that of West Germany and Japan. While the U. S. had to contend with double digit inflation, Japan's and West Germany's inflation rate was below 5%.

The capital investment required in semiconductors has been increasing to close to 20% of every sales dollar. The cost of capital financing, however, is lower by a factor of two in Japan compared to U.S. costs in 1980 and 1981.

Japanese companies do not depend on equity financing but are dependent on loans from banks that have an equity position in the enterprise. It is acceptable to show an after-tax profit of as low as 2%. Such low after-tax profits for U.S. companies could inhibit severely their capability of raising needed capital.

Import duties are uneven. Japan's duty for semiconductors is twice that of the U.S.; Europe's is double that of Japan.

Both Europe and Japan have strong "buy national" policies in the high-technology sector making it difficult for U.S. companies to sell in government-controlled sectors; such as telecommunications and railroads.

Standards and other non-tariff regulations imposed by the national government are barriers to the penetration of foreign manufacturers into the Japanese and European markets, as compared to the "laissez-faire" policy of the U.S.

In order for high-technology sectors to progress and continue to advance, research and development efforts must be expanded, and qualified technical professionals must be made available to industry and academia. On both of these counts, the United States is not keeping up with its world competitors. U.S. R&D spending as percent of GNP has been dropping from a high of 3% in 1963 to 2.3% in 1981. In the same time frame, in Japan this index has increased from 1% to close to 2%, and West Germany's from 1.25% to 2.4%.

With regard to education, the U.S. has been overtaken by Japan in the yearly production of electronic and electrical engineers. This discipline is basic for most high-technology industry sectors; especially semiconductors, computers and the telecommunications industry.

4. *The Semiconductor Research Cooperative— A New Relationship*

The need for research and qualified people, as well as the increased world competition, has focused members of the semiconductor and computer industries on an effort called the Semiconductor Research Cooperative (SRC).

a. *Purpose*

The purpose of the SRC effort is to increase the level of focused research of the U.S. semiconductor industry. It is aimed at both enhancing long-term research efforts (5-10 years) in those areas that, because of the difficulty of the problem, require a long gestation period. It is also aimed at shorter term research that will yield product results in a 3-5 year time frame. It is, however, not aimed at advanced technology or product development endeavors. The participating companies will take the results of the cooperative research and derive from it new products. Cooperation in research does not preclude a vigorous competition in the marketplace.

While the R&D expenditures of both the semiconductor industry and the U.S. industry are not insignificant, probably less than 10% of the R&D expenditures is aimed at research; the remainder is spent on advanced technology and mainly on shorter range product development. Spending additional and new funds for research specifically should materially increase and enhance the basic understanding of concepts that lead to new products.

A further purpose of the SRC is to add significantly to both the supply and quality of degreed professionals. This will be accomplished by having the majority of the research executed by universities, thereby funding new research positions and attracting new talent to these endeavors.

Another benefit is aimed at the upgrading and modernization of the tools required in the pursuit of semiconductor research. Many universitites today lack appropriate equipment and instruments to work in a meaningful way at the forefront of these technologies.

The participating membership of the SRC is a varied one. It not only is composed of semiconductor companies, but also of their major and leading-edge users: computer companies; instrument and equipment companies; defense-oriented, as well as consumer product-oriented companies, and semiconductor equipment makers. What these companies have in common is their heavy dependence on semiconductors for their product line. In order to compete in the world market, they must rely on a dependable and vigorous U.S. semiconductor industry.

They are also manufacturers of semiconductors for sale or for their own use and perform research and development in this discipline.

b. *Rationale for a Joint Cooperative Effort*

Such an effort in all probability could not have been organized a few years ago. One reason for this change is the realization that the semiconductor industry is under severe and continuous pressure from foreign competition. Semiconductors have now become a basic industry and it is important for the well-being of the country to have viable companies in this sector of its economy. The need for defense support alone would justify this position; but the industrial requirements cannot be minimized.

The semiconductor and the computer industries, despite their growth, are still in their early stages and new developments come at an increasingly rapid rate. Therefore, a lead in research will determine market performance in the future.

At the same time, the cost of conducting basic research has been escalating, not only because of inflation and the increasing cost of manpower, but also because of the increasing complexity of the technology and the need for sophisticated tools and equipment. The availability of these tools is especially important in the research phase. The sharing of this equipment and making it available among a large number of participants reduces research cost.

While the universities and some regional institutes have recognized the importance of semiconductor studies and are focusing on research in this field, the early obsolescence of equipment and the continual need for new capital infusion is a major problem.

The support of industry is required; especially since the reduction in government spending has left the universities in a vulnerable position. The SRC effort will substitute industry dollars for government dollars.

The question can be asked why individual companies should not merely increase their own res arch, or else interact individually with universities.

While such an approach is certainly feasible, a joint effort will be able tc attack a research area with the necessary resources. Individual companies frequently can apply only limited funds and facilities to a particular undertaking.

A joint effort further avoids the overlap of endeavors that is so often the case when individual companies pursue their individual research.

c. *Implementation*

While plans have not completely firmed up, it is contemplated that the SRC will be a non-profit organization and operate as a subsidiary of the Semiconductor Industry Association (SIA).

It will be governed by a board of directors, a third of which will be elected by and will be members of the SIA board; the other members will come from participating industry and academia.

Reporting to the board will be an executive director whose full-time job it is to formulate research programs; enter into activities with universities and other not-for-profit institutions; monitor progress, and be a focal point for disseminating the results of this effort. The executive director is to be assisted by a small group of technical people from member companies.

SRC members will pay a fee proportional to the integrated circuit sales volume or the purchase volume of integrated circuits of the participating company. While not firmed up completely, the number of dollars thus raised for this research will be $5-7 million in 1982, and $10-15 million in 1983; hopefully increasing thereafter as both the participating base and the industry is growing. Based on 1980 expenditures, this expenditure should increase the research budget of the industry by 25% in 1983—not an insignificant addition. By preliminary estimates it could more than double the yearly support of the semiconductor and computer industry to university research.

Membership will be open to all companies that manufacture semiconductors in the U.S. The SRC and participating universities will own patent rights and other intellectual property which can be licensed to non-members for an appropriate fee.

C. The Center for Integrated Systems

The Center for integrated Systems (CIS) at Stanford University is an example of cooperation between industry and academia as well as government in research and education dealing jointly with semiconductors and computers. The dual objectives of the CIS are to educate a new genus of technical leader and to research new fundamental concepts for very large scale integrated (VLSI) systems. These objectives impose a compelling need to deal cohesively with an extremely broad spectrum of disciplines ranging from semiconductor materials to computer systems software. The organization, personnel, facilities, research and educational goals of the CIS are summarized in the following discussion, which concludes with an assessment of the overall impact of increased university-industry cooperation in research.

1. *Organization*

Stanford University contains Schools of Business, Earth Sciences, Education, Engineering (E), Humanities & Sciences (H&S), Law and Medicine (M) on a single campus. The principal Departments whose faculty are affiliated with the CIS are Electrical Engineering (E) and Computer Science (H&S). During the past five years the research and curricula of these two departments have been expanding rapidly in many phases of integrated systems. In addition, the Department of Applied Physics (H&S) conducts a substantial research and teaching program germane to integrated systems.

A central feature of the organization of the CIS is an Executive Committee which formulates policy and consists largely of faculty from the electrical Engineering and Computer Science Departments. The Chairman of this Committee and the Co-Directors who plan, initiate and direct CIS operations report to the Dean of Engineering. Nonetheless, the research program of the CIS is university wide in scope, already including important collaborations with the Departments of Aeronautics & Astronautics (E), Materials Science (E), Mechanical Engineering (E), Biological Sciences (H&S),

Applied Physics (H&S), Medicine (M), Radiology (M), Surgery (M) and others.

A key element of the CIS is a Sponsors Advisory Committee consisting of one representative from each of 18 corporations (listed in Figure 1) who have elected to become Sponsors of the CIS and contribute a total of $13,500,000 for design and construction of a new CIS building. Technical advice from the representatives on this Committee will provide important guidance for CIS research. Annual contributions from Sponsors will be used to support CIS research and educational programs. The most serious policy issue facing the CIS is resolution of patent and property rights involving both university and corporate interests.

The singular organizational challenge confronting the CIS is the need to mold a synergistic research program, extending from semiconductor materials through computer systems software, compatible with traditional practice of academic freedom.

Autonomous research project teams led by a faculty member acting as principal investigator are a prominent feature of the CIS. These teams are both intradisciplinary and multidisciplinary and range between 2 and 20 members including faculty, professional staff, technical staff, graduate students and industrial research associates assigned to the CIS on a full-time basis by Sponsor corporations. These industrial research associates on sabbatical leaves from Sponsor corporations are expected to add important new ingredients to the CIS research program. Costly facilities for design, fabrication, test and application of integrated systems are shared by all project teams and centrally managed by the Co-Directors.

2. *Personnel*

More than 30 faculty, 80 members of the research staff and 200 graduate students are now engaged in integrated systems research at Stanford. Their numbers can be expected to grow significantly in the future as a larger proportion of the 90 faculty members in the Electrical Engineering, Computer Science and Applied Physics Departments respond to the unusual opportunities offered by the CIS. Of the 30 faculty with interests in integrated systems, approximately 60% are systems, architecture and software oriented and 40% are materials, device and circuit oriented. Annual sponsored research expenditures of the faculty in the Electrical Engineering, Computer Science and Applied Physics Departments are now approximately $30 million. More than one-third of this total is directly pertinent to integrated systems.

3. *Facilities*

The current research program of the CIS is conducted in a set of laboratories and offices located in five proximate buildings, each occupied in part by the Electrical Engineering or Computer Science Department. The total space available to these Departments for research is approximately 120,000 square feet; about 50% of this is used for integrated systems research. The buildings are linked by a wideband local area communications network providing access via office terminals to more than $2 million of locally installed computer equipment. Research dealing with VLSI systems design and related tools represents a principal use of these computational facilities. A com-

SPONSORS OF THE CENTER FOR INTEGRATED SYSTEMS AT STANFORD UNIVERSITY

NORTHROP CORPORATION
TRW INCORPORATED
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GENERAL TELEPHONE AND ELECTRONICS CORPORATION
INTERNATIONAL BUSINESS MACHINES CORPORATION
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TEXAS INSTRUMENTS, INCORPORATED
MOTOROLA, INCORPORATED
FAIRCHILD CAMERA AND INSTRUMENT CORPORATION
AMERICAN MICROSYSTEMS, INCORPORATED
INTEL CORPORATION
MONSANTO COMPANY

Figure 1

plete integrated circuit processing laboratory, including electron-beam and optical mask making, optical projection alignment, epitaxy, ion implantation, low pressure chemical vapor deposition, diffusion, plasma etching, sputtering and evaporation equipment, is in operation. In addition, dedicated laboratories exist for testing and application of prototype integrated systems, for laser and electron-beam processing and for ultraviolet and synchrotron X-ray photoemission studies of semiconductors. Total investment in specialized facilities and equipment for semiconductor materials, device and circuit research exceeds $12 million. Current expenditures for capital equipment pertinent to VLSI systems design and fabrication are about $3 million annually.

A new CIS building whose basic construction cost will exceed $9 million is scheduled for completion in late 1983. The gross area of this building will be 70,000 square feet. It will provide a net area of 30,000 square feet of additional space for research, including 10,000 square feet of Class 100 clean rooms.

4. *Research Program*

Topics of major existing research projects dealing with integrated systems are listed below.

- Knowledge-based VLSI design: application of artificial intelligence techniques to development of heuristic programs providing expert software systems for VLSI design (in collaboration with the Heuristic Programming Project).
- VLSI information systems: special purpose signal processing algorithms and architectures; design aids and compatible high level language testing programs for VLSI.
- VLSI computer systems: general purpose architectures and design aids for VLSI; high performance graphic work stations; custom "geometry engine" microprocessor for graphics work station; custom high performance microprocessor without interlocked pipeline stages for general purpose use.
- Medical and rehabilitative electronic sensors, circuits and systems: auditory prosthesis; reading aid for the blind; silicon gas chromatograph; totally implantable telemetry for measurement of blood flow and pressure, bioelectric potential, dimensions, strain, temperature and chemical ion concentrations in biomedical research animals.
- Fast turn-around fabrication laboratory for VLSI systems including projections of limits of ULSI.
- Integrated circuit process emulation linking two-dimensional process and device models.
- Laser, electron and ion beam processing of semiconductor materials including new device structures in recrystallized semiconductors.
- Fundamental studies of semiconductor surfaces and interfaces using ultraviolet and X-ray photoemission and Auger electron emission.

The vast majority of the effort described above is funded by agencies of the Federal Government including the DoD, HHS, NSF and NASA. DARPA and NIH have been particularly important sponsors. An increased level of financial and technical support from the CIS Sponsors and the SRC will be pursued in the future.

5. *Educational Program*

The CIS is not an an academic department and consequently confers no degrees. However, through the Electrical Engineering and Computer Science Departments, a goal of 30 Ph.D. and 100 M.S. graduates per year with broad competence in integrated systems is targeted. As a reference point, during the 1980-81 academic year the Departments of Electrical Engineering and Computer Science conferred a total of 79 Ph.D. and 286 M.S. degrees. CIS resources derived from Sponsor annual contributions will be used to establish new courses and educational laboratories and to furnish video tapes of courses to Sponsors. CIS Sponsors have the opportunity to provide fellowships for graduate students.

6. *Conclusion*

To meet the challenge of a growing and increasingly competitive industry, Stanford's CIS is focusing its efforts on creating a new discipline—integrated systems science and engineering, a meld of semiconductor materials and integrated circuits with computer systems—and producing a vital new genus of technical leader well prepared to practice this discipline.

D. Overall Impact of Increased University-Industry Cooperation in Research

The Center for Integrated Systems is a unique entity in that it reflects all of the peculiar features of Stanford University, especially its immediately previous research and teaching programs in semiconductors and computers, its faculty, its material resources and its broad industrial affiliations. In this sense similar efforts at other academic institutions are marked by their distinctive characteristics. For example, establishment of an on-campus laboratory for fabrication of experimental integrated systems markedly expands opportunities for research related to process and device physics and models as well as computer systems. In addition, it opens the door to exciting synergisms between these two broad disciplines. However, the organization, personnel and facilities required to support an integrated systems fabrication laboratory are very sizeable by academic standards, and a large and healthy diversity of approaches exists within academia. A very significant feature of the CIS approach is that without a virtually unprecedented level and kind of commitment from industry, the means for acquiring an integrated systems fabrication laboratory would not exist.

Transcending their diversity, the CIS and corresponding entities at other academic institutions represent a new level of cooperation between academia and industry. By adding a third party to the already fruitful university-government research cooperation, opportunities for productive academic research are both enlarged and enhanced. An expected result is increased academic freedom which can be assured by thoughtful selection of non-proprietary goals in joint university-industry research. Hopefully, the CIS symbolizes a new era of productivity in university research through unprecedented cooperation of academia, government and industry.

SEVEN CASE STUDIES

A. Introduction

Universities and industry in the United States have begun a technological and sociological experiment unique in the nation's history. They are cooperating to meet the challenges of an electronics revolution that is changing the way the world computes, communicates, manages information, manufactures, and learns—and so the way people work, play, and think. The technical, economic, and social impact of this revolution already has surpassed that of the Industrial Revolution, and the former has only started to climb toward its peak. For example, electronics form the basis of an "information industry" predicted to grow into a $500 billion-a-year enterprise by the end of the century—the largest enterprise on Earth.

The electronics revolution extends back to the invention of the telephone more than 100 years ago, but it accelerated dramatically—and became the microelectronics revolution with the invention of the transistor in 1947. Constructed of semi-conducting materials, particularly silicon, these small, lightweight "electronic valves" replaced less reliable, less energy-efficient vacuum tubes in myriads of products from radios to computers.

The other technology central to the microelectronics revolution involves using photolithographic techniques to "print" entire circuits on a silicon chip in one operation instead of individually wiring hundreds or thousands of transistors together manually. The cost of processing a fingernail-size, integrated circuit chip essentially does not increase as the number of transistors on it increases; therefore, the more transistors, the more functions and the less the cost per function. The cost per function of computers, communications equipment, scientific instruments, processing devices, satellites, and other electronic products fell by a factor of 100,000 in less than two decades. The continuing decline in cost per function resulted in an expanding market and a phenomenal 17 percent annual growth rate in the electronics industry from 1970 to 1980. The number of semiconductors on a chip increased from hundreds to hundreds of thousands (450,000 in 1981), and industrial and academic laboratories now experiment with very large-scale integrated (VLSI) circuits containing a million or more elements.

Such growth does not occur without problems. For industry, lack of adequately trained people and need for more efficient ways to design and program highly complex circuits top the list. An 8-bit microprocessor logic chip requires 182 man-days to program; 6 man-years of efforts are needed to write instructions for a 16-bit logic chip. And new chips that handle 32 bits (letters or digits) simultaneously now are available.

The microelectronics boom has produced a growth in job opportunities far beyond the growth in engineering graduates. According to the American Electronics Association, the industry's largest trade group, the number of electrical-engineering graduates at all levels remained about the same in 1980 as in 1972—18,008 versus 17,682—while the industry grew 136 percent. U. S. colleges and universities in June, 1980, turned out only 10 percent of the 54,000 four-year computer-science graduates that industry wanted to hire. At the master's level, the supply totaled 10 percent of the 34,000-job demand. Only 24 percent of the 1,300 openings for Ph.Ds were filled. "Less than 200 graduates a year in this country know enough about VLSI to take a job in this area," states Control Data vice president Walter Bruning.

Prime factors contributing to this manpower situation include faculty members leaving universities for higher-paying industry positions, and outmoded laboratory teaching equipment. "You can easily spend $10 million setting up a microelectronics lab at a university; few schools can afford that amount," notes Stephen Kahne, director of the National Science Foundation's Division of Electrical, Computer and Systems

Engineering. "Equipment is between a factor of four and 20 more expensive than (it was) a decade ago," says John G. Linvill of Stanford University. "Some of that increase has been due to inflation, but most of it stems from the fact that circuit complexity demands equipment with much more exquisite control." New computer-aided procedures are needed to design, manufacture, and test VLSI circuits, and this requires increased capital outlays.

Many industry people see competition from Japan as a bigger problem than the manpower shortage. That nation initiated nationally supported programs that involve cooperation between government, industry and, to a lesser extent, universities. One such venture involves an eight-year $300 million (half from government, half from industry) program to produce a VLSI supercomputer by the end of the decade. "Curricula at universities, which generally lack modern processing equipment, is closely correlated with on-the-job training of graduates, and this fosters a close relationship with industry," comments Bruning. Such cooperative arrangements, known to Westerners as "Japan, Inc.," threaten U.S. technical superiority and dominance of the world market. Japan now holds about 40 percent of the global market for 16,000-bit memory chips, and it is engaged in a struggle with American industry to dominate sales of the 64,000-bit chip.

To meet the challenges of foreign competition and to solve mutual domestic problems, industry and academia in this country have entered into various cooperative ventures. "This is the beginning of a 'USA, Inc.,'" declares Brian Dale of GTE, which maintains working associations with Stanford University, California Institute of Technology, and Massachusetts Institute of Technology. Industry is manpower limited and people are the main product of universities. Industrial facilities contain state-of-the-art equipment needed to properly train students but lacking at many universities. The schools, on the other hand, can provide graduates familiar with new circuit-design methods required by industry to deal with increasing complexity. The Defense Advanced Research Projects Agency (DARPA) combines these capabilities in a $9 million program that translates students' designs into working chips. Students at the California Institute of Technology, Stanford University, Massachusetts Institute of Technology (MIT), Carnegie-Mellon University, University of California at Berkeley, and University of Southern California use computers and the latest architectural techniques to design VLSI circuits which are fabricated at companies such as Texas Instruments, IBM, TRW, Honeywell, Hughes, and Westinghouse.

Industry has led the federal government in conducting electronics research in this country. About one-quarter of all the scientists and engineers in industrial labs work for the electronics industry, and a steady growth has occurred in both the basic and applied segments of their R&D. This growth is likely to continue since it has been a principal factor in price decreases and corporate growth. Basic research averages about 3.5 percent of all R&D, which totaled about $750 million in the microelectronics sector in 1981, according to a National Research Council report, *Outlook for Science and Technology: The Next Five Years.* However, this average includes large corporations which devote 10 percent or more of their R&D funds to basic research and many small firms that have no R&D budget. Emil Sarpa of Intel says that his company spends as much as 15 percent on basic research. Most companies are reluctant to invest large sums over many years with little assurance of when and how benefits will result. This provides another strong motive for cooperation with universities. "Predictions of the nature, placement, and timing of breakthroughs are uncertain, at best," comments Linvill. "These uncertainties are less troublesome in the graduate school environment than in industry. A negative result may bear practically the same educational value as a positive one if it contributes to knowledge."

Cooperative arrangements in the U.S. do not follow the monolithic model of Japan, Inc. They center on regional centers which seek to take advantage of the proximity of the corporations involved to a large university or research complex, and of relationships between faculty and executives that have grown out of common goals and interests. A typical example is Stanford University which lies amid the nation's largest concentration of microelectronics producers and users in "silicon valley", a chain of ten cities and more than a thousand firms stretching south from San Francisco to San Jose and beyond. More than 150,000 people worked in the electronics industry in this area in 1981, about 40,000 of them for the valley's 15 largest semiconductor firms. Stanford has participated in the local electronics revolution since its inception in the mid-1950's. Today, university training, research, and consulting provides industry with manpower, expertise, and fresh ideas. Industry, in turn, awards research contracts, contributes funds, and shares state-of-the-art equipment.

B. Stanford Center for Integrated Systems

To cope with the new problems and challenges of the 1980's, a small group of university and industrial leaders founded a facility known as the Center for Integrated Systems (CIS). Stanford's departments of electrical engineering and computer science cooperate with industry to train students and corporate professionals and to generate new scientific and technical ideas for development of VLSI systems. John Linvill, director of the center, says that two major factors led to its establishment: "First, a university cannot be isolated from the industry it serves; it needs the latest tools and equipment to produce people who can do what is essential for survival and growth of that industry. Second, vertical integration of training is required; students should learn to handle entire computation, communications, and control systems. In 1979, myself and three Stanford colleagues began discussions about how these things could be done. (The colleagues were James Meindl, James Gibbons, and Michael Flynn.) We talked it over with industrial friends who are close to the university geographically, intellectually, and socially." One of the friends was George Pake, a former Stanford faculty member and then, as now, head of Xerox Corporation's research center in Palo Alto. "We had a long history of cooperation with Stanford and obtained enormous benefits from the association," he states. "Therefore, I supported the idea of CIS and joined an advisory committee to help them get started." Linvill and his group presented a plan for the center to the Stanford Board of Trustees, and they received a go-ahead to seek funds in 1980.

"We did not encounter any intentional roadblocks at Stanford," Linvill recalls, "but you always run into problems when you want to do something significantly different. Some people viewed the proposed changes as a threat to their position; others feared that closer ties with industry would compromise the university's independence." Industry was not as reluctant and a development committee headed by John Young, president of Hewlett-Packard, began recruiting sponsors. CIS began formal operation in February, 1981, and had 14 sponsors by the end of the year. These include Digital Equipment, General Electric, GTE, Fairchild, Hewlett-Packard, Honeywell, IBM, Intel, Northrop, Tektronix, Texas Instruments, TRW, and Xerox. These corporations each pledged support of $250,000 a year for 3 years, plus operating funds, to construct and run a design-automation laboratory, fabrication facility, and other supporting structures.

Corporate participation in CIS follows the model of Stanford's highly successful industrial affiliates program, in which companies gain access to the latest research at the university in exchange for membership fees. CIS also draws on a departmental research-assistantship program in which companies sponsor research and benefit from close association with graduate students. Many of the companies had prior associations with Stanford's computer science and electrical engineering departments. The latter includes an integrated circuit lab which has made ICs since the early 1970's. It now includes one of the few facilities at a U.S. university where student-designed ICs are quickly fabricated and returned to them for testing. While awaiting construction of its central facility, CIS will conduct projects in this and other existing laboratories for semiconductor research, information systems, computer systems, and artificial intelligence. Federal funds financed much of this technical base. "Individuals in these various labs received $9 million in federal support in 1981," Linvill notes. "In this sense, CIS is an infant born half-grown."

CIS has specific goals: 1) to produce 30 Ph.D. and 100 M.S. graduates a year, 2) to do fundamental research, 3) to offer short courses, conferences and workshops, and 4) to provide a forum through which work at the center will be coupled with that in industry, other educational institutions, and government facilities. A Dean's Committee establishes CIS policy. Its four members include the chairperson of an 11-member executive committee representing all of Stanford's science, engineering, and humanities departments. A sponsor's advisory committee, composed of high-level executives from sponsoring corporations meets semiannually with the Stanford-faculty representatives. The chairman of the latter committee, now John Doyle of Hewlett-Packard, says that he "meets with the executive committee a couple of times a month."

Pake comments that "Xerox's contribution to CIS is very small compared to what we are investing internally in the same kind of research. (The corporation is constructing a major new IC laboratory in Palo Alto.) For little additional investment we enlarge our perspective by participating in a broad program of basic research. We envision opportunities for joint interaction with the university and with other companies, as well as the ability to recruit students. On a per-dollar basis, it should be a good investment."

Brian Dale is more pragmatic concerning GTE's contribution. "It costs about $100,000 a year to support a top-level researcher in-house," he notes. "We should get as much or more out of the same amount invested in Stanford or any other good school." The main reason, Dale explains, is that "universities have taken the lead in novel approaches to the design of VLSI circuits and we want to catch up."

Pake and Dale say that corporate supporters have no intention of trying to influence the university's freedom to select areas of research. "However," Pake comments, "we will make our interests known, as well as our preferences when several choices exist." Linvill remarks: "If a sponsor sees something his company does not like, we will do our best to accommodate reasonable changes."

One thing that industry does not like is Stanford's patent policy. "Many questions need to be resolved," says Doyle. "The most difficult ones involve visiting scientists who come up with patentable ideas while working at CIS. Also, when you have people from competing companies working side-by-side, you may have to decide whose idea it is. One arrangement would be to give all sponsors royalty-free licenses for hardware and software developments. But this could result in the federal government classifying the corporate contribution as sponsored research. You then must pay taxes and 70 percent overhead to the university. These problems are receiving a lot of attention, and, if both sides bend a little, we solve them."

C. Caltech Silicon Structures Project

Patents loom as a problem in other industry-university ventures. Industrial affiliates receive royalty-free licenses to patents originating from cooperative research conducted as part of California Institute of Technology's Silicon Structures Project (SSP). Caltech obtains the same rights and can sell licenses through its foundation, the California Research Institute. In the only incidence, to date, where the Institute wished to do this, its foundation cleared the sale with corporate sponsors. No sponsor objected. Linda R. Getting, administrative director of SSP, admits that sponsor objections could be a problem in the future. However, no clear line of action has been decided in such a case.

SSP was established to do basic research on VLSI systems and to train students and industrial people in their design. Twelve corporations were contributing $100,000 a year by the end of 1981. As at CIS, these include high-technology giants such as Burroughs, Digital Equipment, Fairchild, General Electric, GTE, Hewlett-Packard, Honeywell, IBM, Intel, Motorola, Sperry Univac, and Xerox. "Fifty percent of the corporate support goes to SSP, the rest goes to the Institute (Caltech)," explains Getting. "We also receive $200,000 a year from the National Science Foundation to support graduate students."

Decisions about supporting research projects with these funds are made by a committee consisting of Getting, SSP technical director George Lewicki, and Carver Mead, professor of computer science and a main driving force behind the program. No advisory board of sponsors exists as it does at Stanford. Each sponsor sends a scientist to Caltech for a year to work on VLSI design. This arrangement has not run as smoothly as anticipated. "We thought we could send who we wanted and this person could do what he or she wanted," complained one corporate executive. "Apparently this is not so." "Some industry people came with specific assignments," said Getting. "This was less than desirable because they used resources without increasing knowledge. Some projects could have been done at corporate laboratories. We want industry scientists to tie their own problems and interests to the interests of the Institute and to the educational requirements of the graduate students."

SSP includes no fabrication facility, such as is planned for CIS. "We decided that a so-called 'silicon foundry' required more management capability and students than we possess," explained Getting. Also, Carver Mead believes that universities should take the lead in circuit-design research while industry concentrates on fabrication. This does not please some of the industrial sponsors. "I see it as a limitation," said one representative. "Students need feedback on what can and cannot be done with circuit materials. Experience in fabrication enhances the whole education process." Les Hogan of Fairchild Camera and Instrument Corporation feels that "students need experience in processing; companies that hire them cannot be expected to provide all the training in this area. Also, when professors become involved in fabrication they often come up with major innovations."

Ivan Sutherland, formerly of Caltech's computer science department, originated the idea of SSP to deal with the overwhelming complexity of VLSI circuits, and to educate students in the disciplines needed to design and program such circuits. His plan was, at first, "cooly received" by the Caltech administration, according to someone familiar with its history. "The SSP proposal caused a lot of negative reaction and resistance throughout the Institute," this person recalls. "Many people felt that the university would be prostituting itself to industry, or at least doing development work that industry should do. When the administration finally decided to pursue industry support, it quadrupled the $25,000 fee proposed by Sutherland."

D. University of California, Berkeley

Several corporations affiliated with Stanford, Caltech, or both also support microelectronics research at the University of California, Berkeley. Besides seeking funds to create its own fabrication and design facility, this university participates in a statewide industry-academia cooperative effort known as the Microelectronics Innovation and Computer Research Operation, or MICRO. Researchers from the nine UC campuses propose projects to companies with which they have developed contacts. If the company agrees to fund the research, matching funds can be obtained from MICRO.

The state program was initiated by Governor Edmund G. Brown to help the electronics industry, which employs 40,000 Californians, and to counter competition from Japan and other sections of the U.S. The state Legislature appropriated almost $1 million for MICRO in 1981. "We expect to get at least that much, and perhaps as much as $2 million in 1982," 1½comments George Turin, the UC, Berkeley, faculty member who chairs the committee that reviews MICRO proposals. The five-member committee consists of faculty from five UC campuses. It operates under the guidelines of an advisory board of state-government, academic, and industry members, which deals with long-range planning, training requirements and manpower needs. "MICRO gives priority to projects that promise industrial fallout in the medium term—4 to 10 years," Turin points out. "We want technical people in industry to form close associations with university researchers. Technology transfer will be encouraged by these contacts, and by graduate students who work on the projects then are hired by sponsoring companies."

Of $980,000 appropriated for MICRO, approximately $50,000 went for administrative costs, and $100,000 for fellowships in microelectronics and computer science. The remaining $830,000 was matched by $820,000 in cash and $540,000 worth of equipment from industry. In 1981, these funds supported 31 projects on six campuses, most of them—about 40 percent—at Berkeley.

The university, in a separate effort, seeks state and federal funds to convert an existing campus building into a microelectronics research center. The state is expected to provide $2.3 million, NSF $1.7 million, and the UC system $500,000 for this purpose. To support research at the center, particularly in computer-aided design (CAD) and computer-aided manufacture (CAM), Berkeley began a campaign to raise $5.5 million from industry. "The center will not duplicate fabrication capabilities available at corporate laboratories," declares David Hodges, professor of electrical engineering. "Our efforts will be limited to advanced and exotic processing that cannot be done at many other places or at any other place." Hogan says that Fairchild may contribute $1 million to this effort. He opines that the Berkeley facility is "just right for training students—not too big and not too small." Hodges expects that the center will attract additional projects funded by MICRO. "Berkeley's approach is not to give industry a list of things they can get for their investment," Turin remarks. "Rather, we ask companies about their needs then try to provide what they want."

Certainly one of the things industry wants from all cooperative arrangements is the chance to recruit good people. Stanford will provide this through increased enrollment at CIS, but Caltech and Berkeley will concentrate on better-educated, not more, students. Enrollment at Berkeley and other schools in the UC system is at its ceiling. The $100,000 provided by MICRO will help Berkeley and the other campuses achieve a goal of "providing paid research assistantships and other incentives for high-quality engineering students to attend graduate schools instead of immediately taking jobs in industry," states Larry Hershman, budget director for the UC system.

E. Massachusetts Institute of Technology

While Berkeley depends heavily on state support for its brick and mortar requirements, MIT will rely on federal funds to provide a central facility for its university-industry Microsystems Program. More than 90 percent of research at the Institute is federally supported and the combined electrical engineering and computer science department looks in that direction for $8 million to renovate a campus building. Plans involve using overhead funds from federal support of all research at MIT not just that related to microelectronics. At the beginning of 1982, the Institute had not received approval to do this, but it was well-along in obtaining industry funds for equipment and annual operating costs of about $150,000. Industrial contributors including Analog Devices, Boeing Aerospace, Digital Equipment, GenRad, GTE, Harris Corporation, Honeywell, IBM, and Teradyne, committed $250,000 a year for three years.

When the program gets underway, industrial sponsors will be invited to send their scientists to the campus. "We envision taking 12-to-15 people annually, each for a period of 9-to-12 months," says Richard B. Adler, associate head of the electrical engineering and computer science department. "These would be top-level people. We would offer new ideas, access to the latest research, and contact with graduate students." Industry is attracted to "the excellent software people at MIT, particularly those in computer science and artificial intelligence, who are developing powerful new concepts for handling very complex circuits," explains Brian Dale. Richard Paine of Analog Devices points to "industry's huge void in IC-design expertise which we want to fill." His company will provide $25,000 a year for five years to support a professorship at MIT. "This enables the school to educate 20-30 more students," comments Graham Sterling of Analog Devices. "We do this because we feel that a slow flow of trained students could constrain the development of our industry."

Industry played a major role in the origin of the Microsystems Program. "In 1974, IBM tried to get our computer-science people interested in designing integrated systems," Adler recalls. "At the time computer people here and elsewhere paid little attention to the engineering involved in circuits they used. And most electrical engineers had a 'bottom up' approach to design; they added functions as they were needed. At MIT, we were not foresighted enough to grasp what IBM told us about designing the complex circuits of the future from the 'top down'." The faculty, however, was more receptive in 1979 when Lynn Conway, now with DARPA, came to MIT. Along with Carver Mead, she wrote the first textbook on VLSI systems. It explains a simplified approach to design and instruction, pioneered at Caltech, which drastically reduces the time required to train circuit designers. "We discussed such new developments in design and education among ourselves and with our close friends in industry," Adler remembers, "then we came up with the idea of the Microsystems Program. In January 1980, MIT announced its creation and began actively soliciting industrial support."

Paul Penfield, head of the EE/CS department directs the program. A high-level technical staff will be hired to handle day-to-day operations. The bulk of research funds, like the renovation money, is expected to come from federal sources. "DoD supports the majority of work in our department," Adler says, "and we do not expect DoD dominance to change for some years."

"Industry cannot tell MIT what to do," Adler declares, "but the Institute cannot limit itself to telling industry what it is doing and will do. We must have a forum." Several representatives of contributing corporations complain that such a forum does not yet exist. "The people at Microsystems promised to set-up a sponsors advisory committee, but they have not done this," GTE's Dale said in January, 1982. Some of the criticism is sharper. "MIT did not hesitate to take our money, but it never bothered to provide a means to get together with us as a group," comments another sponsor representative.

Corporate people generally agree that MIT's standard patent policy is too vague to cover specific cases involving industry scientists working with faculty and with each other on campus. "This area is going to require lots of discussion," opines Dale. "We are considering establishing a common research fund to which all sponsors would contribute," Adler remarks. "MIT and the sponsors would agree in committee on what projects would be funded from this pool. Patent rights would be available on a non-exclusive, royalty-free basis to all contributors."

Cooperative programs at universities also are attempting to deal with the problem of the faculty's desire for prompt, open publication versus industry's need to protect proprietary information and foreign patent rights. "We could agree to delays in publication of 60-90 days to protect industrial investors," Adler notes.

F. Microelectronics Center of North Carolina

Universities and corporations in the Boston and silicon valley areas must cope with high living and labor costs, high taxes, pollution, a steady increase in crowding, and what many consider to be a declining quality of life. North Carolina claims an alternative to this in the form of a new microelectronics center financed by $24 million in state funds and located in the "backyard" of three universities and a complex of federal and private research facilities known as Research Triangle Park. The Park, where the Microelectronics Center of North Carolina (MCNC) is situated lies roughly equidistant from Duke University at Durham, North Carolina State University at Raleigh, and the University of North Carolina at Chapel Hill. MCNC is a non-profit consortium of these three universities, together with the University of North Carolina at Charlotte, North Carolina A&T State University at Greensboro, and the Research Triangle Institute (RTI), a non-profit research organization.

MCNC began with General Electric Company's site search for a new microelectronics plant to produce custom ICs for its own products. "In 1979, after looking at about 30 sites, we selected the Research Triangle Park for a variety of reasons," recalls GE's Don Patterson. "These included the local universities, proximity to other GE facilities on the East Coast, quality of life, attractiveness of the area to recruit into, and the strong support of Governor Jim Hunt."

GE offered the Research Triangle Institute funds to prepare a prospectus on a cooperative industry-state-university research and education venture. "Governor Hunt responded enthusiastically to this idea," says George R. Herbert, chairman of MCNC and president of RTI. Hunt wanted to focus the resources of the North Carolina Board of Science and Technology, which he established in 1977, on areas that would yield the most jobs and revenue. The number of electronics companies in the state had been increasing and microelectronics obviously was a promising area. When GE came on the scene, Hunt called a meeting of the presidents of the universities and RTI and asked them if "it made sense to invest the effort and money to become a major eastern center of microelectronics research," according to Herbert. When the answer was "yes," Hunt asked the State Legislature for, and obtained, in 1981, $24 million for two years support.

About $10 million will go for construction of a new research center at Research Triangle Park and an interim fabrication facility at North Carolina State. The equipment budget totals $8.65 million, and $5.3 million in operation costs includes $2.1 million for research grants and $300,000 for graduate fellowships. To stretch their dollars, MCNC submitted a proposal to NSF requesting matching funds for equipment purchases. The Research Triangle Foundation, owner of RTI, provided an unrestricted grant of $300,000 which enabled MCNC to become a reality in July, 1980, before appropriation of the state funds. GE became the first industrial sponsor with a membership fee of $250,000.

"It's amazing how fast the North Carolina group picked up the cue and put the necessary education programs in Place," Patterson comments. "The president of the community-college association flew to silicon valley to check out curricula and equipment at the technical schools. He established comparable courses here, and graduates who can maintain and operate state-of-the-art equipment will be available starting in the spring of 1982." All five universities offer the Mead-Conway course in VLSI circuit design, and MCNC established four $10,000 fellowships at each of the five universities.

The stated objective of the center is to support the educational and research activities of the participating institutions. However, "MCNC also will serve the needs of industry and government by undertaking, with its own staff, research projects not related to the educational and research functions of the universities," Herbert states. In addition, the center intends to act as clearing-house for non-proprietary research at the participating institutions, make it possible for corporate scientists to spend time with faculty researchers, and invite industry to technical seminars at its facilities. An advisory board of university and industry members will evaluate research proposals and be responsible for long-range planning. They will work under policies established by a board of directors consisting of the chancellors of the five universities, representatives from state government and the private sector, and the president of RTI.

At the beginning of 1982, approximately $10 million worth of grants and contracts to the participating institutions (mostly from federal sources) supported research in microelectronics and relevant disciplines. However, 18 months after its establishment, GE remained MCNC's only industrial sponsor. "Several corporations have expressed interest," Herbert noted, "but we are not actively seeking more sponsors until we find a president." This has not been easy. The board of directors tried to attract one of the key people at the Stanford microelectronics center with a salary of $120,000 per year, described by one professor as "phenomenal in North Carolina," but the overture was unsuccessful.

MCNC institutions also have some catching-up to do. One GE engineer was "astonished to find that RTI and the universities were doing advanced work in gallium arsenide and related semi-conductor materials but not in silicon. "That's where the state-of-the-art advances will be made, so it's extremely important to get into silicon if you want to attract microelectronics corporations." Herbert admits that "we have fallen behind in the development of ICs on silicon chips, but new MCNC Programs will focus on bringing us up-to-date. Our main facility will include the latest equipment for fabrication of silicon-based circuits designed locally or at other microelectronics centers that do not have processing capabilities."

G. Minnesota MEIS

GE, through its California-based Calma Company, also contributed $500,000 worth of CAD equipment to the new Microelectronic and Information Sciences (MEIS) program at the University of Minnesota. In addition, MEIS attracted approximately $2 million each from Control Data and Honeywell, and about $1 million each from Sperry Univac and 3M. "Our target budget is $10.3 million for the first four years," declares MEIS director Robert M. Hexter, "and we have a schedule for approaching other corporations." NSF matched $200,000 of industry funds to renovate a microelectronics laboratory with a small fabrication capability on the Minneapolis campus of the University's Institute of Technology.

MEIS will support basic research projects initiated by member and non-member corporations and by faculty from the mother school as well as other universities. "In most, but not all cases, we require matching funds from a federal grant or other source," Hexter explains. Research will be concentrated in four areas: circuit-design automation, software engineering, microelectronic devices, and materials research. The university's expertise in the latter field won it a 4-year, $1.4 million NSF grant to establish a regional facility for surface analysis. At MEIS, a board of five industry and eight university directors makes decisions about project funding. Their actions are subject to approval by the UM Board of Regents.

Unless a research contract specifies otherwise, MEIS owns patent and copyright rights to hardware and software developed in its program. "These can be licensed to anyone," points out Walter Bruning, Control Data's representative on the board. "Affiliates have royalty-free rights up to the extent of their contribution. We want MEIS to become financially self sufficient as a result of grants, contracts, and royalties."

As an end product of discussions between Hexter, Bruning and others about university-industry synergism, Control Data gave the university a challenge grant of $2.3 million in December, 1979. "We had to raise another $3 million in 12 months or return the money," Hexter says. "We raised it in eight months." The grant, according to Bruning, was stimulated by NSF's establishment of the Regional Instrumentation Center for Surface Analysis. This is a good example of seed money spent by the federal government followed by a major private-sector commitment to get a partnership going. "The Japanese have become our main competition primarily because of such government-industry cooperation," Bruning says.

Control Data expects its investment to support faculty to train more skilled graduates. "We also want universities to upgrade their equipment and have access to modern industrial labs," comments Bruning. "Additionally, cooperation offers super-opportunities for technology transfer from universities to industry and for universities to obtain substantial revenues from royalties." Honeywell vice president Jerry Dineen states flatly that "the principal reason we contribute to MEIS is to assure ourselves of an adequate supply of well-trained people. We expect to achieve this. We also hope for, but do not count on, a synergy between Honeywell's research program and the program at the university. Finally, we hope to contribute to the health of the whole industry by supporting long-range, fundamental research in high-risk areas." "All our projects will involve fundamental research of the kind that most corporations cannot afford to do but that is needed to keep us competitive with other countries," remarks Hexter.

The MEIS program has been criticized for its decision not to construct a central facility. "They could have trouble attracting faculty and students," believes one observer. "A centrally located facility is a very positive thing—one that it is difficult to do without," adds Dineen. Hexter answers: "Having a custom-made facility in the middle of the campus would be terrific. But an estimated $8 out of every $10 spent for basic research goes toward buildings and equipment, and we would prefer to spend that money on good people and good research." Control Data, as a compromise, seeks to rent MEIS a building it owns near the campus. "We have proposed lease-holder improvements to accommodate MEIS, the surface analysis center, and materials-research facilities funded by DoD," Bruning says. "I feel confident that we will develop a central site as momentum in the program increases"

H. National Facility for Submicron Structures

Materials research such as that going on at MEIS and the surface analysis center is becoming more crucial as the microelectronics revolution accelerates into its next phase—circuit devices with dimensions smaller than one micron. "At this point, electronics has penetrated almost every aspect of our lives," notes Joseph M. Ballantyne, director of Cornell University's School of Electrical Engineering. "But ever greater changes and impacts lie ahead with the decrease in size, cost, and energy requirements that will come with introduction of submicron circuit structures."

The shift also will aggravate some existing problems. As devices become vanishingly small, the cost of equipment to fabricate and test them becomes prodigiously large. Only the largest companies can afford them. Universities do not possess funds to purchase state-of-the-art machines to train students. NSF, in 1976, reacted to this situation by organizing a series of workshops to explore the feasibility of establishing a national laboratory for research on submicron structures. Academic and industrial scientists could perform at a central facility a broad range of research which NSF does not have the resources to fund at a large number of individual laboratories. An overwhelming concensus favored the concept and, after reviewing proposals from universities, government and non-profit laboratories, NSF announced, in July, 1977, that it would support establishment of the National Research and Resource Facility for Submicron Structures (NRRFSS) at Cornell.

The Foundation provided funding of $6.65 million for the first five years. Cornell contributed $5 million; $3.8 million of this in construction and renovation and $1.2 million for equipment. About 3,000 square feet of existing space was renovated and a new 8,000 square-foot facility was dedicated on October 1, 1981. Initial NSF support extended from July 1, 1977 to June 30, 1982. Edward Wolf, who succeeded Ballantyne as NRRFSS director in July, 1978, says that the facility requested approximately $13 million for its second five years. This breaks down to $1.4 million for operations, $500,000 a year for Cornell-faculty research projects, and the remainder for equipment.

Research at the facility "reaches beyond that in industry," notes Ronald J. Gutmann, who oversees NRRFSS for NSF. "Except for a few giant corporations, most research is dedicated to improving what already exists. Industry does not have time and funds to invest in understanding basic phenomena, particularly at submicron sizes. Yet this understanding is necessary for new devices and for insight into why devices do and do not work. Universities cannot provide this understanding without sophisticated, state-of-the-art equipment and concomitant resources. Industry and academia move forward incrementally, while the idea of the submicron facility is to leapfrog evolution and provide the knowledge base for revolutionary advances in microelectronics."

The goals of the facility are: 1) to promote and carry-out research to advance submicron technology, and to train engineers and scientists in this field; 2) to provide a resource for the academic community and for industry to use to fabricate advanced devices or research structures with submicron dimensions; 3) to stimulate innovative research by all investigators whose work can benefit from use of the facility or will shed light on fundamental physics or materials problems that affect submicron technology; 4) to keep the technical community apprised of the capabilities of NRRFSS and the work done there.

In keeping with the first goal, the facility has $500,000 per year to support Cornell researchers, including resident Ph.D. candidates. In implementing the second goal, priority goes to representatives of academic institutions. Although researchers from 13 other universities used facility resources during its first four years of operation, Cornell faculty accounted for the major portion of use. This generated criticism about accessibility, and Wolf is attempting to raise visitor time to 50 percent of the total. Industry users include researchers from Westinghouse, GTE, GE, Eastman Kodak, Varian, Bell Laboratories, Microwave Associates, Honeywell, IBM, and ITT. They pay a modest fee of $50 to $200 per hour, depending on the equipment used. Research is not confined to semiconductor work; it includes studies of superconducting Josephson junctions, microwave circuits, structures for integrated optics, surface-wave devices, amorphous metals, ultrapressures, and a variety of other areas.

Those who wish to use the facility submit a short proposal that outlines the objectives of their project and estimates what equipment would be used and for how long. A program committee, composed of four people from Cornell and six from other universities, together with a non-voting NSF representative, reviews these proposals. Cornell members do not vote on proposals made by researchers from other universities. The users' funds support approved projects. Per-hour rates for equipment use are less for academic than for industry researchers. A policy board, which deals with long-term planning, facility objectives, and operation guidelines, consists of members from industry and universities, including those affiliated with the microelectronics centers.

Investigators also can interact with NRRFSS through NSF's industry-university cooperative-research program. During fiscal 1980, this program spent $10 million on joint basic-research projects, including $1.06 million on nine projects in the fields of solid-state microstructures engineering and computer science. This program has, however, been criticized for its lengthy processing procedures. Normal NSF peer review of proposals is time-consuming, and further time may be consumed in negotiating the necessary administrative agreements between the company and the university. Industrial research managers are accustomed to moving faster than these procedures permit.

I. Assessment

University-industry cooperative centers also are being planned or developed at several other locations in the U.S., including Carnegie-Mellon University in Pittsburgh and Rensselaer Polytechnic Institute (RPI) in Troy, NY. RPI invested $1.1 million of its own funds and plans to raise $30 million from industry by 1986 to support its new Center for Integrated Electronics. Considering all these efforts, NSF's Stephen Kahne characterizes the state of government-industry-university cooperation in microelectronics as "helter skelter." "There exists no nationally accepted way to do things because each company and university attempts to satisfy its own needs," he says. "Some of the arrangements will succeed and some will not, but the result will be a patchwork of regional centers." Many people in the industry and academia do not feel that this would be bad.

It is unlikely that any of the centers will survive without continued federal research support, as the situation to date shows. In 1980, investigators in laboratories and departments considered part of Stanford's CIS received $9 million in federal research grants/contracts, more than two-and-a-half times the annual membership revenue pledged by industry sponsors. Caltech's Silicon Structures Project receives $200,000 annually from NSF to support graduate students and depends on DARPA funds for its VLSI design and fabrication program. MIT cannot build its planned new fabrication center without federal funds, and DoD projects are expected to dominate research there for the foreseeable future. California provided funds to build a center at UC, Berkeley, but federally sponsored research will be needed to keep it going. The institutions that make up the Microelectronics Center of North Carolina currently receive about $10 million in federal research grants and contracts, and the State provided $24 million in the expectation of attracting more federal dollars. A major underpinning of MEIS is the federally supported Regional Instrumentation Center for Surface Analysis, and the program hopes to attract money from DoD, NSF, and other agencies to match industry funds.

Given continued federal support, industry and academia are still sizing-up each other. Most of the participating corporations say that it is too early to decide about funding the centers beyond the present commitment. The comment of John Doyle, is typical: "I have no reason to feel discouraged, but I don't have much reason to be satisfied because we have not achieved much yet."

Industry does believe, however, that continued cooperation is vital to combat what it sees as the major threat to its health. "In 15 years or less, the Japanese will dominate the worldwide IC market unless we all pull together to do something about it," opines Del Thorndike of Digital Equipment Corporation. "The U.S. must bring together the elements of government, industry, and academia to form an effective USA, Inc.," comments Brian Dale. "Otherwise, the U.S. will get buried in the next 10 years by Japanese technology. We have made a beginning; university and industry people sit down together to discuss mutual problems and work with each other in laboratories. They have to do more of this and the government—state and federal—should do all that is possible to make it easier."

Progress is being made despite mutually negative stereotyping, but prejudices must be overcome for success to be achieved. Many academics see the arrangements with industry as a threat to intellectual freedom and the responsibility of universities to seek knowlede for its own sake. They believe that their institutions have "sold out" to corporations. Some industry people regard the universities to which they contribute as "an endless hole for money for which we get little in return," or "a group of professors who will not give up their independence to participate in integrated or team research activities." "University people are accustomed to working as principal investigators—as sovereigns of their research projects," Doyle points out. "Corporate scientists work as equal partners on teams whose goals are defined by management. Large amounts of understanding must be achieved before these two types work together successfully. We are talking freely and openly about this, but we have not done any research yet."

Industry praises arrangements they regard as involving team efforts but criticizes those where "professors act in a vacuum." "Berkeley is putting together a group of device physicists, computer scientists, and circuit-architecture people who work together," notes John T. Mendel of Hughes Aereospace Corporation. "And the MICRO program has a bottom-up approach wherein projects come from professors and corporate technical people working together. This makes that university sensitive to the needs of industry. Other centers have a top-down approach; direction comes from deans and department heads who may not be interested in the same problems as individual professors or corporations." Hughes decided, on this basis, to participate heavily in the MICRO program but to not contribute to Stanford.

IBM's Tom Horton represents another point of view. "It's naive to expect specific benefits from these arrangements," he insists. "If a company wants something specific, they should negotiate a contract for it. You have to support these ventures on the faith that they will lead to new, useful knowledge, successful technology transfer, and more well-trained people which will keep the industry healthy in the face of worldwide competition." A number of corporations accept this view and voice satisfaction with the cooperative ventures. Don Patterson reports that GE believes that its commitment to the MCNC is "well worth it from the point of view of educating company people, gaining new knowledge, and having a chance to recruit good people."

Because no nationally accepted way to do things exists, and the patchwork of microelectronics centers is becoming more dense, a company that is not satisfied with the policies of a university can look elsewhere to fulfill its needs. Centers such as CIS have a heavy commitment to processing technology; others, such as Caltech and MIT, possess expertise in circuit design and software. Yet others try to achieve a balance and be attuned to the requirements of companies in their geographic area. The growing number of centers creates what Bruning calls "a cooperative venture attitude," that will certainly lead to more and different types of arrangements. "We expect to see more of the type of cooperation that Control Data has pioneered," he predicts. "Our company works successfully with Honeywell and NCR in sharing research and development, but this does not prevent us from being very competitive in marketing." The Semiconductor Industry Association, a trade group, has established the nonprofit Semiconductor Research Cooperative through which it plans to spend $20 million on long-term research at universities in 1982-4. (See Chapter I).

Doyle concludes that "the sociological part of the university-industry experiment will be more difficult than the technical." There are no concrete results yet," he admits, "but people from both sides are trying hard to work together." Stanford's president, Donald Kennedy, echoes these sentiments: "There are fundamental differences between what universities are willing to provide and what industry requires. Not infrequently, there also are differences between the conditions set by universities and those acceptable to industry. Satisfactory arrangements, not only in the field of microelectronics but in biotechnology, energy research and other areas, require special, often demanding negotiations. That's not a minor chore, but neither is it an insurmountable one."

A big step in this direction was taken in March, 1982, when university presidents, faculty members, and businessmen with connections to the academic institutions met in seclusion at Pajaro Dunes on the California coast. The presidents of Stanford, Caltech, MIT, University of California, and Harvard discussed the problems of collaboration with representatives of 11 corporations. The meeting focused on commercialization of biology but the issues do not differ substantially from those involved in microelectronics ventures. The conferees set no policy, and they agreed to leave resolution of the more contentious issues—such as conflict of interest, patents and licenses, and disclosure of research contract provisions—to individual university faculties. They did, however, agree on the necessity to preserve academic freedom and values, a consensus that Harvard president Derek Bok called "reassuring." A summary draft statement declared that "research agreements and other arrangements with industry (must) be so constructed as not to promote secrecy that will harm the progress of science, impair the educational experience of students and postdoctoral fellows, diminish the role of the university as a credible and impartial source, interfere with the choice by faculty members of the scientific questions they pursue, or divert the energy of faculty members and the resources of the university from primary obligations to teaching or research."

J. Involving the Federal Government

The success of arrangements resulting from industry-university collaboration depends heavily on assistance from the federal government. This does not have to come solely, or even principally, in the form of increased spending; instead, it might involve changes in allocation of funds, tax incentives, and reduction or clarification of regulations.

Several corporate sponsors want their contributions used to support research rather than to construct facilities and buy equipment. "Until World War II, buildings were constructed by federal and state governments, and engineering research was supported mainly by industry," observes Fairchild's Hogan. "Now the situation has reversed. The government only wants to sponsor research, and industry finds itself funding brick and mortar, something it does not want to do." Turin of UC, Berkeley agrees: "State and federal funds traditionally were used for buildings and equipment, but universities now go to industry for this."

Industry wants changes in the targeting of funds to be coupled with tax benefits. The Economic Recovery Tax Act of 1981 (ERTA) provides tax incentives for equipment makers to donate items of their own manufacture to universities. Therefore, notes Intel's Emil Sarpa, "NSF and other agencies can designate more grant dollars for research and facilities and less for equipment. Microelectronic centers should be able to procure the equipment they need from corporate sponsors. Federal guidelines for grants could even require that potential grantees make an effort to acquire equipment that they need in this way." Analog Devices' Graham Sterling wants to go further by convincing the government to extend ERTA incentives to all donors of new and used equipment whether or not of their own manufacture.

Industry is not alone in seeking tax breaks for the research it supports. "As our national attention is fixed on the extraordinary difficulty of paring back government expenditures, one hears it asserted that the private sector can be expected to accomplish those things from which the government now proposes to withdraw," Donald Kennedy told the Senate Finance Committee in May 1981. "The plain fact is that significant changes in private-sector support, especially for research, will require new incentives. I simply do not believe that significant sources of funds exist in the private sector that we are not now tapping."

The ERTA provides such incentives in the form of tax credits for 65 percent of the cost of research contracted to a university. Sterling and others would like this changed to 100 percent. Other corporate representatives mention the need for additional write-offs against internal R&D allowances for participating in matching-fund programs such as MICRO, or consortia such as that proposed by the Semiconductor Industry Association. Sterling also suggests that the ERTA "safe harbor leasing" concept, which allows corporations to sell tax and depreciation credits, be extended to universities and other non-profit institutions. "If this were done," he comments, "universities could obtain 40-45 percent effective discounts on capital equipment that they purchase with their own funds to keep their laboratories current with high technology."

Other items on industry's "wish list" include more support for graduate students, tariffs on imports of Japanese electronic products equal to those levied against imports of U.S. goods, and antitrust regulation that allows more corporate cooperation in research and development. "Control Data and Honeywell broke the ground in this area," Doyle says, "but we (Hewlett-Packard) would not feel comfortable doing the same thing with IBM or Digital Equipment under the present restrictions."

Some of industry's wishes obviously are self-serving. Others could provide ways for government to make university-industry collaboration easier without additional expenditure. They could make the sociological part of the experiment less difficult and facilitate growth of a USA, Inc., not of the same type as Japan, Inc., but effective in helping universities and corporations solve nagging problems, and the nation to retain its dominance in the microelectronics revolution.

Report on a National Science Foundation Workshop on Intellectual Property Rights in Industry-University Cooperative Research

by

National Science Foundation
Office of the General Counsel
27 April 1981

CONTENTS

CHAPTER I

INTRODUCTION

On 27 April 1981, the National Science Foundation hosted a one-day Workshop on Intellectual Property Rights in Industry-University Cooperative Research.

The purpose of the workshop was to find out whether intellectual property issues were inhibiting cooperative research and, if so, how. The intent was to identify problems that require further study or corrective action—even if not necessarily by the NSF.

The workshop included participants from business, academia, and Government. An attempt was made to obtain a cross-section of opinion in each of these three sectors by inviting persons from a variety of positions within representative organizations. Attendees are listed in Appendix A.

This report summarizes the five major topics discussed:

- Benefits and dangers of cooperative research,
- Cooperative research and intellectual property rights,
- Trade secrets and proprietary information,
- Patent rights,
- Solutions and further actions.

CHAPTER II

BENEFITS AND DANGERS OF COOPERATIVE RESEARCH

Underlying the workshop was an implicit assumption that cooperative research should be encouraged. This reflected both the policy of the NSF and the personal judgment of the workshop planners. Since the participants were selected partly for their known interest in and experience with cooperative research, most, if not all, approved that policy and shared that judgment. However, comments of participants several times raised dangers and drawbacks of cooperative research as well as opportunities for universities, firms, and the research community.

A. Reasons for undertaking cooperative,research

One university representative declared that industry-university cooperation, or "coupling", is an essential part of the technology transfer process. Universities and firms must attempt to move the latest scientific discoveries from campus laboratories to the production line if America's productivity and balance of payments difficulties are to be solved. He also noted that cooperative research is vital for engineering and applied sciences because feedback from industry helps to establish both research direction and educational emphasis. Several academic participants commented that reduced Federal spending is forcing universities to find other support for research. University researchers and administrators must seek funds from industry for the same reason Willie Sutton robbed banks: "Because that's where the money is."

One business participant opined that much cooperation between individual faculty members and firms takes place without the knowledge of the universities. Cooperative research programs merely formalize and control an inevitable phenomenon.

B. Dangers of cooperative research

Among the doubts and misgivings expressed were those of one academic participant who was concerned about the effect of interactions between highly-structured business (which he termed "crystalline") and largely unstructured university research departments ("liquid" or, jokingly, "gaseous"). He feared cooperative research might adversely affect the focus and functioning of academic researchers.

Participants from all three sectors worried that industrial support could pervert universities' priorities, channeling research into areas that produce short-term profits from those that advance scientific knowledge. In particular some fear that Federal budget cuts will cause a "gold rush" towards industrial sponsorship, particularly by smaller or less-prestigious universities. This might trigger a "race to the bottom", as universities compete for industrial support by compromising their principles. One academic research administrator said that such pressures are already great at smaller universities. An industrial participant noted that academia cannot rely upon the generosity of strangers to save them. If a university offers its birthright for a mess of pottage, a business firm will take the bargain.

According to one university researcher, cooperative research projects should be on the basic end of the research spectrum. Firms should come to universities not for answers to specific problems, but for knowledge to cure deep ignorance. An industrial participant agreed that cooperative projects should focus on basic research, the traditional province of campus researchers, rather than applied research or development, the main concern of firms' "in-house" researchers. He said that applied research and development are naturally more likely to produce results that have immediate commercial significance and that consequently firms want to impose greater restrictions on applied research and developmental projects. He noted that universities must expect to incur "in-house"-type restrictions if they seek to perform "in-house"-type research.

A representative from a public university said that universities, both state-chartered and private nonprofit, have to carefully avoid going into the research "business" for practical as well as philosophical reasons. He identified Federal tax problems and conflicts with small research companies as possible results of increased university involvement with applied research or development.

C. Consensus

The consensus of the participants was that cooperative research—on the whole, at its present volume, and as currently conducted—is clearly good for both universities and industry. Cooperative research, however, is not without its dangers, which may be exponentially related to the volume of cooperative research or the proportion of cooperative research to total university research.

CHAPTER III

COOPERATIVE RESEARCH AND INTELLECTUAL PROPERTY RIGHTS

A. Intellectual property rights matters inhibit cooperative research

The participants agreed that intellectual property rights sometimes prove a stumbling block to industry-university cooperative research. A research administrator noted that in the industrial Northeast less than four percent of academic research was industrially sponsored. He said that time and again during cooperative research negotiations, at meetings of governmental commissions, and in private discussions with businessmen, patents were given as the reason firms do not sponsor more on-campus research. Others echoed this observation, although the thought was expressed that intellectual property problems might occasionally be more excuse than reason for failing to undertake cooperative research.

All agreed that intellectual property rights are a stumbling block—an inhibition—not a roadblock to cooperation. In many cases, the problems are more apparent than real. However, firms and, on occasion, universities may not bother to investigate beyond the appearance. One participant thought that cooperative research, like any new activity, is often the victim of inertia. Intellectual property rights problems inhibit cooperative research not because they are so serious or difficult to resolve, but because they abet such inertia, causing delay and nuisance both within and between the organizations involved.

B. Industry-university negotiations difficult

Many explanations were offered for difficulties in industry-university negotiations. The differing structures of a university and a firm might be to blame. A research administrator noted that both university and business hierarchies resemble pyramids, but that the academic pyramid stands on its apex, not its base. He said that business negotiators were often surprised—or appalled—to learn how often university policies are established by the faculty and cannot be modified by the research administrator or even the university president.

The perspectives of business and academia differ as well. As an industrial representative noted, firms are accustomed to purchasing goods and services through binding contracts. Universities, on the other hand, get the bulk of their external research funding from appropriations, donations, or Federal grants, which attach relatively few conditions. A firm's contract administrator seeks to protect its interests through standard contractual "boilerplate". Academic administrators and researchers naturally resist what they perceive as unusual restrictions on university research activities. Each side resents the other's departure from standard operating procedure. (One of the Federal employees suggested that the same clash of perspectives can occur when a Government agency supports research as a "procurement" rather than "assistance" activity.)

The clash of perspectives seems to be only one symptom of a more serious problem—a failure to adequately understand the other party's interests. From the comments made by university participants, this misunderstanding lies mostly, though not exclusively, on the industry side. As an academic with much experience in cooperative research noted, firms sometimes forget that a university is not just a research performer. Universities have three institutional responsibilities: advancement of knowledge, education, and public service. The last of these is particularly important for state-run universities, which get most of their funds through a political process.

C. Intraorganization obstacles

Some of the participants indicated that industry-university differences and misunderstandings are frequently less troublesome to cooperative research than intraorganizational ones. Several persons commented that academic and industrial scientists seldom have trouble in identifying and designing worthwhile research projects. The difficult cooperative research negotiations are those between staff (research administrators and lawyers), not line (researchers). Some believe this phenomenon is partly explained by the fact that an organization's staff may have a better, broader, view of organizational responsibilities, priorities, and goals. Legitimate concerns of the university or firm may not be apparent to the researchers. A few participants, however, felt strongly that cooperative research negotiations also often run afoul of the specialized concerns and narrow interests of university or industry staff who handle negotiations—that the tail wags the dog. If true, this might explain the disproportionate difficulties intellectual property rights, particularly patents, create in negotiating cooperative research arrangements.

Everyone at the workshop agreed that patents are *the* intellectual property rights issue. Copyrights were hardly mentioned and trade secrets reportedly seldom cause serious disagreement between universities and firms. One participant noted that in his experience, once agreement on patent rights is reached, other intellectual property rights questions are quickly resolved. A major reason for this is probably that patents are perceived to be more valuable than other forms of intellectual property. Another reason might be that patents are "countable". If a trade secret is disclosed, the economic advantage that might have been provided by exclusivity is forever unknown. The value of an invention that is disclosed but not patented is also forever unknown. If a patent is obtained, however, the economic value of the underlying invention may be identified and traced. "Countability" begets accountability. Someone can be held accountable for not having obtained rights to an invention at the time of negotiation, at the time the invention is made, or at any time during the seventeen-year life of the patent. Nobody wants to be labeled "the one who gave away the gold-mine patent". The only way to insure against later regrets at not having obtained patent rights is to obtain patent rights. The natural human fear of failure, or of being seen to fail, presses the negotiator into an uncompromising position. Unfortunately, this pressure affects both industrial and academic negotiators. Conflict and even stalemate can result.

Some at the workshop, chiefly nonlawyers, were convinced that intellectual property rights negotiations are particularly difficult because they are usually handled, directly or indirectly, by lawyers. Lawyers are heavily involved with intellectual property rights because intellectual property, more than real or personal property, depends on satisfaction of legal conditions. Information does not become a trade secret unless it has certain attributes and, more importantly, is treated by its owner in a certain way. A writing is not fully protected by copyright (even under the 1976 Copyright Act) unless certain formalities are observed. A patent cannot be issued unless the invention and patent application satisfy the statutory criteria. For this reason, intellectual property rights matters are the particular concern of lawyers. Lawyers, by training and (some argue) by nature, are cautious individuals, forever guarding against the lawsuit that never occurs. Adding lawyerly caution to human fear of failure increases the "viscosity" or "friction" caused by patent negotiations in industry-university dealings.

D. Consensus

The consensus of the participants was that though cooperative research negotiations, particularly on intellectual property, are often difficult because of intersectional misunderstandings and intraorganizational interests, compromise and understanding can resolve the difficulties

CHAPTER IV

TRADE SECRETS AND PROPRIETARY INFORMATION

Trade secrets and proprietary information, while potentially a source of great conflict between academia and industry, appear to be nonissues in most cooperative research arrangements. The participants reported that problems result most often from lack of thought or preconceptions, not from any basic conflict between academic and business ethics. There was general agreement on appropriate protection of a firm's pre-existing trade secrets and prompt publication of research results.

A. Pre-existing secrets

Everyone agreed that a firm must protect its pre-existing secrets and that secrecy would conflict with the education and advancement of knowledge functions of the university. This general conflict, however, apparently causes few specific problems. Only one instance was mentioned in which secrecy questions prevented cooperative research. That involved a refusal by a firm's lawyer to modify or omit some standard secrecy "boilerplate"—a clash more of perspectives than of essential interests.

There may be few problems in this area chiefly because firms have elected to keep their trade secret-related research entirely "in-house". One industrial participant opined that a firm would be foolish to entrust a valuable trade secret to outside researchers, whether academic or industrial. A decision that trade secret-related research is inappropriate for cooperative research might result from a firm's judgment that universities cannot or will not keep secrets. An academic research administrator noted that universities undeniably can keep secrets (the Los Alamos atomic research facility, after all, is run by a university), but that many have policies which rule out "secret research".

What is difficult or forbidden at the institutional level, however, can apparently often be accomplished by individuals. When university researchers do research in industrial laboratories, one academic said, they do often sign confidentiality agreements.

A businessman noted that, in fact, technical trade secrets are seldom an issue. Proprietary information—such as the fact that a firm was exploring a certain technology or planning to enter a particular market—is more often involved. No one saw a conflict between academic responsibilities and nondisclosure of that kind of information.

B. Secrecy of results

There was also general agreement that the results of cooperative research should be made public. The industrial participants recognized the university researchers' need to publish, both to exchange information and to establish academic credentials. An academic participant said many firms feel that the inevitable delay between submission and publication gives these firms sufficient advantage over their competitors. Everyone agreed that delaying publication for a limited time to permit filing of patent applications is reasonable. Periods of delay ranging from thirty days to one year were mentioned. One firm's patent attorney even suggested that a time limit would help avoid tardiness in filing.

C. Consensus

The consensus of the participants was that a firm's pre-existing secrets should and could be protected and that, except as necessary to protect patent rights, publication of cooperative research results should not be restricted.

PATENT RIGHTS

A. Basic patent rights

Representatives of some companies and universities say that they insist on "title" to or "ownership" of patents. This can be misleading because "ownership" of a patent, though typically evinced by holding legal title to it, actually consists of a package of different legal rights. Few—if any—negotiators need or really insist on having all of these.

The basic rights secured by a patent are:

1. The right to exclude others from practicing (making, using, or selling) the invention (This is the basic legal right secured by a patent, and is enforced by prosecuting infringers),
2. The right to practice the invention (without being prosecuted for infringement),
3. The right to license others to practice the invention,
4. The right to license the right to exclude others, and
5. The right to receive royalties from those licensees.

The legal "owner" or "titleholder" may alienate any or even all of these rights by a patent license. Correspondingly, a person may acquire, through license, any or even all of these rights without having title to the patent. If the "owner" licenses all patent rights, retaining only bare legal title, the licensee becomes owner for all practical purposes.

B. Strategies and interests

Some of the industrial representatives at the workshop said that their firms wish to be able to take advantage of the so-called "patent monopoly" and exclude their competitors from practicing an invention. Most companies follow this "exclusive" strategy". Other business participants, however, said that their companies only want to assure their own access to relevant technology and do not care whether others may practice an invention. They thus follow a "nonexclusive strategy". One person noted that his firm follows *both* strategies depending on its contribution to the research and the importance of the particular technology to its markets.

To pursue an exclusive strategy, a firm should "own" (i.e., control) at least the first four, and ideally all five, basic patent rights. To pursue a nonexclusive strategy, on the other hand, a firm need only obtain or retain one—the right to practice the invention.

Universities have three primary interests in patents. Primarily, they (and particularly their patent administrators) want to share in the income generated by university inventions. Second, they wish to protect themselves against charges that they have conspired to suppress or impede a new technology by ensuring that such inventions are commercialized. Finally, they wish to minimize the legal complications of commingling research support. To satisfy these interests, universities would prefer to "own" all five basic patent rights.

C. Problems between universities and exclusive-strategy firms

The conflict between exclusive-strategy firms and universities is obvious, since both ideally would like to have complete control of the patent rights, although for different reasons. Three issues seem to dominate negotiations in these cases: ownership of title, control of exclusivity, and, last but not least, royalties.

Ownership of title—in itself mostly a matter of form, not substance—is often the threshold issue. The critical point, of course, is not "bare legal title" but who controls the important patent rights. (Astute negotiators, recognizing that, may be able to trade "bare legal title" for substantive concessions.) Universities do have a valid reason for wanting title as such—the commingling problem. Separating research funding sources is a difficult or perhaps impossible task in the informal academic environment. Under Federal grants, which support most academic research, the university can retain "title" to Government-supported inventions without difficulty, but cannot assign it without permission and holds it subject to certain Federal rights. If a university obligates itself to assign an invention to a firm and then discovers that, through commingling, the invention also received support from the Government or another firm, it may find itself in the position of having sold something twice. The universities may also want legal title for political reasons, since faculty members or state legislators unsophisticated in patent matters might equate not taking title with surrendering all patent rights. Why some companies insist on "title" is unclear.

The second issue is who will control the patent exclusivity and so determine who may practice the invention. The firm wants to be able to practice the invention itself, or not, and to license others, or not, as it determines is best for its business. If the firm sees that profits are maximized by keeping the price of the patented product high, it will do so. If it determines that its investment in an alternate technology would be destroyed, it may choose not to practice or permit others to practice a patented process. (Several investigations, however, have shown this last to be more a theoretical possibility than an actual practice.)

These practices are consistent with the university's desire to maximize its patent income (provided, of course, that the firm shares its profits or savings), but not with its public service responsibilities. The university, whether a public or private organization, is seen by its faculty, its students, and the general public as having a responsibility to promote the public interest. After all, state institutions and nonprofit organizations exist (in theory) because society has found that, due to market imperfections, some "public goods" or "good works" would not be supplied or performed by the private sector. Consequently, the university wants to ensure that its employees' inventions are commercialized so that the benefits are available to the public on reasonable terms. Universities do often grant exclusive licenses, but the workshop participants involved with academic patent licensing noted that they prefer to grant a license for a term of five or eight years (rather than the full seventeen-year life of the patent), to give exclusive rights only for certain fields of use, and to impose "working" requirements to protect the public against nonuse of the invention.

The final issue is money—slicing the patent income pie. From the workshop discussions, difficulties seem to arise from an inequality of bargaining power between the university and the firm. Academic patent administrators feel that firms too often fail to give universities a fair share of patent-related income. They say that firms exploit the academic researcher's much greater interest in current research support than in future university income from possible patents to obtain licenses for low, or often no, royalties. They say that while this occasionally results in "windfalls" for the companies, it tends to poison the industry-university relationship. On the other side, firms insist that they have the right, indeed the duty, to strike the best bargain they can. Business representatives point out that eliminating royalties entirely is desirable because that forecloses disputes between the university and firm as to whether a certain invention is incorporated in or used to manufacture a particular product. They also maintain that the exchange of future patents for current funding may be a good deal for the university as a whole, if not for its patent administrators.

D. Problems between universities and nonexclusive-strategy firms

The conflict between universities and nonexclusive-strategy firms may seem less obvious, but may actually be more troublesome, particularly since these firms currently fund much, perhaps most, of industry-university cooperative research.

The "title" question does not arise, of course, since nonexclusive firms are willing to let the university keep most patent rights so long as they receive a right to practice.

However, the "exclusivity" question is stood upon its head, to the university negotiator's disadvantage. Now the firm insists on nonexclusivity, at least to the extent that it always be allowed to practice the invention. A firm that follows a nonexclusive strategy usually has one or more of the following characteristics:

1. It is involved with a fast-moving technology. Patents are of little value because an invention will likely be obsolete before one issues and because competitors can "invent around" the patent.
2. Its products are complex, containing many patentable components. As a result, the potential costs of negotiating individual patent licenses is high and the industry naturally gravitates towards cross-licensing.
3. Finally, the firm is a large, market-dominating company which is more likely likely to be hurt than helped by restrictions on the spread of technology.

General Electric, AT&T, International Business Machines, and Exxon, four nonexclusive strategy firms mentioned at the workshop, each obviously has at least one of these characteristics. A nonexclusive right to practice held by one of these firms is believed to discourage commercialization by anyone else. Another firm may be reluctant to bear the costs of introducing a new product if it knows that the dominant firm has the right to come into the resulting market, which it is likely to dominate as well. If the large firm's license thus discourages others from practicing the invention, the university obviously cannot earn royalty income from anyone except its former cooperative research partner. This means that the university patent administrator gets a patent that cannot be successfully licensed.

Instead of limiting exclusivity to protect the public against nonuse or excessive "monopoly" profits, the university in this case tries to preserve exclusivity to salvage its licensing opportunities. Those unfamiliar with the innovation process, however, often do not understand the notion that a patented product may be produced only if the number of persons able to produce it is limited so that the prospects of extra profits will justify undertaking the often extraordinary investment and risk-taking associated with initial commercialization. As a result, the university finds itself in an uncomfortable position, arguing against free access to technology and for more profits. From the firm's view, of course, to expect it to fund research without assuring that it can use the fruits of that research is unreasonable. After all, a nonexclusive license to possible inventions seems a very small return for thousands of dollars of research support.

Universities might find this situation easier to accept if the firm's nonexclusive license bore substantial royalties. However, the inequality of bargaining power between the university and the firm is perceived as particularly great with nonexclusive firms and the university often gets no royalties from its nonexclusive license. Since one characteristic of a nonexclusive firm is the complexity of its product, such firms may have a particular incentive to foreclose patent disputes by obtaining royalty-free licenses. This is obviously a very sore point with universities, certainly with their patent administrators. So it is that negotiations between universities and nonexclusive-strategy firms are often difficult and bitter.

E. Miscellaneous rights

In cooperative research negotiations with both exclusive and nonexclusive firms, numerous subsidiary patent issues arise. These include:

1. Who controls publication of results to protect patentability,
2. Who decides whether or not to file a patent application,
3. Who drafts the patent application, particularly the claims,
4. Who pays for patenting and maintenance costs, and
5. Who decides when to sue for infringement.

Except for the first, these issues are of interest primarily to patent attorneys, but they can be another source of delay and difficulty in putting together industry-university deals. From the comments of the workshop participants, a "clash of perspectives" may complicate negotiations over these subsidiary issues. Representatives from industry thought these matters should be specified in the cooperative research agreement, while those from universities indicated that these items could be left until after an invention is made.

F. Consensus

The consensus of the workshop was that there are genuine conflicts between universities' interests in patents and firms', particularly in respect to exclusivity and royalties. These conflicts, however, can be, and typically have been, resolved through good faith negotiations.

CHAPTER VI

SOLUTIONS AND FURTHER ACTIONS

The workshop participants agreed that many of the intellectual property rights difficulties in industry-university cooperative research projects are caused by inexperience and misunderstanding. More information is needed, especially by new entrants. Several private groups were reportedly considering the creation of an cooperative research information clearing house to help alleviate this problem.

The participants saw little role for the Government in resolving these difficulties. Several believed that the Bayh-Dole Act (35 U.S.C. §200 *et seq.*), enacted in late 1980, would encourage cooperative research by lessening the commingling problem and by publicizing the fact that universities can give companies patent rights. (Experience since the workshop has apparently confirmed this belief.) The participants felt that successful industry-university collaborations would beget more interest in cooperative research and that a "snowball" effect would occur without any major attempt to promote cooperative research.

APPENDIX A: Participants in NSF Workshop on Intellectual Property Rights in Industry-University Cooperative Research

Government

Charles H. Herz
General Counsel
National Science Foundation
Workshop Secretary

Frederick W. Betz
Director, Industry/University
Cooperative Research Program
National Science Foundation

Richard I. Gerson
Office of Renewable Resources
Department of Energy

Robert F. Kempf
Assistant General Counsel for Patent Matters
National Aeronautics & Space Administration

William Raub
Associate Director for Extramural
Research & Training
National Institutes of Health

University

Norman Hackerman
President
Rice University
Workshop Chairman

Roger Ditzel
Patent Administrator
University of California

Milton Goldberg
Executive Director
Committee on Governmental Relations
National Association of College and
University Business Officers

Don Keating
Director, Center for Industrial Research
College of Engineering
University of South Carolina

Clive Liston
Patent & Copyright Manager
Stanford University

Dillon Mapother
Associate Vice-Chancelor for Research
University of Illinois

Clark A. McCartney
Director, Department of Contracts-Grants
University of Southern California

Eli M. Pearce
Chairman, Chemistry Department
Polytechnic Institute of New York

Allen J. Sinisgalli
Director, Office of Research
and Project Administration
Princeton University

Nam P. Suh
Department of Mechanical Engineering
Massachusetts Institute of Technology

Industry

R. S. Detrick
Manager, External Research
Koppers Company, Inc.

Brice Farwell
Contracts Administrator
International Business Machines Corp.

C. Harold Herr
Senior Patent Attorney
E. I. DuPont De Nemours & Co.

Mark E. Kelly
Director of Chemicals and Plastics Research
Dow Chemical USA

Marvin Margoshes
Scientific Liaison
Technicon Instruments Corp.

William Miles
President
University Patents, Inc.

Pauline Newman
Patent Counsel
FMC Corporation

Judith Obermayer
Moleculon Research Corp.

Mrs. Hesna Pfeiffer
Assistant Director of Patents
Merck & Co., Inc.

John D. Upham
Monsanto Company

UNIVERSITY-INDUSTRY RESEARCH RELATIONSHIPS: AN ANNOTATED BIBLIOGRAPHY TO EARLY 1982

compiled by

Carlos E. Kruytbosch
Executive Secretary
Committee on 14th Annual Report of the
National Science Board

SUBJECT INDEX

[1] United States/Department of Commerce/Office of Productivity, Technology, and Innovation.
[2] European Industrial Research Management Association

AUTHOR INDEX

Atkinson, Richard C. "Planning for Science in the 1980's." Speech at the Public Affairs Symposium, Annual Meeting of the Federation of American Societies for Experimental Biology, Anaheim, California, April 14, 1980. 11 pp.

Discusses areas of future emphasis in planning for the biosciences. Nearly two pages are devoted to discussion of the university-industry connection and the associated changing patterns of research performance and scientific careers.

Baer, Walter S. *Strengthening University-Industry Interactions.* Santa Monica, California: RAND Corporation, January 1980. 28 pp.

Analyzes policy objectives of attempts to increase flow of university-industry interactions, and examines current state of knowledge regarding effects of three broad types of university-industry relationships upon industrial innovation. Sets forth eight policy options. Bibliography.

Battenburg, Joseph R. "Forging Links Between Industry and the Academic World." *Journal of the Society of Research Administrators,* Vol. XII, Winter 1981.

Battenburg is with the Corporate Research Department of the Eaton Corporation of Michigan. The paper examines the problems associated with university-industry interactions. "Gap size" factors are listed, i.e., those tending to widen or reduce the gap between the sectors. Ten types of mechanisms to promote closer relationships are listed and briefly discussed. Specific first steps for initiating contracts—both for universities and companies—are suggested.

Bearn, Alexander A. "The Pharmaceutical Industry and Academe: Partners in Progress" *American Journal of Medicine,* 71, July 1981, pp. 81-88.

A useful review of the state of university-industry relationships in pharmaceuticals by an official at Merck Sharp and Dohme International.

Bement, A. L. "DARPA's Experience with University-Industrial Interactions in Materials Research," Notes (slides) for a presentation at DOE/IRI Conference on Mechanisms of University-Industry Interactions, December 7-8, 1978, Reston, VA.

The Director of the DARPA Materials Science Office lists DARPA's various "institutionalized" programs, and examines the "coupling" programs (1966-1973) in some detail. Proposes a number of "lessons learned" from the experience.

Appended is NSF's 1973 "MRL Program Policy Statement" which governed the takeover of these interdisciplinary laboratories for materials research from DARPA.

Bindon, C. "Output Measures of Cooperative Research: The Case of the Pulp and Paper Research Institute of Canada"' *Scientometrics,* 3 (1981), pp. 85-106.

This paper describes and analyzes the scientific output of a cooperative industrial research institute (¼1Pulp and Paper Research Institute of Canada, PAPRICAN). It compares the employment patterns of McGill graduate students who have done their thesis research under the auspices of the industrial laboratory with graduate students from the same departments who have not worked at PAPRICAN. A comparison is also made of the publication practices of three groups: PAPRICAN staff not associated with the university (McGill), the PAPRICAN staff who also hold academic appointments at McGill, and the faculty of the Chemistry Department at McGill who do not hold staff positions at PAPRICAN.

It is found that the academic association with PAPRICAN during graduate research has a significant impact on the number of students who go on to careers in industry.

The publication record is compared to various standards so as to judge various qualities of the scientific output of the different groups. The PAPRICAN staff performs as would be expected of industrial researchers, and the McGill faculty show normal characteristics for an academic group. However, those who hold positions in both the industrial institute and the academic sector reveal the special role they play in linking the "science" of the second with the "technology" of the first.

Bok, Derek. "President's Report: Business and the Academy" *Harvard Magazine*, May/June 1981, pp. 23-35.

Can the universities enter the marketplace without subverting their commitment to learning and discovery. This indepth review covers most of the issues, starting from the position that better industrial/commercial utilization of academic research (technology transfer) is an important and desirable goal.

Bok posits six conditions necessary to maintain the highest quality of fundamental research in science, and examines the state of academic science with reference to each one. He further posits four dangers to the quality of academic science from increased emphasis upon technology transfer.

- "...the prospect of reaping financial rewards may subtly influence professors in choosing which problems they wish to investigate."

- "...professors may be diverted from any form of research (and teaching) in order to perform other tasks involved in the process of technological development."

- "...the risk of introducing secrecy into the process of scientific research."

- "...a threat to the quality of leadership...the state of morale...(and) the reputation for disinterested inquiry (that) helps to preserve the confidence and respect of the public— a state of mind that is ever more essential to the progress of academic science as its dependence on external support continues to rise."

Borstein, Morris, *et al. The Planning and Management of Industrial Research and Development in the USSR.* Joint US-USSR Science and Technology Exchange Program, Final Report, Technical Note SSC-TN-7557-7, under NSF Grant INT78-18699, Task 1, June 1980. 63 pp.

Report of a December 1979 visit by a US delegation of specialists to study the Soviet experience in planning and management of research and development, and the introduction of the results of R&D in "Science-Production Associations" (N.P.O.s).

Describes case studies of two N.P.O.s in which research-oriented institutes for scientific research are associated with experimental and full-scale production plants. Instructive financial comparisons are drawn with the US corporation Union Carbide.

Branscomb, Lewis M. "Opportunities for Cooperation Between Government, Industry, and the University," *Annals of the New York Academy of Sciences*, 334, December 14, 1979. pp. 211-227.

The author of this article is Vice President and Chief Scientist of IBM, a former Director of the National Bureau of Standards, and since 1980, Chairman of the National Science Board.

The article focusses attention on the inadequacy of "technology demonstration projects" as a government means to stimulate commercial technology. It discusses two possible alternatives for government-industry-university cooperation in technology development: "Exploratory Generic Technology," and, more speculatively, "Cooperative Development of Product Prototypes."

The typical Federal concern with commercial technology development has involved massive demonstration projects, e.g., in synfuels, solar energy, and personal rapid transit. The shortcoming of this approach is that it leaves out the costly investments in engineering and production tooling and processes that make the product commercially manufacturable. The author uses the example of the proposed Cooperative Automotive research Program to illustrate the lack of connection with product and process design and manufacturing engineering.

Branscomb, Lewis M. "Strengthening Industry's University Connection," *The Bridge* (National Academy of Engineering), 2, Fall 1981. pp. 35-38.

Article by the Vice President and Chief Scientist of IBM and Chairman of the National Science Board argues for the need for increased flexible funding of university research and training in science and engineering through corporate philanthropy. The IBM Program of Departmental Grants is discussed— the program makes grants of $25,000 to selected departments in fields of science and engineering relevant to IBM.

The British Council. *Academic/Industrial Collaboration in Britain and Germany: Proceedings of the British-German Seminar on Academic Research and Industry.* The British Council, Cologne, February 1977. 31 pp.

A report of two days of discussion of academic research and industry by six German and six British senior researchers, administrators, and managers from industry and the universities.

The objectives of the seminar were to examine and compare experience in the two countries and to make recommendations on the ways in which academic institutions can usefully increase or more effectively select the industrially orientated aspects of their scientific research, but without essentially impairing their freedom of study. The discussions focussed principally on engineering and those technologies and related sciences which support the manufacturing industries.

Brodsky, N., Kaufman, H. G., and Tooker, J. D. *University Industry Cooperation: A Preliminary Analysis of Existing Mechanisms and their Relationship to the Innovation Process.* New York: NYU Center for Science & Technology Policy, July 1979. 108 pp. [Under National Bureau of Standards Order No. NB79NAA/A8898.]

A catalogue of existing university-industry relationships with short descriptions of case examples. Assessment of contribution of each type to four phases of the innovation process:

- Additions to knowledge/experience pool;
- Development of new concepts;
- Development of new products and processes;
- Market development.

Brown, Alfred E. "The Industry/University Interface in America Today." Paper presented at the American Society for Metals, Materials, and Processes Congress, Cleveland, Ohio, October 28-30, 1980. 18 pp.

A manager from the Celanese Corporation discusses: (1) current mechanisms of industry/university cooperation; (2) barriers to cooperation; (3) suggestions for improvement of the interface. Leans heavily on the 1978 NYU study of industry/university connections. His suggestions include: more effective communication to professors by companies of their research interests; greater personnel movement—including permanent career changes—between the sectors; university establishment of interdisciplinary research centers; experimentation with novel joint arrangements.

Brown, George E., Jr. *University-Industry Links: Government as Blacksmith.* Paper presented at AAAS Symposium on "Government/Industry/University Relations," San Francisco, CA, January 5, 1980. 16 pp.

Congressman Brown assesses some effects of the changing environment for innovation upon existing and potential university-industry linkages. Describes six current Federal efforts to foster linkages, and six additional areas of linkage which "should be considered."

Bugliarello, George. "Focusing on the Function of the University." *Proceedings from the First Midland Conference,* sponsored by Dow Chemical Company, October 1979. pp. 153-170.

Useful brief compilation of statistics on the sources of support for and performers of R&D, focusing on the university-industry relationship. Presents more detailed information on chemistry and chemical engineering.

Valuable listings of eight major obstacles to a more fruitful university-industry relationship, and six strategies for dealing with these problems.

Business Week, Special Report, "The Second Green Revolution: Harnessing Biotechnology to Produce More Food with Less Energy." August 25, 1980. 4 pp.

Discusses university, industrial, and Government activities in plant bioengineering and focuses upon the "rapid buildup in corporate bioengineering research." Notes the competition between academic and corporate laboratories for competent scientists.

Cannon, Peter. "A Model for Industry-University Minority Doctoral Engineering Programs," *Research Management,* July 1980, pp. 21-23.

Dr. Cannon, Vice President for Research, Rockwell International, describes a program begun 3-1/2 years ago by Rockwell International Science Center (Rockwell's corporate research laboratory) aimed at increasing the number of minority engineers with Ph.D.s in solid state electronics.

The principal mechanism utilized was to sub-contract company funded research on gallium arsenide to two historically black universities—Howard and North Carolina A&T. NASA has also participated in this project.

Cantwell, Katherine M. "University-Industry Research Relationships at the Stanford Synchrotron Radiation Laboratory." A report submitted to the National Science Board, July 1980. 6 pp. and appendix.

The Assistant to the Director of the SSRL describes joint industrial-university cooperation at the laboratory.

All of the advisory panels have industrial members. Of the 88 institutions experimenting at SSRL, 26 are private corporations; and of the 309 proposals for research at SSRL active in March 1980, 55 involved joint university-industrial research.

Three types of cooperation are identified:

- Cooperation on specific research proposals;
- Industrial contributions to facility beam line development and instrumentation;
- Implementation of new scientific techniques by industrial groups, which then become available to the general user community.

A list of industry-university proposals is appended.

Chemical Week. "Weighing University Research Proposals." February 3, 1982, pp. 55-56.

Describes Monsanto's new Office of External Research and Development—a central corporate clearing house to weigh all university grant proposals—whether internally or externally generated. The article also briefly discusses mechanisms employed at Dow Chemical and DuPont for initiating research contact with universities.

Committee on Economic Development. *Stimulating Technology Progress.* (New York & Washington, DC. Committee on Economic Development, January 1980) 96 pp.

Discusses the nature of technological progress and its relationships to economic growth. Focuses primarily on the hindrances to technological progress required by tax policies, Government constraints upon innovation, and patent policies. The role of universities in basic research is briefly discussed. Recommends provision of a tax credit for support of nonproprietary university research.

Council for Financial Aid to Education. *Voluntary Support of Education, 1979-80.* New York: CFAE, May 1981.

An annual survey of educational philanthropy dating from 1954-55. The survey for 1979-80 reports actual returns from each of the participating 914 four-year colleges and universities and 105 two-year colleges. These data are extrapolated to arrive at estimates of total national voluntary support of colleges or universities—the total for 1979-80 being $3.8 billion. It is estimated that 15.2% of the total, or $577 million, were gifts earmarked for research purposes. "Business corporations contributed a record 18.3% of total voluntary support as a result of a 25.2% increase in their grants."

Council of Graduate Schools/National Science Foundation (CGS/NSF), *Industry/University Cooperative Programs: Proceedings of a Workshop Held in Conjunction with the 20th Annual Meeting of the Council of Graduate Schools in the United States, December 2, 1980.* [illegible]3 pp.

Useful compilation of cases of a variety of academic/industrial programs both from industrial and university perspectives. University programs discussed include: MIT Industrial Liaison Program, University of Delaware Composites Center, Case Western Reserve Polymer Science and Engineering, Materials Research at Pennsylvania State University, Animal Science Programs at Iowa State University, and a cooperative computer science degree program at New Mexico State University. Companies expressing their perspectives included: Shell Development, Johnson & Johnson, Pfizer, IBM, and Rockwell International. Also described is the unique Philadelphia Association for Clinical Trials—a consortium of six area academic medical institutions which aims to coordinate the resources available to provide an attractive opportunity for the placement and performance of clinical trials of new drugs and devices.

Culliton, Barbara. "Harvard and Monsanto: The $23-Million Alliance" *Science,* 25 February 1977, pp. 759-763.

An intensive case study of this highly visible agreement. Discusses:

- The antecedents of the agreement; the "readiness" and motivations of the parties to cooperate. One of the Principal Investigators had been a long-time Monsanto consultant, and Monsanto wanted a "window" on the new biology as well as rights to a long-shot possible cancer cure.
- The tortuous process of negotiation;
- The patent and publication issues and their resolution (Harvard changed its patent policy);
- The appointment of a prestigious national advisory committee to oversee the public interest aspects of the agreement;
- Three kinds of monetary support which are estimated to total $23 million over twelve years:

(1) $200,000 a year for each of the co-investigators;

(2) $1.4 million to equip laboratories;

(3) A $12 million endowment—current income from which would support the project research, but which would ultimately be used as general, string-free funds.

Culliton, Barbara. "Biomedical Research Enters the Marketplace," *New England Journal of Medicine,* 304 (May 14, 1981), pp. 1195-1201.

Reviews recent steps in the progress of biotechnology—in particular recombinant DNA and monoclonal antibody techniques—toward front stage. The role of the press in publicizing the phenomenon is examined. A brief history of Harvard's patent policy is presented, followed by a description of Harvard's proposed biotechnology company and a discussion of the various arguments and points of view that led to its rejection.

The suit and countersuit between Hoffmann-LaRoche and the University of California over the proper utilization of the KAI cell line which produces interferon are described and discussed as an example of the difficulties of establishing substantial collaboration between academic institutions and industrial corporations.

Concludes that there is room for collaborative arrangements that suit both sides.

David, E. E., Jr. "Science Futures: The Industrial Connection" *Science*, March 2, 1979. pp. 837-840.

The president of Exxon Research and Engineering Company explores the idea that the traditional diversity of mechanisms for the transfer of knowledge and ideas to industry, as well as the communication of realistic problems to academic researchers, may not be adequate for the future.

A rich and detailed discussion of trends and characteristics of industrial research laboratories is compared with a cursory treatment of academic orientations. The paper concludes with an optimistic review of "strands for the industrial connection."

Davis, Bernard D. "Sounding Board: Profit Sharing Between Professors and the University?" *New England Journal of Medicine*, 304, May 14, 1981, pp. 1232-1235.

Weighs the pros and cons of two mechanisms by which university inventions enter the commercial market:

- Patents;
- Formation of private corporations by faculty members.

Presents arguments for a third kind of arrangement—institutional profit sharing—which is seen as both providing a fair share of profits to the university and the scientist inventor, while avoiding some of the dangers to science posed by the existing arrangements. Davis argues that the rejected Harvard proposal for profit sharing did not receive a fair hearing due to high emotions, press ballyhoo, and the Genentech stock offering episode.

Davis, Lance E. and Kevles, Daniel K. "The National Research Fund: A Case Study in the Industrial Support of academic Science." *Minerva*, 1974, 12:207-220.

The story focuses on the period 1915-1932 and the attempts of a number of individuals to generate industrial support for "pure" scientific research. The eventual failure of the effort provides an instructive case study in the behavior of business enterprises in the financing of academic research.

George E. Hale, of the Mt. Wilson Observatory, was instrumental in the creation of the National Research Council (NRC) in 1916 which was designed to bring together government, industry, and the universities to mobilize science and engineering for the national defense. In 1918 the NRC was made a permanent agency, and Hale had it create an Industrial Advisory Commission, which he encouraged to promote a campaign for business support for university science. In 1925 a plan and organization emerged when the National Academy of Sciences (NAS) authorized the creation of a National Research Endowment—which was to raise $20 million in capital from industry, to be disbursed by the NAS as grants in aid of research. The word "Endowment" was soon changed to "Fund" because corporations were not permitted to engage in philanthropy—they had to demonstrate that donations worked to the corporation's profit-making advantage. Herbert Hoover was chairman of the Fund. But in three years the fund had raised less than half of its goal and that from a few large corporations. The goal was reduced to $10 million, and this amount was pledged by 1930, but when the Fund tried to call in the pledges in the first year of the Depression, the National Electric Light Association, a trade association of electrical generating and equipment manufacturing firms which had pledged $3 million, found that its members could not pay. By 1932 the promoters agreed that the National Research Fund was dead.

The economic-theoretical concept of "externalities" is used to explain the failure of the National Research Fund (NRF). "The campaign for the NRF was an attempt to finance academic science in which those who paid the costs could not avoid having much of the resulting benefits flow to others"—the "free rider" problem. Eventual government funding of basic research provided a solution to the problem that gained the support of industrial corporations.

Declercq, Guido V. "A Third Look at the Two Cultures: The New Economic Responsibility of the University." *International Journal of Institutional Management in Higher Education*, July 1981.

The Administrator of the Catholic University of Leuven in Belgium explores the idea that the relations between the economy and the world of learning and research are changing under the pressure of the scientific revolution, as the economy of the developed world is increasingly based on high technology and applied science.

"Universities are being drawn to the centre of high technology based national economies from their former position at the outer fringe of economic society. As a result of this new development, universities are *being forced into new roles for which many are not prepared* and that *raise a number of new and urgent questions.* This may lead, in Eric Ashby's words, to a "thorough revision of the inner logic of universities." (Eric Ashby, *Adapting Universities to a Technological Society*, Jossey-Bass, 1974. p. 114) We are fast moving away from the monastic conception of Newman's university with its pursuit of knowledge irrespective of its utility."

"The new economic responsibility demands that the university in the innovation process, develop a broker's function, either by the university itself or by means of professional outside help, to bring the two parts of the innovative process together." Several such brokerage mechanisms are discussed.

Declercq, Guido V. "Technology Transfer from Campus to Industry" *International Journal of Institutional Management in Higher Education*, 3, October 1979, pp. 237-252.

Since World War II universities have been considered as elements in industrial development of countries, and more recently in terms of their functions as sources of innovative ideas for economic regeneration. This article examines the question of how universities should fulfill this role.

A discussion of three general questions is followed by examination of examples of mechanisms to improve university-industry interfaces in several European countries, Canada, and the United States. The three questions discussed are:

- Do universities have something to offer to industry?
- Does industry, or society, expect a return, in the form of inventions, from the large financial inputs that go into our higher educational system?
- Why are universities as such apparently weak in transferring technology to the marketplace?

"Existing professional transfer formulas" discussed include:

- Industrial liaison centers—possibly in cooperation with local or central governments;
- Profit-making or non-profit "campus companies;"
- Research parks.

Dickson, David. "'Summit' Set on Academe-Industry Big Links" *Science and Government Report*, 12, March 15, 1982. pp. 1-4.

Report on a scheduled meeting between the presidents of five major research universities and the presidents of about ten biotechnology companies to explore guidelines for future relationships. This activity is taking place as the State of California's Fair Political Practices Commission (FPPC) gave formal approval to a rule which will require university faculty members to disclose whether they have any financial interest in companies that provide them with research grants.

The case of Raymond Valentine, Professor of Plant Biology at the University of California's Davis campus is discussed at length. Professor Valentine was closely involved in setting up a private genetic engineering company in Davis—Calgene. He also had a $2.3 million research contract from Allied Chemical to investigate the nitrogen-fixing properties of plants. When it was revealed that Allied Chemical had purchased a large block of Calgene shares, conflict of interest concerns were raised which resulted in an ultimatum to Valentine from the U.C. Davis administration that he must either withdrawn from the research project or from Calgene—he chose to withdraw from the project.

The debate, however, continues on the difference between occasional consulting on the one hand, and long-term commitments involving substantial financial interest on the other. It was argued that the latter was "already stifling free exchange of information and ideas on the Davis campus."

Dietrich, J. J. and Sen, Rajat. "Government-University-Industry Interaction in Research and Development: A Case Study" *Research Management*, September 1981, pp. 23-25.

Two managers of the Diamond-Shamrock Company, a major force in electrochemical technology and in the chloralkali industry, describe the development of a cooperative agreement between the company, the U.S. Department of Energy, and Case Western University (Dr. Ernest B. Yeager, international leader in electrochemical research) for research in oxygen electrocatalysis.

The proximate goal of the research is to invent an oxygen depolarized air cathode which, if fitted to a membrane cell for the production of pure caustic, could save the U.S. chloralkali industry billions of kilowatt hours of electricity annually.

The article describes the organizational and legal arrangements which permit all parties to maximize their divergent interests.

Conclusions are drawn concerning the conditions for successful interactions of this kind.

Doan, Herbert D. "New Arrangements for Industry-Academic Research" *Research Management*, March 1978, pp. 33-35.

Two proposals are offered for interlocking university and industry research more closely, and thereby raising the effectiveness of the U.S. research effort.

Engles, E. F. "A New Initiative in Stimulating Industry/University Cooperation: The First Midland Conference on Advances in Chemical Science and Technology." Paper presented at the Congress of the American Society of Metals, Materials, and Processes, Cleveland, Ohio, October 30, 1980. 14 pp.

A research manager for Dow Chemical provides a useful account of the genesis and development of the 1979 Midland Conference and its 1980 sequel at Allentown, PA.

European Industrial Research Management association (EIRMA), Working Group Report No. 7, *Industry/University Relations*. Paris: EIRMA, 38 cours Albert Ier, 75008 Paris, France, 1972. 58 pp.

A useful discussion of the following topics:

- Mental attitudes;
- Joint and sponsored research;
- Exchange schemes;
- The role of government;
- The special situation of the small firm.

Discussion of each topic is followed by conclusions and recommendations.

Fakstorp, Jorgen and Idorn, G. M. "University-Industry Relations in Europe" *Research Management*, July 1978. pp. 34-37.

Two technical executives of Danish firms argue that because the political and social unrest of the sixties disrupted what ties there were between industry and academia, a dialogue should be initiated to explore cooperative R&D activities. Differences between the U.S. and European traditions relating to university-industry relationships are described—these are less developed in Europe. In addition, much of the post-war expansion of public funding for research resulted in the creation of a number of national research institutes which neither possessed a graduate program, nor cooperated with industrial sectors.

Farris, H. W. "The Campus and Industry" *Industrial Research*, April 1964, pp. 76-81.

The article by the associate director of the University of Michigan Institute of Science and Technology expresses an "aid to industry posture." Discusses four mechanisms for matching university capabilities with industry needs. Attempts to define appropriate kinds of industrially supported work in the university.

Fernelius, W. Conrad and Waldo, Willis H. "Role of Basic Research in Industrial Innovation" *Research Management*, July 1980, pp. 36-40.

An analysis of 78 case histories of successful commercial developments since 1965 was conducted to determine what role was played by basic research information (since 1945) in the process, and to evaluate the resultant economic benefits as quantitatively as possible.

Fox, Jeffrey. "Can Academia Adapt to Biotechnology's Lure?" *Chemical & Engineering News*, October 12, 1981, pp. 39-44.

Reviews the problems of conflict of interest, intellectual property, and the openess of scientific research created by the commercial vitality of the new biotechnology.

"As an idea, this technology has already touched off an epidemic of enterpreneurial activity that is running rampant on university campuses. Cool-headed scientists have turned into feverish schemers caught up in a heady delirium of corporate planning, real estate speculation for lab expansions, and market watching."

"Neither political leanings nor social standing is a guarantee of immunity from this new 'bug'. As one still resistant university scientist puts it, 'It's like the original version of the movie *The Body Snatchers*. You look into the eyes of someone and realize it's too late."

Report contains interviews with ten faculty members involved in commercial activities and a valuable summary of conversations with postdocs in the field.

Fox, Jeffrey. "Plant Molecular Biology Begins to Flourish" *Chemical & Engineering News*, June 22, 1981, pp. 33-44.

Informative survey of U.S. and international academic, industrial and joint activities in adapting genetic engineering techniques to plant molecular biology. The R&D thrusts of the various groups are discussed.

Fusfeld, H. I. "New Approaches to Support and Working Relationships." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

This article argues that more effective links in R&D activities must be forged between industry, academia, and government. Several new mechanisms are suggested.

Fusfeld, H. I. "The Recent Science and Engineering Doctorate from an Industry View." Paper presented at the AAAS Annual Meeting, San Francisco, CA, January 8, 1980. 15 pp.

Argues that stimulation of the growth of cooperative research between universities, government, and industry, on the basis of current mechanisms, "could amount to $500 million in five to ten years. This would support close to 10,000 Ph.D. scientists and engineers, about 40% of those not on faculty today, or about 25% of the research effort not accounted for by tenured faculty.... This expansion would not be in new funds, but would represent a restructuring and a shift in commitments from government and industry."

Gallagher, Colin. "Time for an Industrial Research Council." *Times Higher Education Supplement*, September 26, 1980. 1 p.

The Head of the Industrial Management Department at the University of Newcastle in Great Britain presents arguments for a national body to look after the university-based research needs of industry. A close analogue is made to the proposed U.S. National Technology Foundation.

Gilpin, Robert. *Technology, Economic Growth, and International Competitiveness.* A report prepared for the Subcommittee on Economic Growth of the Joint Economic Committee, Congress of the United States, July 9, 1975. Washington, D.C.: USGPO, 1975, 87 pp.

This report is excellent background reading for a broad understanding of the role of technology and research and development in the economy. It contains a thorough examination and assessment of the scholarly literature on the role of technology in economic growth, an examination of the performance of the U.S. economy in the light of this knowledge, and an assessment of the role of government in facilitating several strategies for growth.

In a section on Government Support and University Research, Gilpin advocates, "...the need for a new alliance between government, university, and private industry in newer areas of concern to replace the declining efficiency of the anachronistic alliance forged at the end of the Second World War. On the university side the situation is ripe for cooperative efforts which would invigorate scientific and technical research relevant to our emergent set of national priorities."

He also maintained that, "The government side of this potential alliance has yet to develop its full potential" due to inadequate leadership structure which at that time centered upon the Director of the NSF, and a lack of appreciation in the mission agencies of the importance of exploratory development and basic research.

A very useful section summarizes "what we know (and don't know) about industrial innovation" including a discussion of the role of basic research. Another section discusses what the government should and should not do.

A selected bibliography is appended.

Hamilton, W. B. "The Research Triangle of North Carolina: A Study in Leadership for the Common Weal" *South Atlantic Quarterly*, Vol. 65, Spring 1966, pp. 254-278.

"The tale of the Triangle is one of local and state leadership for the common weal and of the interrelationship of ideas and action, of cooperation among businesmen, university professors, and political leaders. The concept evolved by that leadership was unique at the time; its eventual realization was a product of such good old fundamentals as hard work, brains, persistence in the face of difficulties, and philanthropy; of the presence of universities growing in grace; of the exertion of political influence; and of an expanding national economy. A priceless ingredient was a decent state atmosphere for human relations."

The details of the story of the development of the Triangle from 1952 to 1965 are well told by this professor of history at Duke University.

Healey, Frank H. "Industry Needs for Basic Research" *Research Management*, November 1978, pp. 12-16.

The vice president for research and engineering of the Lever Brothers Company reviews data from NSB *Science Indicators*— 1976 bearing on the decline in industrial support for basic research.

Applauds the initiation of the NSF University Industry Cooperative Research Program and argues that "it is unlikely that industry will spend any more of its own money on basic research unless some positive incentive is provided."

Hencke, W. R., Greene, J. H., Rosner, D. E., and Nordine, P. C. "A Program for Student Involvement in Industrial R&D." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

This article describes a novel industrial research training approach in which students perform as consultants to industry on real-life problems.

Heylin, Michael. "Confusion Over Innovation Highlighted Again" *Chemical & Engineering News*, March 3, 1980.

Report on a February 1980 conference at Massachusetts Institute of Technology (MIT) on the role of cooperative R&D among industry, the universities, and government in stimulating technological innovation. The conference was cosponsored by the MIT Laboratory for Manufacturing and Productivity, and the NSF.

The article described the conference as "a love-in for cooperative research" but said that few new policy recommendations emerged.

Several individuals expressed reservations about university-industry cooperative programs—they were worried about unanticipated effects upon universities ("a potential threat to academic freedom") and the poorly understood linkage between growth in science and technology and growth in innovation.

Hill, Lamar. "Negotiating with the Community: UCI Industrial Associates" In OECD/CERI Centre for Educational Research and Innovation, *Institutional Mechanisms of Interaction Between Higher Education and the Community: Illustrative Examples,* Paris, OECD, 1980. CERI/CR/79.06.

This case study, written by an historian, examines the means employed by the University of California, Irvine, to negotiate with the surrounding community through a specifically created entity: UCI Industrial Associates. The case study begins with a background statement regarding the origins of UCI, a description of its environment, and a description of the circumstances surounding the organization of the negotiating entity. There follows a description of the development and current status of the Industrial Associates. In conclusion there is an analysis of the results of the negotiating entity's activities, of its relationship with the University, of the continuing problems which derive from the discordant mentalities in the University and the surrounding community, and of the integration of Industrial Associates with specific academic and research programs in order to reduce the mutual isolation which this discordance occasions.

Honan, James P. "Corporate Education: Threat or Opportunity?" *AAHE Bulletin*, March 1982, pp. 7-9.

A useful review of the literature on corporate-based education programs which have grown in both scope and magnitude during the past decade. Several large corporations including IBM, AT&T, Wang, and Xerox are assuming a major role in educating and training their employees in fields heretofore primarily the responsibility of colleges and universities. Some of the corporate programs are even granting degrees. Concludes that the corporate programs should be seen as an opportunity for higher education to become more sensitive to the needs of industry and to expand cooperative efforts. Bibliography.

Industrial Research Institute, Inc. *Industrial Innovation: The Impact of Federal Policies on Industry/University Relations. A Position Statement by the Industrial Research Institute.* New York: Industrial Research Institute, September 26, 1980. 1 p.

The IRI strongly supports increased interaction between industry and university research, and urges that Federal policies be developed to promote closer collaboration between universities and industrial organizations.

The recommended policies include:

• Tax incentives to stimulate industrial support of university research and graduate education;

• Federal funding agency programs to enhance coupling;

• Uniform patent policies which permit universities to retain title to inventions made using government funds;

• Improve forecasting of scientific and technical manpower requirements.

The NSF's University/Industry Cooperative Research Program is "especially commended." But, "the IRI views with great caution proposals to establish new 'Generic Technology Centers,' since there is significant risk that such laboratories may become a self-perpetuating drain on national resources and lack the necessary inputs on market needs and opportunities to be an effective force in the innovation process."

Industrial Research Institute/Research Corporation. *Contribution of Basic Research to Recent Successful Industrial Innovations* (Final Report to NSF under Grant No. PRA 77-17908, September 1979). 18 pp. plus 271 pp. of attachments.

Query of 529 companies to accumulate 54 usable case histories of industrial innovations.

Johnson, Elmima C. and Tornatzky, Louis G. "Academia and Industrial Innovation" in Gerard G. Gold (Ed.) *New Directions for Experiential Learning: Business and Higher Education—Toward New Alliances*, San Francisco: Jossey-Bass, 1981, pp. 47-63.

A useful analytical approach to university-industry linkages, geared toward their role in industrial innovation. An "array of operational options" is presented. Several integrating concepts from the literature on organization theory dealing with inter-organizational behavior are discussed: goal congruity and compatibility, boundary-spanning structures, and organizational incentives and awards.

These concepts are utilized in examining several cases described in the literature: MIT Polymer Processing Program, Harvard-Monsanto Research Project, Rockwell International-Black Colleges, NSF Innovation Centers, Harvard University-Genetic Engineering Company.

Kenyon, Sir George. "The Public View of the Universities: Direct Services to Industry." Speech to the 12th Commonwealth Universities Conference, Vancouver, B.C., Canada, August 1978. 14 pp. Summarized as "No Egg, No Chicken" in *Manchester Guardian*, March 6, 1979.

The Chairman of Manchester University's Council discusses university-industry relationships, both in training and research. Describes a range of efforts currently underway by the 44 British universities to "sell themselves to industry."

"Teaching companies" and "sandwich courses" are two instructional innovations bridging the gap between the sectors. Several universities have formed separate companies for the purpose of acquiring industrial research contracts.

Kiefer, David M. "Forging New and Stronger Links Between University and Industrial Scientists" *Chemical & Engineering News*, December 8, 1980, pp. 38-51.

Substantive overview of current developments in the area. Includes discussion of:

- The available statistics;
- Existing NSF programs;
- The Carter Administration initiatives for Department of Commerce support of "generic technology centers" and the Cooperative Automotive Research Program;
- The Exxon-MIT combustion research agreement;
- The Harvard-Monsanto arrangement for research in biology and biochemistry of organ development;
- The University of Delaware Center for Catalytic Science and Technology with 20 industrial sponsors;
- An extensive treatment of the movement toward establishment of a Chemical Research Council.

Langrish, J. "The Changing Relationship Between Science and Technology" *Nature*, 250, August 1974. pp. 614-616.

The author examines the premise that technological innovation stems from scientific research, and suggests that relative to the early decades of the twentieth century, the relationship between science and technology has changed drastically. To test this premise, abstracts in five volumes of the *Journal of the Society of Chemical Industry* between 1884 and 1952 were classified by institutional locus, the main geographic divisions being Britain, the United States, and Europe. A marked decline in university-based contributions is paralleled by a concomitant increase in industrial-based research over time. When citations from 1957, 1961, and 1967 Industrial Reviews are examined by institutional locus, again a notable decrease in the relative contribution of the university to industrial chemistry emerges.

Lepkowski, Wil. "Academic Values Tested by MIT's New Center" *Chemical & Engineering News*, March 15, 1982, pp. 7-12.

An in-depth description and critique of the $125 million Whitehead Biomedical Research Institute at MIT. The story is constructed from interviews with David Baltimore, the head of the Institute, and both proponents and opponents among the MIT faculty and administration. There is discussion of the issue of potential conflict of interest centering on Baltimore's reported $3.5 million equity stake in the biotechnology firm of Collaborative Research, Inc. The president of this company is also interviewed.

Libsch, J. F. "The Role of the Small, High Technology University." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

Smaller universities need means to achieve a 'critical mass' effort of people and capabilities in selected research areas without destroying opportunities for individual research efforts.

Linvill, John G. "University Role in the Computer Age" *Science*, Vol. 215, February 12, 1982, pp. 802-806.

The Director of Industrial Programs at Stanford University's Center for Integrated Systems discusses the role of the university in the development of manpower resources in computer technology, and opportunities in university-industry linkages.

Little, Arthur D., Ltd. *New Technology-Based Firms in the United Kingdom and the Federal Republic of Germany.* London: A. D. Little, Ltd. for the Anglo-German Foundation for the Study of Industrial Society, 1977.

This comparative assessment of the environment for new technology-based firms (NTBFs) was undertaken to provide a detailed analysis of the environmental factors within each country which influence the development of NTBFs, and to make recommendations on how the creation and growth of such firms might be encouraged.

In contrast to the situation within the U.S. where there are several thousand NTBFs with sales of billions of dollars, there are only about 200 NTBFs in the U.K. and slightly less in Germany.

Among the factors cited as more favorable in the U.S. for the generation of NTBFs are:

- greater mobility of individuals between academic institutions and private industry;
- the behavioral and attitudinal character of American scientists, many of whom are willing to set up their own businesses in order to exploit their technical knowledge.

A section on the role of universities in "spinning off" NTBFs reports on two British studies in 1969 and 1970 which documented the reluctance of university scientists to become involved in industry.

Lohr, Steve. "Campuses Cementing Business Alliances." *New York Times*, November 16, 1980.

Prompted by Harvard's disclosure that it was considering establishment of a commercial genetic-engineering company, this article reports on a range of issues and activities in the university-industry area. In addition to the standard examples of Exxon-MIT and Harvard-Monsanto, mention is made of: a Purdue-Control Data project on computer design and production, and establishment by Estee Lauder of an Institute of Dermatology at Johns Hopkins University.

Lucchesi, Peter J. "Exxon's University-Industry Program" *Proceedings of the First Midland Conference on Advances in Chemical Science and Technology.* September 1979. pp. 173-179.

Describes the following Exxon programs:

- Scientific Grant Program—about $500,000 a year in grants to professors selected by Exxon's basic research staff.
- (Under development) Exxon Fellowship's Program to assist promising non-tenured faculty.
- Visiting University Scientists program—currently supporting eight university scientists working summers at Exxon labs.
- Exxon Faculty Fellow program—five year support to a prominent academic scientist who must spend 20% of his time at Exxon labs doing work of his own choice. One Fellow currently has support, and a second is soon to be named.
- Exxon-MIT 10-year agreement on combustion research—support at about $600,000 a year. Participating faculty devote 50% of their research time to working on agreement projects.

Lyon, R. E., Jr. "A Bridge Reconnecting Academia and Industry through Basic Research" (Paper presented to the George Washington University, Graduate Program in Science, Technology, and Public Policy. Seminar series on, "The Research System for the 1980's: Public Policy Issues" March 26, 1980. 5 pp.

The paper explores the following five main points:

- The "connection" should be at the basic research level;
- The "connection" must be at the cooperative, working level;
- Government should assist the process, but not attempt to "steer the science and technology;"
- A tax incentive for industry is the first step;
- "Industry funding should supplement and complement, not totally replace" Government funding of academic research.

MacCordy, E. L. "Prospects for Government/University/Industry Research Cooperation." Paper presented before the Division of Science Resource Studies, National Science Foundation, Washington, D.C., September 22, 1980.

Explores the emerging role of the Federal Government in stimulating greater collaboration between universities and the industrial sector in research and development, and discusses the potential such linkages have for matching the technological development interests of industry with the research interests of university scientists. Government participation is described as including: the continued financing of fundamental research through university laboratories; the development of a climate of understanding and support for this collaborative process; the identification and evaluation of impediments in the innovation process; and the collection, analysis, and publication of statistics to monitor the progress of this triparty arrangement. Suggestions for ways in which universities and the industrial sector might contribute to the development of a research partnership are also provided.

Mansfield, Edwin. "Basic Research and Productivity Increase in Manufacturing." *American Economic Review*, 70 (December 1980), pp. 863-873.

The results of Manfield's study indicate that there is a statistically significant and direct relationship between the amount of basic research carried out by an industry, or by a firm, and its rate of increase of total factor productivity, when its expenditures on applied R&D are held constant.

Mansfield also collected new and original data on basic and applied R&D expenditures of 119 companies, concerning the changes in the mix of R&D between 1967 and 1977, and the changes they expect between 1977 and 1980. The findings indicated that "practically all industries have cut the proportion of their R&D expenditures going for basic research. Most industries have cut the proportion going for relatively risky projects."

Mansfield cautions that correlation is not causation and that basic research expenditures could be a function of high productivity growth rather than vice versa.

Mansfield, Edwin, *et al.*, *Research and Innovation in Modern Corporation.* New York: WW Norton, 1971

This classic textbook treats the several phases of R&D in several R&D intensive industries. In Chapter 8 on major pharmaceutical innovations (originally the dissertation of co-author Jerome Schnee) data are presented on the sources of innovations for 68 of the most widely used drugs in the U.S.

Three major findings are advanced:

• "External sources—sources other than the innovating firm—have played a major role in the technological progress of the ethical pharmaceutical industry in the U.S. These external sources provided 54% of the discoveries which produced pharmaceutical innovations during 1935-1962.... in particular the innovations contributed by universities, hospitals, and research institutes (23% of the...total) had substantial...importance."

• "...the grouping of the innovations into two time periods indicates that external sources have declined in importance over time." During 1935-1949 external sources provided 62% of the discoveries, which declined to 43% during the 1950-1962 period.

• There was considerable variation among product categories in the sources of discoveries. A major factor accounting for these differences is the existing state of the art within the categories. The biological test and screening systems used by pharmaceutical firms have greater potential for uncovering new and useful chemical structures in those areas where there is reasonably high correlation between animal tests and clinical trials—e.g., digestive and genitourinary drugs, and respiratory system drugs. But in product categories not amenable to biological tests system approaches, such as drugs for neoplasms and the endocrine systems, the non-screening approaches of external sources have been relatively more fruitful.

Mansfield, Edwin. "Tax Policy and Innovation" *Science*, March 12, 1982, pp. 1365-1371.

A comprehensive, scholarly review of what is known about the quantitiative impact of particular tax measures upon the rate of innovation and R&D investments. Includes a detailed examination of the provisions of the Economic Recovery Tax Act of 1981 relating to R&D investments.

Concludes, "Without question, our nation's tax policies have a major impact on the rate of innovation. But because practically no studies have been conducted to estimate the effects of past or proposed tax changes, we have little or or no dependable information concerning the quantitative impact of particular changes of this sort on the rate of innovation."

Marcy, Willard. "Patent Policies at Educational and Nonprofit Scientific Institutions." Paper presented at the 175th meeting of the American Chemical Society, March 13-14, 1978. ACS Symposium Series 81. 12 pp.

Provides a brief history of the development of administrative mechanisms for handling the transfer of useful technology from the university laboratory to the marketplace, beginning with the pioneer efforts of Dr. Frederick Gardner Cottrell who founded the Research Corporation in 1912. Reviews the purpose, objectives, and administration of university patent policies, including procedures for reporting inventions and for distributing income realized from patents. Considers factors influencing university patent policies such as Government policies and foreign patenting opportunities. Concludes with several examples of basic problems ".... which suitably drafted patent policy guidelines can help resolve."

Massachusetts Institute of Technology, Office of Sponsored Programs. "Research Agreements with Industrial Sponsors: Review Draft." MIT, Cambridge, MA, November 5, 1981. 31 pp.

This comprehensive guide summarizes the broad principles and specific contract provisions applicable to research agreements between MIT and industrial and commercial organizations. George Dummer, Director of the Office of Sponsored Programs, states in a separate letter, "This is still a review draft.... consequently it shoud not be cited as representing an official statement of MIT policy, although it accurately reflects current practice."

McConnell, J. Douglas. "Productivity Improvement in Research and Development and Engineering in the United States" *Society of Research Administrators' Journal*, Vol XII (Fall 1980), pp. 5-14.

This article focuses primarily on internal management and personnel factors in productivity. However, a useful listing is presented of four nationwide factors that accounted for decreasing R&D productivity in the U.S. from 1960 through 1975.

- Changes in capital gains tax codes in the late 1960's;
- An obsession in the 1960's among many companies with the idea of rapid growth while minimizing risk to short term earnings;
- Low (compared to Japanese and German industry) investment in process engineering and manufacturing technology R&D;
- Overenchantment by many companies with the glamor of high technology. "One mining [company] supported research in solid state physics and semiconductors for some 15 years without a payoff because top managment felt it enhanced the image of the company."

Mogee, Mary Ellen. "The Relationship of Federal Support of Basic Research in Universities to Industrial Innovation and Productivity." In, U.S. Congress, Joint Economic Committee, Special Study on Economic Change, Volume 3, *Research & Innovation: Developing a Dynamic Nation*. Washington, D.C.: U.S. Government Printing Office, December 29, 1980. pp. 257-279.

Section II examines "The Relationship of Basic Research to Industrial Innovation" and concludes that the contribution is usually delayed and indirect, but that science, "seems to act as an "engine" of technology."

Section III examines "The Relationship of Industrial Innovation to Productivity," and concludes that there is consensus of scholars that, "the contribution of R&D to economic growth is high." Section IV on "The Relationships Between Universities and Industry" notes the "natural barriers" between university and industry that may obstruct the transfer of academic basic research to industrial utilization. These include differences with regard to patents, publications and freedom of research directions. Concludes "the transfer of knowledge between academic science and industrial application requires active effort on both sides."

Miller, Julie Ann. "Spliced Genes Get Down to Business." *Science News*, Vol. 117, March 29, 1980, pp. 202-205

Examines the founding and growth of Genentech, Cetus, Biogen, and Genex.

Murray, Thomas J. "Industry's New College Connection," *Dun's Review*, May 1981, pp. 52-54, 59.

An overview of developments in the university-industry area. The optimistic tone of the piece is reflected in the following: "Both academic and corporate leaders seem confident that they can meet their mutual goal to increase industry's share of total college research to 15% or $600 million during the 1980's. To help the cause along, they are currently lobbying hard to get tax incentives for corporate funding of projects."

Mullins, R.T. "A Technical Enrichment Program for Minority Students." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

A preparatory and support program at Stevens Institute of Technology helps engineering students overcome the deficiencies of high school education and lowers the attrition rate.

Nason, Howard K. and Steger, Joseph A. *Support of Basic Research by Industry*. Washington, D.C.: National Science Foundation, 1978. 55 pp. [Prepared for NSF/STIA/SRS under Grant NSF C-76-21517.]

Presents results of a 1975 survey of company expenditures for R&D. Concludes that there had been a "real" decrease in industrial basic research expenditures. Advances five principal explanations for the decline.

National Academy of Engineering. *Academe/Industry/Government: Interaction in Engineering Education. A Symposium at the Sixteenth Annual Meeting October 30, 1980*. Washington, D.C.: National Academy Press, 1981. 74 pp.

Panels of distinguished speakers addressed three broad topics:

In-house Industry Engineering Education Activities. Representatives from GM, IBM, Bell Laboratories, Hughes Aircraft, and GE described their programs.

Academe-Industry Joint Programs. Programs are described at Digital Equipment Corp. (for equipment grants to universities); the Purdue-Control Data Corp. effort in the CAD/CAM area; another CAD/CAM course at UCLA assisted by several corporations.

The Support Role of Government. Federal programs are described including NSF's Industry/University Cooperative Research program, NSF's University/Industry Cooperative Research Centers, Innovation Centers, and its graduate fellowships. DOE's programs to help support university industry interaction in research are described, as well at its $3 million institutional awards program which requires the universities to develop mechanisms to ensure that there is long term industrial participation. The role of the DOE supported National Laboratories is also mentioned.

National Association of College and University Business Officers. "Survey of Institutional Patent Policies and Patent Administration," *Administrative Service Supplement*, March 1978.

Examines the findings from a survey of university patent policies and practices conducted by the Society of University Patent Administrators in 1977. Data are tabulated for the 48 major research insititutions responding to the survey, and the implications of the results are discussed. More than 70% of the responding institutions have established "patent committees" whose functions include making decisions on patenting inventions, formulating patent policy, and determining royalty distributions for the institution. Well over 80% of the institutions use patent management firms such as the Research Corporation. The majority of institutions invest their share of royalties from patenting activities in further research. Among the other issues analyzed are: the number of patents applied for and issued during the last 10 years; the use of arbitration in the event of disagreement about the institution's rights in an invention; methods to obtain invention disclosures; institution patent agreements with Federal agencies.

National Commission on Research. *Industry and the Universities: Developing Cooperative Research Relationships in the National Interest*. August, 1980. 38 pp.

Reviews the post-war funding history of basic research in universities and industry. Concludes that, with appropriate safeguards, increased research relationships between universities and industry, "currently have an opportunity for growth, and out of that growth will come increased innovation."

Report contains a systematic statement of the benefits and hazards of cooperative research relationships to universities, industries, and government. In addition, the roles and responsibilities of the partners are described. A one-page bibliography is appended.

National Research Council, "Research in Europe and the United States," Chapter 13 in *Outlook for Science and Technology: The Next Five Years*. San Francisco, W. H. Freeman, 1982.

This chapter describes the R&D systems of the United Kingdom, France, and Germany. The materials were primarily collected and written up by Dr. Charles V. Kidd of George Washington University and Dr. Bruce Smith of the Brookings Institution. Each country report contains a number of references to university-industry research and training linkages, seen in the perspective of the total research system of the country.

Noble, David F. and Pfund, Nancy E. "The Plastic Tower: Business Goes Back to College." *The Nation*, September 20, 1980, pp. 233, 246-252.

Noble teaches the history of technology at MIT, and Pfund is a research associate at the Health Services Research Division of Stanford Medical School.

The authors view the emergent phenomenology of university-industry relationships from a socialist perspective. The universities and their faculties are seen as being induced through a variety of incentives into structuring their research along lines dictated by corporate profit motives.

The universities are seen as "an inherited resource that rightfully belong to us all, a substantial social investment" with a large degree of public accountability for their work. "This fact is recognized explicitly in the case of government support. Funds are given in the name of the citizenry by government to foster social ends that are shaped and defined in the political process—a multiplicity and diversity of ends which oftentimes conflict."

The authors argue that in the case of the $23 million Harvard-Monsanto agreement, "the firm has in essence transformed part of the public sector social resource into a private sector preserve, with little public scrutiny or accountability over its use of the facility."

The authors further argue that in the eager campus quest for industrial support, a social climate has been created in which dissenters and critics of industrial perspectives will be elbowed aside and their voices suppressed.

Noble's book, *America by Design: Science, Technology and the Rise of Corporate Capitalism* (New York: Oxford University Press, 1979.) provides a full historical analysis from this general perspective.

Norman, Colin. "MIT Agonizes Over Links With Research Unit," *Science*, October 23, 1981, pp. 416-417.

Reports on the debate in the MIT community about the proposed establishment of the Whitehead Institute for Biomedical Research with a unique affiliation between the institute and MIT. Mr. Edwin C. Whitehead, a self-made millionaire, proposed to spend $20 million to build and equip the institute, provide $5 million a year in operating funds, and leave an endowment of $100 million when he dies. He characterized the proposed institute as "a purely philanthropic enterprise."

Faculty concern revolves around three issues: the administrative structure, appointment of faculty, and selection of research projects.

Omenn, Gilbert S. "University/Industry Research Linkages: Arrangements Between Faculty Members and Their Universities." Paper presented at AAAS Symposium on Impacts of Commercial Genetic Engineering on Universities and Non-Profit Institutions, Washington, D.C., January 6, 1982.

Substantive review of cases of faculty who have sought opportunities to combine academic and commercial roles. Materials are included on:

- The history and functioning of the Wisconsin Alumni Research Foundation (WARF);
- Indiana University and Crest Toothpaste;
- MIT's Industrial Liaison Program;
- Two cases in econometric forecasting—Otto Eckstein's Data Resources Inc. and Laurence Klein's Wharton Econometric Forecasting Association;
- Medical school clinical practice plans, including income sharing plans for basic science faculty.

Omenn prescribes a pluralistic approach but says, "We should encourage coherent institutional responses and explicit, openly negotiated arrangements with their most precious resource—their faculty—for their mutual benefit and for the public interest.

Pake, George E. "Some Industrial Perspectives on the University-Industry Relationship," Council of Graduate Schools, *Communicator*, Vol. 12, April 1980, pp. 1-2, 8-10. Revised version published in *Physics Today*, January 1981, pp. 44-47.

The Vice President for Corporate Research of the Xerox Corporation presents a typology of mechanisms for university-industry interaction. They include:

- Participation of business and industrial leaders in university governance: (1) Boards of Trustees, (2) Visiting Committees;
- Direct support by industry of programs in universities: (1) Direct funding of academic research programs, (2) Joint research ventures, (3) Company funded fellowships and scholarships, (4) Industrial philanthropic grants;
- University services provided to or for industry: (1) Continuing education programs, (2) Extension services, (3) Specially tailored short courses, (4) Industrial associate or affiliate programs.
- Enhancement of personal development of individuals: (1) Faculty sabbaticals in industry, (2) Industrial leaves to university faculties, (3) Faculty consulting to industry, (4) Placement of graduates in industry.

The role of Government is also discussed, especially in relation to tax arrangements for R&D investments.

Place, Geoffrey, "The Government Role in the Development and Commercialization of Technology" in NSF, *Science and Technology: Annual Report to the Congress*, June 1980 Volume II of the ASTR Commissioned Papers Series.

A manager of Procter and Gamble Co. discusses three factors upon which the effectiveness of the process of the development and commercialization of new technology depends. The third factor is, "The effectiveness of coupling among the various sectors of the national R&D resource." Cites several authorities to argue that the current level of university-industry coupling is far below optimum.

Explores possible Federal roles in stimulating these partnerships: "jawboning", matching industrial grants to universities with Federal awards, and tax incentives for industry support of university research.

Prager, D.J. and Omenn, G. S. "Research, Innovation, and University-Industry Linkages," *Science*, Vol. 207, January 25, 1980, pp. 379-384.

At the time of writing, Prager and Omenn were with the Office of the President's Science Adviser.

Carter Administration actions to enhance basic research and stimulate industrial innovation have focused attention on the importance of formal university-industry cooperative relationships in science and engineering. This paper examines the status of, and potential for, university-industry research consortia and research partnerships and the current and prospective roles of the federal government in stimulating such relationships. A useful typology of university-industry relationships is presented.

Rabkin, Y.M. and Lafitte-Houssat, J.-J. "Cooperative Research in the Petroleum Industry," *Scientometrics*, 1 (No. 4, 1979), pp. 327-338.

Paper describes an unusual historical case of cooperation in petroleum research between industry, Government, and the universities.

"After years of debate, the American Petroleum Institute (API), a trade association representing America's oil companies, decided in 1926 to sponsor nearly thirty research projects connected with various aspects of the science of petroleum. One of the projects, known as API Research Project 6, was conducted at the National Bureau of Standards (NBS) in Washington and from 1950, till its termination a decade later, at the Carnegie Institute of Technology in Pittsburgh. The project was remarkable in many respects. For one, while it was financially sponsored by the API, i.e. by the entire petroleum industry, its operation took place outside industry, and its results were openly published."

"The project's organization was of a novel cooperative nature. The cooperation among the oil companies embodied by the API, and the cooperation between the API, on the one hand, and the Federal Government and several universities, on the other, affected the goals and the modes of operation of Project 6. Both kinds of cooperation involved contradictions. One basic contradiction could be noticed in the initial formulation of the research program. It had to generate knowledge relevant to the interests of the petroleum industry. At the same time that knowledge had to be fundamental, i.e., not 'too relevant,' because the practical application and commercialization of the results had to be left to individual companies. The maintenance of a balance between relevance and fundamentality was a major concern for those involved in the research planning at the API."

Rae, John. "The Application of Science to Industry," in Alexandra Oleson and John Voss (eds.), *The Organization of Knowledge in Modern America, 1860-1920.* Baltimore: Johns Hopkins University Press, 1979. pp. 249-268.

The author, Professor emeritus of the History of Technology at Harvey Mudd College, provides a compact summary and interpretation of the uses of science by industry in the period covered.

"Since America was a new country...there was normally more work to be done than there were hands available to do it. There was therefore a premium on devising techniques and gadgets that supplemented labor. It was important to be able to make devices that worked, but it was not important to know why they worked."

The absence in America of well established universities or any considerable body of "gentleman scientists" led to an American tradition that 'minimized the pursuit of science for its own sake and magnified...the untutored but ingenious gadgeteer." Further, the absence of sufficient trained craftsmen in America strengthened the role of the "cut-and-try" tinkerer. "The ingenious tinker enjoyed an astonishing longevity as an American folk-hero, reaching an apex in fact in the 20th century with Thomas A. Edison and Henry Ford." The creation of institutional structures for the application of science to industry took the form of development of professional societies during the late 19th and early 20th centuries, and the growth after the turn of the century of in-house industrial research laboratories. Many of these were initially geared towards analysis and testing.

The First World War created a situation where, "for the first time in American experience, scientists and engineers from industry, government, and the academic world came together to work cooperatively in group research.... There was a lesson to be learned, and it was." When the country returned to peacetime activity it was ready for a new stage in the utilization of science by industry—the substitution for "cut-and-try" methods of the application of science through organized and systematic research.

Research Corporation. *Science, Invention and Society: The Story of a Unique American Institution.* New York: Research Corporation, 1972. 40 pp.

Describes the formulation (in 1912), growth and functioning of the Research Corporation. In 1979 competitive peer-reviewed awards for basic research totaled $2.3M. An additional $0.5 million was pledged in 1979 by a variety of corporations and foundations to support basic research through Research Corporation programs.

The Research Invention Administratio... provides institutional visiting and e... (including legal) services to identify inv... potential for technology development, ...st in the patenting process. The amount ... was expended in 1979 in support of a... evaluate nearly 400 inventions from 114 insti... Royalties and license fees from successful pa... in this program are shared by RC, the inven... and their institutions. In 1979 a gross income of $4M from these activities was allocated as follows: $1.8M to institutions; $0.8M to inventors; and $1.4M for support to RC programs.

Ridgeway, James. *The Closed Corporation.* (New York: Random House, 1968) 273 pp.

A best selling Vietnam era radical critique of the "military-industrial-academic complex."

Numerous cases are presented of close relationships between professors and presidents and corporate enterprise. These are taken as evidence for the "corruption" of academia. Many of these same cases today are seen as the harbingers of new roles for academia in society—increasing technology transfer to raise industrial productivity. A case in point is the WARF—Wisconsin Alumni Research Fund—which was castigated by Ridgeway for engaging in price fixing, but which today is hailed as model for obtaining university benefits from university research.

The book contains many briefly discussed cases of professor-entrepreneurs running businesses while retaining their university positions, corporate board activities of academic administrators (including a lengthy list of names), university owned business deals, the varieties of consulting and the related conflicts of interest, and the strategies for investment of academic endowment funds. Several accounts are made of the role of professors with consulting or research relationships with industry or trade associations giving Congressional testimony for or against bills in the interest of their patrons—cases in the pharmaceutical, automobile, and tobacco industries are treated in detail.

A whole chapter is devoted to several University of California enterprises ("Multiversity Inc."). Examined are U.C.'s relationships with the AEC, the Pacific Gas and Electric Company, agribusiness on the braceros issue and the Irvine Company. The private industry connections of the university administrators are catalogued in detail.

Roberts, Edward B. and Peters, Donald H. "Commercial Innovations from University Faculty." *Research Policy,* 10 (1981), pp. 108-126.

Study of a sample of faculty of the Massachusetts Institute of Technology (MIT) has determined that many academic scientists and engineers have commercially-oriented ideas, but that few take strong steps to exploit their ideas. "Idea-havers" scored high on creativity measurement instruments and participated in more diverse work environments. Academic "idea-exploiters" are marked by personal background characteristics of family, religion, and parental occupation that have been identified in earlier research as characteristics of new technical company entrepreneurs. Other indicators reflecting high need for achievement were also observed in the idea-exploiting group. Finally, professors reporting commercial ideas were much more likely to be involved in consulting with business or government than were those who did not report ideas. Policy implications for universities and countries interested in technology-oriented development are discussed.

Robinson, Arthur L. "National Synchrotron Light Source Readied." *Science* 214, October 16, 1981.

Reviews the evolution of policies for expansion, equipping and industrial utilization of national facilities for synchrotron radiation sources.

The innovative concept of "participating research teams" (PRTs) was developed at the new Brookhaven National Laboratory National Synchrotron Light source.

"A group (industrial, university, or government laboratory) accepted as a PRT would build and finance one or more experimental stations in exchange for unrestricted use of the facilities for 75 percent of the running time. The PRT would also have to give outside users access to its instrumentation for the remaining 25 percent of the time. Included in PRT's selected so far are IBM, Bell Laboratories, Exxon, and Xerox, who together account for about 40 percent of the PRT-supplied experimental stations."

The financial contributions of the industrial members of the PRT's provide a way to get the light source instrumented at a much faster pace than would otherwise be possible given the available government funding.

Rogers, Everett M., Eveland, J. D., and Bean, Alden S. "Extending the Agricultural Extension Model." Stanford University Institute for Communication Research, September 1976. (U.S. Department of Commerce, NTIS # PB-285119) 172 pp.

This report is responsive to concerns among government and industrial officials that the U.S. lacks adequate mechanisms for linking the performer and users of research together for purposes of enhancing technological innovation. It is often asserted that "the agricultural extension model" should be the basis for improving upon existing technology transfer and research utilization mechanisms. This report describes the historical development and current operating structure of the Cooperative Extension Service (CES) of the U.S. Department of Agriculture, in order to accurately portray the major features of what is commonly called the "Agricultural Extension System." Comparisions are made between the CES and seven other Government programs designed to enhance innovation and ostensibly modeled after the CES. Conclusions are drawn about the degree of correspondence between the CES and its imitators and their relative effectiveness. Recommendations for future research are noted.

Science Council of Canada, *Annual Review 1981*. "University-Industry Interaction" Statement of the Chairman, Dr. Claude Fortier, 1981. Minister of Supply and Services, 1981. Cat. No. SS1-2/1981. pp. 21-44.

Explores at length the issues of the government role in the provision of university trained science and engineering "operational manpower" and "research-trained manpower."

Section on university-industry cooperation discusses three model relationships: the Pulp and Paper Research Institute of Canada and McGill University, the Center for Cold Ocean Resources Engineering and Memorial University in St. John's, and the research brokering functions of the Industrial Research Institutes, and the Centres for Advanced Technology—both created by the Federal Department of Industry, Trade, and Commerce. Additional programs discussed:

- (L'Institut National de la Recherche Scientifique, a constituent branch of the University of Quebec) INRS-Telecommunications—a center for graduate studies and research situated within the laboratories of an industrial organization (Bell Northern Research);
- PRAI grants—Project Research Applicable in Industry;
- the "Relevant Research" Approach;
- Industrial Innovation Centers in Quebec and Ontario;
- Initiatives by industry;

Servos, John W. "The Industrial Relations of Science: Chemical Engineering at M.I.T., 1900-1939," *Isis* 1980, 71, pp. 531-549.

This study examines the questions: "How did industrial patronage (for scientific research and training at universities) affect the evolution of academic science, basic and applied, and how did it influence the goals and values of scientists themselves?"

Using primary materials from MIT archives the study documents two major transformation of the institution. The first, around the turn of the century, saw the shift from a local, vocational/technical school to a nationally recognized institution with both basic (A. Noyes) and applied (William H. Walker and A.D. Little) research and training capabilities.

During the decades of the 1910's and 1920's, the applied research orientation came to dominate MIT, with strong ties to and support from industrial organizations.

The second tranformation, during the 1930's, saw a realignment of the balance between basic research and basic science training, applied research and training in current industrial technique. The study is an instructive case on the limits of industrial support of an academic institution. During the 1910's and 1920's "(W) Walker and (A.D.) Little has been willing to allow industry to determine the priorities of the Research laboratory for Applied Chemistry and indeed to subordinate the program in chemical engineering to the immediate interests of business. They were willing to do so because they perceived an identity of interests between businessmen and applied scientists. Their successors were, to a much greater degree, sensitive to the need for disciplinary independence and eager to follow their own judgements regarding the best opportunities for research. In part this attitude arose from their experience with the restrictions imposed by sponsors; in part it resulted from the increasingly abstract character of chemical engineering itself.

Shapero, Albert. *University-Industry Interactions: Recurring Expectations, Unwarranted Assumptions and Feasible Policies*. Columbus, Ohio: Ohio State University, July 31, 1979. 47 pp. (Prepared for NSF/STIA/PRA under PO-SP-79-0991.)

Explores implications of several aspects of university social and organizational structure for possible expansion of university-industry relationships. Five "exemplar options" are recommended. Bibliography.

Sinnott, Maurice. "University-Industry Programs: An Analysis of a Series of Joint University-Industry Research Programs Sponsored by the Defence Advanced Research Projects Agency." Paper presented at a Conference on University Research Management, June 6-7, 1977. 7 pp.

Written by an associate dean of engineering at the University of Michigan, these remarks track and interpret DARPA's experiments in "coupling" companies and universities in R&D during the 1960's.

The author believes that the principal lesson learned from these experiments was the development of a better appreciation by both industry and the universities of each other's strengths and limitations in R&D.

Small, Henry and Greenlee, Edwin. *A Citation and Publication Analysis of U.S. Industrial Organizations* (Final Report for NSF Contract PRM 77-10048.) Institute for Scientific Information, 325 Chestnut Street, Philadelphia, PA 19106. January 1980. 95 pp.

This is an exploratory study using Science Citation Index data for 1973 and 1976 to see how these data and techniques can be used to examine industrial research.

The study determines the extent to which industrial organizations cited research performed in the university, Government and other sectors, and the extent to which industrial organizations were cited by the various sectors. Several kinds of evidence were noted of a gradual decline in publication productivity of industrial organizations from 1973-1976—especially in basic research.

Interesting citation measures of association between specific industrial firms are presented to map the relationships between these organizations. A structure which reflected research field and product orientation was formed.

Smith, Lee. "The Unsentimental Corporate Giver," *Fortune*, September 21, 1981, pp. 121-124, 129, 132, 137, 140.

Useful examination of the patterns and motivations of corporate philanthropy. Contrasts two philosophies of corporate philanthropy: That espoused by Milton Friedman, "supposedly the headmaster of the give-nothing school"; and the view that "the purpose of business is to serve society," sponsored by Lawrence A. Wien and Kenneth N. Dayton.

Some relevant facts cited are:

• In the late 1970's corporations (and corporate sponsored foundations surpassed the independent foundations in total gifts for the first time since the mid-1950's.

• Average gifts have oscillated around 1% of pretax earnings since the 1950's.

• Five of the ten top recipients of corporate largesse were universities.

• The proportion of total corporate gifts going to education (about 40%) declined slightly between 1965 and 1979.

Swalin, R.A. "Improving Interaction between the University and the Technical Community." Special "Industry/University R&D" issue of *Research Management*, 19, May 1976.

A number of steps taken at the University of Minnesota have substantially increased cooperative efforts between the University and the surrounding technical community.

Sweden. Utbildnings Departementet. *Adjungerade Professorer: Utvardering av forsoksverksamheten aren 1973-1979*. Stockholm: LiberForlag, 1979. (Ds U 1979:13) (In Swedish).

An evaluative study, based on interviews, of seven years of experience with an "adjunct professor" program between industries and universities in Sweden. Descriptive information is presented on the 60 participants—their education, employment, work activities and field of competence. Description of the administrative arrangements--including percent of time and salary adjustment. Recruitment to the program and motivations are explored, as are effects upon the incumbents.

Thomas, Lewis "Business and Basic Science." *Bulletin of the New York Academy of Medicine*, 57(6):493-502, Jul-Aug 81.

"The recent examples of marketable products from hybridoma antibodies and recombinant DNA genomes ought to be raising new anxieties.... (corporations) are or should be uniquely concerned, out of pure self interest, for what will be available in, say, the year 1995 or 2000, waiting then for application to new products. If long-term investments in basic science are not continued, they will find themselves out of business or at least out of competition with their counterparts."

Tokyo Chamber of Commerce and Industry, *The Current Condition and Future Prospects of Industry-University Cooperation in Research and development and in Manpower Development*. May 1973

Report is in Japanese, but a 10 page English summary was prepared for NSF.

In 1972/73 about 700 Japanese companies returned questionnaires dealing with their modes and levels of interaction with universities. Past, current, and desired future cooperation were described. The study analyzes present and expected future involvement in 13 types of interaction, including "joint research," "offering scholarships," "sending employees as lecturers to universities," and "utilizing facilities of universities," by size of company and type of industry. Thus, for example, 29% (52%) of all the manufacturing companies reported current involvement in "doing joint research and commissioned research"—32% (58%) for the "machine and tool" industry, 48% (60%) for concerns in the "chemical, rubber, ceramics, and earth and rocks" industry, and 21% (46%) of the companies in "steel, metal, and non-ferrous metal." The percentages in parentheses are the companies expectations for future cooperation—thus, in 1973 Japanese companies held optimistic expectations of expansion of their research connections with universities.

United Nations Association of the USA. Economic Policy Council, Technology Transfer Panel, *The Growth of the U.S. and World Economies through Technological Innovation and Transfer*. New York: UNA-USA, Inc., 1980. 76 pp.

This report examines the development of industrial technology and its international transfer. It claims that it, "is in the main a consensus view among the business, labor, and academic groups represented on the Panel."

Amongst the recommendations aimed at the generation of new technologies in the U.S. were:

- "Business, labor, universities, and financial institutions should work together more closely at all levels—plant, community, industry, trade association, and national organization—to develop new technologies at home and to acquire new technologies from abroad."
- "The U.S. Government should play an important but largely indirect role. It should support technologies with industry-wide or inter-industry applications..."
- Business is encouraged "to invest greater resources in joint industry-university research...."

United States. Department of Commerce, Office of Productivity, Technology and Innovation, Office of Cooperative Generic Technology. *Cooperative R&D Programs to Stimulate Industrial Innovation in Selected Countries*. Washington, D.C.: various dates in 1979 and 1980.

Appendix 17—A Summary, by Elaine Bunten-Mines, Julie Menke, and Carl W. Shepherd, June 1980. 75 pp.

Appendix 16—*Sweden*, by Carl W. Shepherd, June 1980. 55 pp.

Appendix 14—*Japan*, no author listed, November 1979. 73 pp.

Appendix 11—*Federal Republic of Germany*, by Carl W. Shepherd, May 1980. 124 pp.

These studies were carried out in response to an OMB directive to "review past Federal and State cooperative technology programs... and those of other countries" in order to determine the viability of the Department of Commerce's proposed Cooperative Generic Technology Program. All of the reports are considered working papers for discussion only, and do not represent official policy or conclusions of the Department of Commerce.

United States. Department of Energy/Industrial Research Institute. "Mechanisms of University-Industry Interaction." IRI/DOE Conference, December 7-8, 1978, Reston, VA. 117 pp.

Packet of materials for attendees containing: four short statements of problems and issues by participants; short descriptions of nine actual workshop, fellowship, intern, equipment and liaison programs; short descriptions of seven joint research programs.

United States. Department of Justice. *Antitrust Guide Concerning Research Joint Ventures*, November 1980. Washington, D.C.: USGPO, 1980. 113 pp.

An outgrowth of the Carter administration Domestic Policy Review of Industrial Innovation, this document seeks to clarify Department of Justice policy on collaboration among firms in research to make certain that the antitrust laws are not "mistakenly understood to prevent cooperative activity...."

The Guide includes a general introduction explaining the Antitrust Division's analytical approach to research joint ventures, followed by a number of hypothetical cases designed to exemplify the most important or difficult situations, and the Division's approach to them. In addition, the Guide contains summaries of previous business review clearances and advisory letters of the Antitrust Division relating to joint research.

United States. House of Representatives, Committee on Science and Technology, Subcommittee on Science, Research and Technology. Hearings on *Government and Innovation: University-Industry Relations*. July 31; August 1-2, 1979. Washington, D.C.: U.S. Government Printing Office, 1979. 522 pp.

Contains testimony, letters and articles by a variety of persons prominent in R&D relating to proposed legislation entitled, "National Science and Technology Innovation Act of 1979."

United States. National Science Foundation, *1980 Industrial Program Grantee Conference Proceedings*, edited by David D. Douglas, Industrial Research and Extension Center, University of Arkansas, Little Rock, Arkansas 72203. 172 pp.

These *Proceedings* document the substance of a conference held Hot Springs, Arkansas, May 12-14, 1980, on the theme of innovation and productivity in America. Seven sections containing 4-6 papers each were on the following topics:

1. Thematic presentations on innovation and productivity.

2. Current programs: university/industry coupling.

3. Current programs: innovation center/technology innovation projects.

4. Current programs: small business innovation research.

5. Current programs: planning experiments.

6. Government views—university/industry cooperative research.

7 Lessons learned/new opportunities.

United States. National Science Foundation. *Proceedings of a Conference on Academic & Industrial Basic Research*, Princeton University, November 1960. NSF 61-39.

Participants from 43 major R&D companies, universities and Government examine the conditions for advance in basic science. The roles of the several sectors in basic research were discussed, and four papers examined the industrial experience in basic research (G.E., Bell Telephone, Merck, Celanese). The interdependence of academic and industrial basic research was discussed in three papers on: polymers, semi-conductors, and aerodynamics.

United States. National Science Foundation. *Research in Industry: Roles of the Government and the National Science Foundation*. Washington, D.C.: NSF December 1976. 21pp., plus 160 pp. attachments.

Reviews role of scientific research in non-academic institutions with special attention to NSF programs and policies relating to private industry. Contains much data and bibliography.

Useem, Elizabeth. "Education and High Technology Industry: The Case of Silicon Valley. Summary of research findings," Boston, MA. August 1981, mimeo. 32 pp.

Dr. Useem, sociology professor at the University of Massachusetts, Boston, has documented the varieties of relationships between the over 500 high-technology firms in the Santa Clara valley (Silicon Valley) and all levels of the educational system—secondary schools, two-year community colleges, and four-year colleges and universities. The study explores the degree and manner in which educational institutions are changing to meet the demands of a rapidly transforming technology.

The general conclusion is that the relationships are positive, strong, and evolving in appropriate directions at the university level. At the community college level relationships are bedeviled with misunderstandings, mistrust, and discontinuities, with no real improvements perceived. At the secondary level, science and technical education is in complete disarray, still sinking fast, and with few exceptions the high-technology business community is paying little attention. During 1981/82 Dr. Useem will carry out a comparative study of education-industry relationships in the Boston/Route 128 area.

Useem, Michael. "Business Segments and Corporate Relations with U.S. Universities," *Social Problems*, 29 (December 1981), pp. 129-141.

It is generally assumed that business derives important benefits from higher education and provides financial support in return. This presumes that business is relatively undifferentiated, and that corporate relations with universities are largely uniform. Using data on the governing boards and characteristics of 341 colleges and universities selected through a national sample, this paper shows that what is called the "dominant stratum" of business, rather than business as a whole, has formed an enduring relationship with universities that are oriented toward education of the elite: the governing boards of these universities are disproportionately composed of members of the dominant stratum; universities with high proportions of dominant stratum trustees are more successful than others in raising financial support from corporations; and members of the dominant stratum take a direct role in obtaining corporate contributions. The findings imply that relations between business and higher education are structured less around business as a whole and more around a distinct segment of business. Bibliography on corporate and university ownership and control.

Watson, Kenneth M. "Technologists in Top Management, Part One: The Business SUCCESS Factor," and "Part Two: Management, Technologists, Coordination, and Communication," *Chemical Engineering Progress*, Vol. 55 (February and May 1959), pp. 37-44, 37-41.

- The papers examine the factors determining business success and the role of technology among them. "In the study reported herein, a *business success factor* was developed by evaluating and combining annual profit on invested capital with rates of income growth and capital expansion. A technology factor was then developed by combining level of research and development activity with percentage participation of technologists in management.

"The business and technological performances during the ten years 1948-58 are compared for 20 large oil companies and 20 large chemical companies on the basis of readily available published data. Companies having higher technological factors are found to show significantly greater success indexes. No significant relationship is found between business success index and either research level, or technological participation in management alone. There are indications, however, that a high level of research activity may be a liability unless combined with a technologically perceptive management.

"Such results are believed to provide standards of comparison which will be generally useful to management, technologists, and investors."

Weber, David. "A new Industry Springs to Life," *Venture*, May 1981, pp. 88-93.

This article catalogues the mushrooming of entrepreneurial biotechnology companies—at least 40 since 1978. The new companies include those aiming to produce products in fields ranging from medicine to plant and animal breeding, and from energy production to industrial chemistry. Other companies focus on support activities, making biological materials, such as already modified DNA, machinery with which to conduct research, and even a new crop of newsletters and journals.

A significant proportion of these companies have direct academic connections.

Weiner, Charles. "Relations of Science, Government, and Industry: The Case of Recombinant DNA" in AAAS, *Policy Outlook: Science, Technology, and the Issues of the Eighties*, A draft report to the NSF, Washington, D.C.: American Association for the Advancement of Science, 1981. pp. 109-156. Forthcoming, Westview Press, Boulder, CO, Spring 1982.

Comprehensive short history of the problems posed by the rapid development of recombinant DNA techniques. Topics treated include the concerns about risks in the 1970's, the current status of DNA technology and its regulation, and policy problems and prospects for applied molecular genetics in the 1980's. The perceived damage to the health of basic scientific research posed by its close association with highly profitable commercial ventures is discussed in detail. Bibliography.

Weiss, Malcolm A. and White, David C. "The MIT Energy Laboratory and the Role of Industry/University Interaction." Paper presented at the 1980 ASM Materials and Processes Show and Congress, Cleveland, Ohio, October 30, 1980. 12 pp.

The Director of the MIT Energy Laboratory describes four methods by which industry sponsors research at his laboratory. The lab has a $12 million budget, roughly two thirds from government and one third from industry. He states, "although it doesn't come easy...Government money comes easier...industry sponsored research is worth going after." The benefits for MIT and for the sponsoring companies are listed and four models of support—in addition to the traditional one-shot support of a single faculty member's research—are listed:

- *Center for Energy Policy Research*—basically an "associates" program with 3 year rolling commitments according to no fixed formula (24 companies, 9 other organizations). No restrictions on MIT's choice of topics. Many associates have their senior staff participate in projects. 1980 budget about $500,000.

- *Electric Utility Workshop*—seminar-workshop program in which electric utility companies identify problems and then sponsor research projects. Sponsors have prepublication review rights, and non-exclusive royalty free patent rights. Up to 15 sponsors spend about $500-700,000 annually.

- *Exxon Research and Engineering Combustion Research*—a ten year bilateral agreement for annual project support of about $600,000 predominantly for specific basic research projects mutually agreeable to Exxon and MIT in the combustion of fuels containing carbon. Some portion of the support will be spent at the sole discretion of MIT researchers. Exxon has the right to review proposed publications for patent applications and to ensure that no proprietary information disclosed by Exxon to MIT is included. MIT owns the patents and Exxon has a nonexclusive royalty free right to use the patents. Termination of the agreement requires two year's notice. The MIT researchers agree to make at least half their research time available to the program.

- *ASPEN Project*—a large computer program developed with DOE support as a tool to simulate proposed or existing industrial processes. Firms (48 so far) commit $15-25,000 at MIT over two years, for which MIT trains their personnel in the use of ASPEN and make available the MIT computer to work real problems of the firm, and to assist in installing ASPEN on an in-house computer if desired.

Concluding *bon mot*: "How does a university negotiate with a firm to a mutually satisfactory agreement? The same way any negotiation is carried out—by knowing the location of both pressure points and erogenous zones and when to touch which."

Wolff, Michael. "The President's Initiatives for Industrial Innovation," *Research Management*, January 1980, pp. 7-12.

Useful report on the substance and political background of President's Carter's initiatives relating to his Domestic Policy review of Industrial Innovation. While some of the measures received fairly universal approval, e.g., in the patent area, considerable disappointment was expressed in industrial circles that no tax measures were proposed to "address the disincentives to capital formation."

Wolff, Michael. "The Why, When, and How of Directed Basic Research," *Research Management*, May 1981, pp. 29-31.

"The enthusiastic growth in basic research that occurred in industry during the booming 1950's and 1960's was throttled by the financial turbulence of the 1970's. For the decade of the 1980's, however, concern with U.S. productivity and technological competitiveness spells a potential resurgence in industrial basic research—but with one difference: this time it will be directed research.

"At a recent IRI Special Interest Session a group of research managers addressed four key questions related to directed basic research (DBR). The answers provide useful guidelines for the successful conduct of this often misunderstood type of research."

One manager included the following criterion for deciding what DBR to undertake: "Leverage your research dollar whenever possible with working university relationships and competitively won Federal study contracts in areas of basic research relevant to your company's technologies."

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