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Industrial Involvement in National Science Foundation Engineering Research Centers

A Report to the Subcommittee on VA HUD - Independent Agencies of the United States Senate Committee on Appropriations

Engineering Research Centers Program
April 22, 1993

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Introduction

As we enter the 21st century, society's well being will increasingly depend upon maintaining a preeminent engineering work force and technical knowledge base. Building a new technology that can generate high-paying jobs requires integrating creative contributions from widely different scientific, technical and business sectors. American universities must educate professionally oriented engineers who are able to move new knowledge more effectively into profitable implementation in industry and assume broad leadership roles in society. In partnership with a concerned industrial constituency, engineering research and education can play a critical role in improving the process of wealth creation for the nation.

NSF Engineering Research Centers (ERCs) were established in 1985 to educate engineers and engineering researchers for an increasingly competitive global economy and to help maintain a leadership position for the U. S. in economically important technical areas. The National Academy of Engineering recommended in its plan for the ERC Program that the nation should support 25 ERCs with $100 million of NSF funds. So far the Foundation has established 21 ERCs, and currently supports 18 ERCs, at an average annual level of $2.5 million each. An NSF ERC award has a duration of five years and may be renewed by NSF up to a maximum of 11 years. To receive NSF support beyond the 11th year of operation an ERC team must compete for a new award in an announced competition along with new proposers.

To look beyond the existing technology, an engineer must understand it thoroughly, but this is not enough. ERCs must teach students more than how to do research defined by a single faculty advisor. They must show students how to see their work as contributing to a large-scale engineering system, how to formulate a new vision and plot a course to make it happen, and how to assemble and manage a diversity of personal expertise in a team that can make revolutionary advances with profit potential for industry. The right engineering research problems to work on will not always produce the most publishable results, and can rarely be localized within a discipline corresponding to an existing academic department. To fulfill their mission, the ERCs must change the way academic engineering research has been done.

In the universities where they exist, ERCs are large and visible enough to influence the academic engineering culture and its reward structure. Over time, ERCs are proving that high-quality academic engineering research can be relevant and profitable to industry. Sustained, committed industrial involvement in engineering research and engineering education is an essential part of this process.

In 1992, the number of companies that were ERC members was 441 for the 18 Centers; there were 589 ERC memberships, showing that a large number of firms have joined two or more ERCs. Of these companies, 32% are small businesses and 11% are foreign-owned.

NSF Strategy for Industrial Involvement in ERCs

Since 1985, NSF has evolved a strategy for oversight of the ERCs that focuses them toward greater and more substantive industrial involvement. One of NSF's first responses to program-level industrial advice was to require each ERC to develop a **strategic plan** for its research agenda in concert with influential members of its industrial sector. With a strategic plan in place, the ERC was better able to increase the number of **joint projects with industry**. NSF then emphasized large-scale **experimental testbeds**, again jointly planned, designed and built with industry. Testbeds are in many cases the first and most important step toward practical application of engineering research. They force the integration of individual efforts and expose problems that must be solved to build a system that will work. Later stages of **implementation and deployment** of ERC research results in industry are now the major focus of NSF's strategy for developing the ERCs into national resources for their industrial sectors.

The following are the elements of NSF's oversight of the ERCs as it is currently carried out:

<u>Cooperative Agreement funding mechanism</u>

Unlike the more common single-investigator NSF research grant, the ERC award is managed as a Cooperative Agreement between the Foundation and the awardee university. In signing this document, the university agrees to participate in the culture change that the ERC represents and to support the ERC strongly. NSF may terminate an ERC award if insufficient progress is being made toward implementing the objectives of the program; for example, having too little substantive industrial involvement in planning and conducting the research.

<u>Annual site visit reviews; NSF site team meeting with industrial members</u>

The ERC Program uses technical expert reviewers from industry, both in initial selection and on every annual site visit review. Typically a site team will be composed of 30-70% reviewers from industry, with the remainder from academe. During annual NSF site visits at each ERC, the site team meets privately with the ERC's industrial representatives to ask questions and solicit suggestions for improving the ERC's performance.

The third- and sixth-year reviews are more comprehensive than the other annual reviews, and constitute a major part of NSF's decision process for renewal of ERCs. Three of the 21 ERCs have had their NSF support terminated after an unsuccessful third-year renewal review.

Industrial advisors to the ERCs

The ERCs form an Industrial Advisory Board and at least one Technical Advisory Board with industrial members, to review formally the ERC's research projects, progress and plans several times per year. ERCs require cross-disciplinary faculty/industry teams to define a research strategy toward a new generation of technology for a particular industrial sector. One of the major tasks of the Industrial Advisory Board is to work with the ERC to develop an evolving Strategic Research Plan targeting its research toward the long-term needs of the industry as a whole.

Individual ERC strategies for industrial involvement

Each ERC must find the most effective way to serve its own industrial sector. ERCs focus on a wide range of technology areas, including manufacturing and design, optoelectronics and microelectronics, civil infrastructure systems, biomedical engineering, biotechnology, energy, and the environment. Differences exist among the industrial sectors in their economic strength and stability, their foreign competition, the typical size of their firms, their level of sophistication, and their experience with university research partnerships. NSF requests both quantitative and descriptive information in the annual reports from ERCs, to accommodate these differences in judging an ERC's performance and plans.

Annual reporting of industrial support and indicators of involvement

The ERCs report industrial support, restricted (e.g., directed research contracts) and unrestricted (e.g., center membership fees), cash and in-kind, and the value of engineers from industry working at the ERC. One table required by NSF is used to describe the involvement of each participating company, and another table itemizes and characterizes technology transfer successes. Numbers of patents and licenses to industry, numbers of joint projects and joint publications with industry, numbers of industrial engineers working at the ERC, and numbers of ERC graduates recruited into industry, are also reported.

NSF ERC Program Directors

NSF ERC Program Directors are the focal point for NSF's oversight of the ERCs. They have industrial research management experience and experience with cross-disciplinary engineering research, and communicate regularly with industrial engineers and managers in their technical fields. They participate in meetings of industrial associations to provide a Federal government perspective and to keep abreast of industry's concerns. They also work with OSTP, NIST, ARPA, and other agencies within various task groups, and review industrial proposals for other technical programs.

Annual Meeting of the ERC Directors

NSF holds an Annual Meeting every October, with required attendance of the ERC Directors, to develop strong interaction among the ERCs and with NSF.

Industrial advice to NSF ERC Program management

Periodically, the ERC Program holds a workshop in Washington, where engineers and managers from industry who know the ERCs well give NSF advice at the program level. In 1993, NSF will ask for help from this group to define a more aggressive strategy for ERC-industry partnerships within the Clinton administration's technology policy. Defense technology reinvestment and retraining of defense-sector engineers will be one focus. Active partnering between industry and universities is becoming necessary across the nation. NSF will work with industry to use its experience with ERCs as a prototype for this new way of doing business.

The ERC Program is planning a competition to form at least one new ERC in 1994. Industrial advice was solicited and received in drafting the NSF Program Announcement, and industrial engineers and managers will be used by NSF in all stages of the review and selection process.

Finally, some companies that have recruited engineers extensively from ERCs have told NSF that ERC graduates are so much more valuable to them than other graduates, because of their experience with engineering systems, that they have stopped recruiting anywhere else. However, many companies still recruit engineers by discipline and by university reputation, and are unaware of the existence of the ERCs and the unique education ERC graduates have received. This year, NSF will work to improve the national visibility of the ERC Program and to solicit participation from a larger subset of American industry in the continuous improvement of the program's performance.

Forms of Industrial Interaction in the ERCs

Industrial participation and technology transfer in ERCs takes place through the following mechanisms:

- Joint strategic planning of the research agenda
- Engineers on loan from industry working at the ERC
- Joint projects including experimental testbeds
- Technical advisory groups
- Patents; especially, licenses of patents and software
- Placement of ERC graduates in industry
- Start-up companies based on ERC advances
- Consortia formed with industry and the ERC to work on specialized problems
- Contracts for individual faculty research from industry attracted by the ERC
- Students: work with engineers from industry on joint projects; mentors; thesis committee members from industry; summer jobs; visits to companies; and seminar speakers from industry
- Industrial support: cash for membership fees and research contracts; equipment donations; personnel exchange

Indicators of Performance

For the period June 1991-June 1992: the ERCs made **61 patent applications**, were **granted 45 patents**, and **licensed 228 patents and software products** to companies.

Industrial support for the 18 ERCs totalled **$40.1 million** for the period June 1991-June 1992.

Over the life of the ERC program, the ERCs have applied for and received **200 patents** and **licensed 483 patents and software products** to industry.

434 engineers in residence from industry have spent time working at the ERCs.

There have been **73 products** incorporating ERC research advances that have been marketed in industry.

Over **530 joint projects** between industry and ERC teams have occurred in the ERCs.

To date, the ERCs have graduated **875 Ph. D. students**.

Attached are a pie chart of ERC support distribution for the period June 1991-June 1992 from all sources and a bar graph showing the growth of total support from all sources for the ERCs over the life of the program.

Examples from the ERCs

The examples below illustrate technology advancement from industrial participation in ERCs, and highlight some of what we have learned about approaches that succeed.

Thermal Process Testbed (Purdue University, ERC for Intelligent Manufacturing Systems)

The ERC's thermal process testbed integrates several research projects serving needs in quenching, temperature measurement, and residual stress experiments and modeling. The testbed, along with supporting instrumentation in associated laboratories, supports: 1) laboratory measurements of radiative properties of well-characterized process metals under simulated process conditions; 2) characterization of sample materials for topographical, chemical, and microstructural features; 3) development of generalized algorithms for relating surface and radiative properties; and 4) hardness and residual stress measurements. Process models are related and parameters affecting the complete heat treatment/quenching process are verified experimentally.

A dual-wavelength temperature sensing technology that the ERC demonstrated with this testbed is now used in 18 galvanneal steel mills. Four instrumentation companies have product development projects underway incorporating results of the ERC's thermal process technology.

Traveling Salesman Algorithm (Carnegie Mellon University, ERC for Engineering Design)

A joint project with an industrial resident from DuPont at the ERC developed a parallel branch-and-bound algorithm for solving the asymmetric traveling salesman problem. The corresponding mathematical model can be used to optimize the production sequence of lots in multiproduct batch processing plants. A major accomplishment of this work was that problems with up to 7,000 lots were solved to optimality in less than 20 minutes of computation time. A student who worked on the project was hired by DuPont to implement the model. The software was transferred to DuPont and applied to the operation of several manufacturing facilities, yielding savings on the order of $10,000,000 per year.

Variable-Temperature, Mechanically Stable Scanning Tunneling Microscope (University of Illinois at Urbana-Champaign, ERC for Compound Semiconductor Microelectronics)

When atomic resolution scanning tunneling microscopy (STM) was invented in 1982, the properties of surfaces could be studied with three-dimensional atomic-scale resolution. One of the ERC's researchers invented a new STM that is radically different from earlier STM designs. Thermal drift of the sample is several orders of magnitude lower than that of other designs, and it is so mechanically stable that atomic resolution images can be obtained with no need for vibration isolation. Earlier STMs were large, typically 12 feet tall and 4 feet square, with almost all that volume dedicated to vibration and thermal isolation. The ERC's new design fits in the palm of a hand.

The ERC's STM design was patented and licensed to three companies who are all now shipping units to customers.

Advanced Systems Research used in Design of New Chemical Process Plant (University of Maryland and Harvard University, Institute for Systems Research)

Exxon asked the ERC to incorporate its state-of-the-art systems research into the design and construction of a new chemical processing plant to market a new family of products. Working with Exxon, a team of ERC researchers and students developed new software for reaction modeling and control in the new processing plant using parameters and data from Exxon's ongoing pilot plant studies. Process control engineers now use the ERC's software for process analysis, optimization, and debottlenecking in the plant. In addition, the ERC team visited the plant site regularly during its construction to review progress and give training sessions. The ERC's work with Exxon enables the new plant to provide safe and profitable operations while meeting strict product quality specifications.

Software Platforms for High-Performance Communications Networking (Columbia University, ERC for Telecommunications Research)

NEST is a network simulator testbed tool consisting of a software environment to test network designs and scenarios. NEST has been installed in over 400 companies and universities, where it has been extensively applied in a wide range of networks and distributed systems studies and designs. It has also been used as a tool in teaching graduate-level courses in networks and distributed systems.

NETMATE is a comprehensive network management platform consisting of tools to model and organize massive and complex managed information, tools to support visual access to managed information and control capabilities, and tools to support effective interpretation of managed information. For example, Citibank chose NETMATE as the centerpiece of the platform it now uses to manage its enterprise network worldwide.

Pilot Plant Testbed for Recombinant Protein Production and Purification (Massachusetts Institute of Technology, ERC for Biotechnology Process Engineering)

The ERC has built an industry-funded $2.5 million pilot plant facility for fermentation and downstream processing. This facility has been integrated into the ERC and has become a testbed for teaching, research and materials preparation.

Protein Polymer Technology, Inc. (PPTI), is a startup biotechnology company formed to produce recombinant proteins for biomedical applications. In 1989, PPTI collaborated with the ERC on both lab and pilot scale fermentation and protein recovery, first at the company site and later at the ERC's pilot plant testbed. The ERC provided assistance with process development, scale-up, and economic analysis for the manufacture of a specific protein biopolymer. In March 1991, six people from PPTI and six faculty and students from the ERC worked together to carry out large-scale production in the pilot plant. Multikilogram quantities were produced and used by PPTI in further work on the material properties in its product development.

Cluster Tool Testbed for Single-Wafer Integrated Circuit Processing (North Carolina State University, ERC for Advanced Electronic Materials Processing)

The Semiconductor Research Corporation, an industrial consortium to support relevant university research, and SEMATECH, an industrial consortium to improve American semiconductor processing equipment, are both members of this ERC, along with other major electronics manufacturers.

The Cluster Tool is an experimental testbed at the ERC and consists of interconnected vacuum chambers for wafer processing. The industrial consortia and the ERC's other industrial members have participated in the design of this cluster tool. It serves as a flexible engineering environment where new process ideas can be tested in order to demonstrate their viability for use in production. The Cluster Tool represents a precompetitive, generic technology of interest to all the industrial sponsors. Participation in research using the ERC's testbed allows companies to avoid costly duplication in the early stages of research on the radical new processing technologies that will become necessary to maintain competitiveness in the industry in the future. Engineers from industry spend on the order of 75 person-days per year working at the ERC.

Small Company Program (University of Minnesota, ERC for Interfacial Engineering)

In January of 1990, the ERC established the Small Company Program to help high-technology companies solve problems in the processing, fabrication, and performance of interfacial systems. The program combines research, technology transfer, and education through joint projects with engineering student participation focused on design and manufacturing of interfacial products.

By the end of 1992, 22 companies had become participants in the program and they had initiated 26 projects. The program is supported with $130,000 from the member companies and $75,000 in funds from the State of Minnesota. In the program's second year, 19 faculty, 29 undergraduate interns, and 8 graduate student mentors participated in joint projects with the small companies in the program.

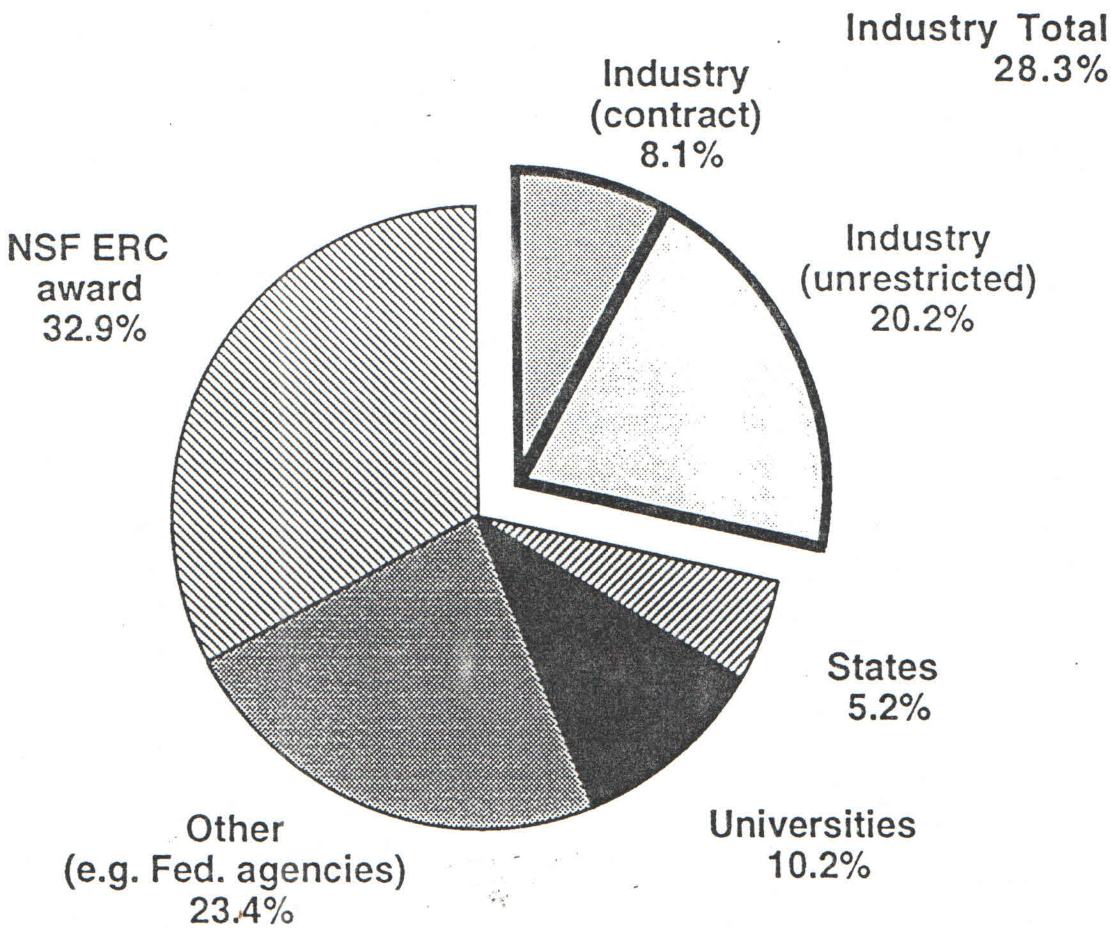
Spinoff Company from the ERC (Massachusetts Institute of Technology, ERC for Biotechnology Process Engineering)

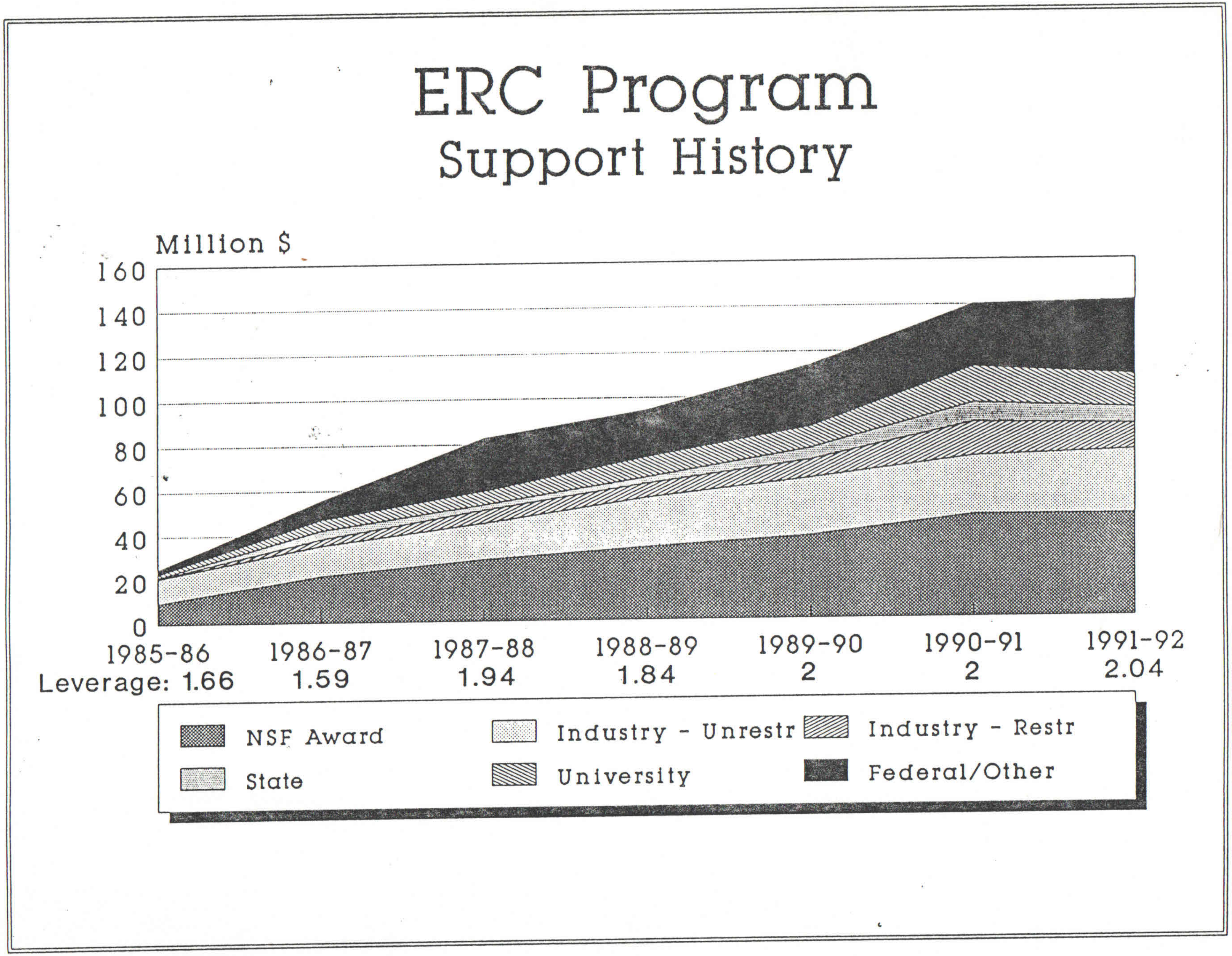
In 1989, one of the Ph. D. graduates from the ERC founded the company PerSeptive Biosystems, Inc. During his doctoral research, this student was one of the principals to have developed the Continuous Affinity Recycle Extraction (CARE) process for protein purification. He recognized the need for purification technologies that have higher throughput and are scaleable.

The ERC provided some of the basic equipment and laboratory access in support of the company's startup. Venture capital and private investment was secured over the period 1989-1992, and the ERC's existing network of biotechnology companies helped the new company make itself known within the pharmaceutical and biotechnology industries.

In 1992, PerSeptive Biosystems raised additional capital through an initial public offering on the NASDAQ. The company now has annual sales in excess of $4,000,000. Market sectors include chromatography media, in analytical process scale and in production scale, for the purification of therapeutic proteins. The company employs 60 people and has operations in Europe and Asia. Ten percent of the personnel of the company were once associated with the ERC.

ERC Support Distribution, June 1991-June 1992





ERC Program
Support History
Million $
160
140
120
100
80
60
40
20
0
1985-86
1986-87
1987-88
1988-89
1989-90
1990-91
1991-92
Leverage: 1.66
1.59
1.94
1.84
2
2
2.04
NSF Award
Industry - Unrestr
Industry - Restr
State
University
Federal/Other