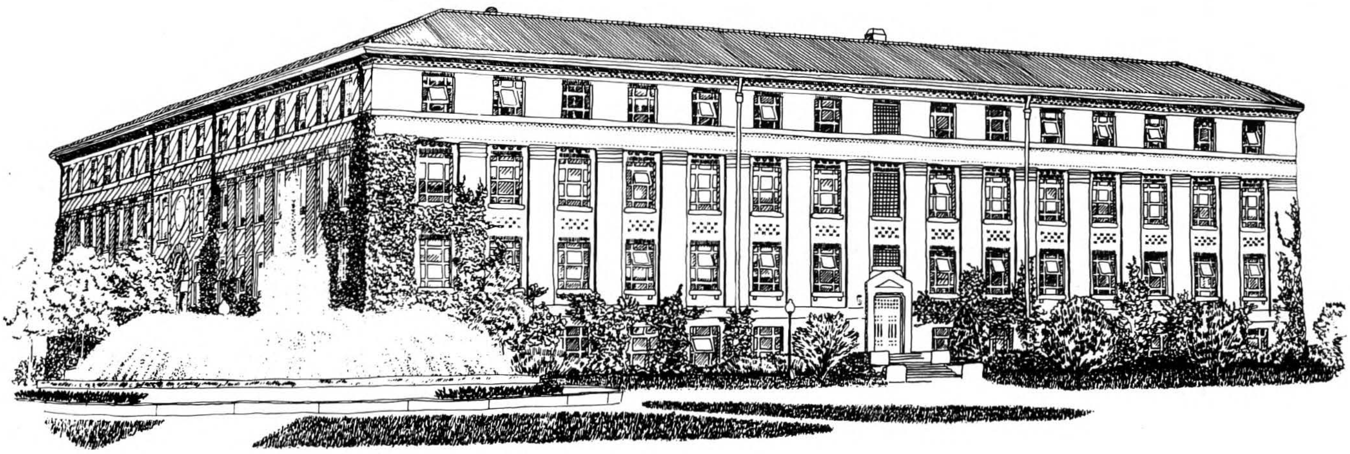


ChE department

PURDUE UNIVERSITY

SEVENTY FIVE YEARS OF CHEMICAL ENGINEERING

W. NICHOLAS DELGASS AND
NICHOLAS A. PEPPAS
Purdue University
West Lafayette, IN 47907

One-fifth of the more that 338 PhD graduates from Purdue have continued in academia, many achieving prominent positions. A recent survey . . . identified a total of 164 alumni that have become university faculty.

THE PAST

As we celebrate 75 years of chemical engineering at Purdue we look, as always, to the future but also back to our roots. The origins of chemical engineering education can be traced almost exclusively to the first half of the 19th Century in Germany. During that period important chemists such as Justus von Liebig, August Kekulé, August von Hoffman, Robert Bunsen and others established in three major universities—University of Heidelberg, University of Göttingen and University of Giessen—chemical laboratories which nurtured many generations of theoretical and applied chemists.

Industrial chemistry, the forerunner of chemical engineering, originated from these laboratories and became an important field of research at many universities during the last quarter of the 19th Century. The first chemical engineering course was given at the University of Manchester in 1887 by George E. Davis in the form of twelve lectures covering various aspects of industrial chemical practice. At Purdue University, which had been established as a land-grant university in 1874, the first chemical engineering course was offered in 1902.

Chemical engineering at Purdue University started in the Chemistry Department. In 1900, the pioneering head of chemistry, Percy N. Evans, suggested that some industrial applications be incorporated into the course, "Technical Analysis." In 1902, fascinated by the first edition of G. E. Davis' *Handbook of Chemical Engineering*, Evans offered a course called "Industrial Organic Chemistry Lectures" to a select group of undergraduate students in chemistry. It immediately became very popular with the students, and in 1904 Evans introduced three more "chemical engineering" courses, which he shared with Edward G. Mahin.

On April 16, 1907, President Winthrop E. Stone's recommendation to the Board of Trustees was approved, and a "chemical engineering curriculum" was formed within the Department of Chemistry. The first BS in chemical engineering was awarded to Benjamin M. Ferguson (a Purdue quarterback!) in May 1909. A second degree was awarded in 1910 and nine more in 1911.

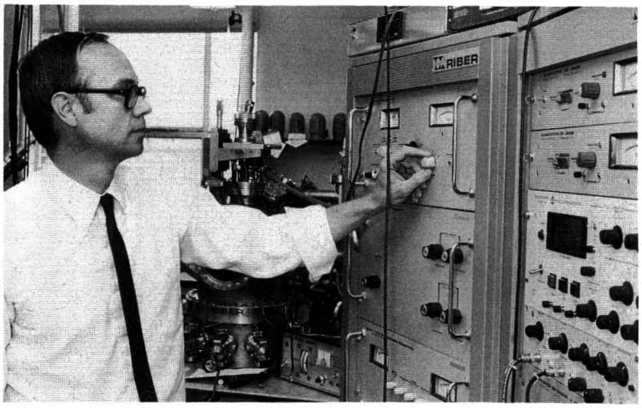
Only four years after the introduction of the chemical engineering curriculum there were 79 undergraduate students enrolled in the chemical engineering program. Thus, in 1911 President Stone, Dean Charles Benjamin and Professor Evans sought to establish an independent school of chemical engineering.

On June 14, 1911, the Board of Trustees approved the recommendation of President Stone and Purdue's School of Chemical Engineering became a reality. Its first faculty member and head was Harry C. Peffer, former director of research at the Aluminum Company of America (Alcoa) in East St. Louis. Peffer directed the school from 1911 until 1934. Faculty members of the pre-World War II period who served for a significant time were John L. Bray, Harold L. Maxwell, Robert B. Leckie (who developed a gas engineering option), Frederick L. Serviss (who introduced an engineering geology option), Clifton L. Lovell, Edward C. Miller and George W. Sherman, Jr. In 1930, R. Norris Shreve, a 1907 graduate of Harvard University, was hired to establish an "organic technology option."

A graduate program was established in 1916, and the first MS degree in chemical engineering was awarded in 1921 to Ernest H. Hartwig. Shreve (unit processes and industrial chemistry), Bray (metallurgy) and Lovell (unit operations) became the three main researchers of the school. The first PhD was awarded in 1935 to William N. Pritchard, Jr. A strong graduate program with more than 50 graduate students already existed in the late 1930's. At the same time the undergraduate program had become the largest in the country with 296 undergraduates in 1920, and 441 undergraduates in 1932.

Bray was named head of the school on Peffer's death and served from 1935 until 1947. He was followed by Shreve from 1947 to 1951, Edward W. Comings from 1951 to 1959, and Brage Golding from 1959 to 1966.

In the post-war years, new additions to the faculty added to the excellence of an already flourishing program. Prominent among the new faculty were Joe M. Smith (1945-57), Carroll O. Bennett (1949-59), John E. Myers (1950-66), and H. C. Van Ness (1952-56). These Purdue faculty members were authors of pioneering textbooks in thermodynamics, kinetics and transport phenomena that are still used today. In 1945, Shreve published his monumental *Chemical Process Industries*, which has sold more than 180,000 copies. The research programs of the school were also augmented by the work of J. Henry Rushton on mixing and that of Comings on high pressure thermodynamics. In the early 1960's another best-selling textbook was prepared at Purdue by D. R. Coughanowr and L. B. Koppel, *Process Systems Analysis and Control*, a book that has served at least two generations of chemical engineers.



Ronald P. Andres at the controls of a secondary ion mass spectrometer in one of the catalysis research laboratories.

THE PRESENT

The 70's saw a growing emphasis in the school toward fundamental and interdisciplinary research and on engineering science. This shaping of the current educational and research philosophy began with the appointment of R. A. Greenkorn as head in 1967, was accelerated by L. B. Koppel from 1973 to 1981 in a dedicated effort to add to the excellence of the graduate program, and is now in the hands of R. P. Andres, who became head in 1981.

The faculty have continued the tradition of textbook writing with *Transfer Operations*, R. A. Greenkorn and D. P. Kessler (1972); *Thermodynamics of Fluids*, K. C. Chao and R. A. Greenkorn (1975); *Introduction to Material and Energy Balances*, G. V. Reklaitis (1983); *Engineering Optimization*, G. V. Reklaitis, A. Ravindran and K. Ragsdell, (1983); and *Linear Operator Methods in Chemical Engineering*, D. Ramkrishna and N. R. Amundson (1985). The faculty are also recognized for excellence in research (recently the 1984 AIChE

Awards in Computing in Chemical Engineering and in Materials Engineering and Sciences and the Giuseppe Parravano Award in 1985) and in teaching (recently the George Westinghouse [1984] and Western Electric Fund (1984) awards of ASEE and Purdue's Potter Engineering Teaching Award [1985]).

FACULTY

The faculty member with the longest tenure in the history of the school is **Alden H. Emery** who joined Purdue in 1954 fresh from his PhD at the University of Illinois. His research interests include thermal diffusion, mass transfer, fluid mechanics, polymer rheology, and most recently biochemical engineering, with a focus on modelling algae and plant cell growth. **Lyle F. Albright,** who joined Purdue in 1955, is an authority on chemical processes and applied catalytic research. Lyle, who is the author of books on polymers and chemical processes and the editor of several ACS symposia volumes, has been particularly active in the AIChE, where he served as a director in 1982-84.

Eight faculty joined the school in the 1960's. **Robert G. Squires** joined in 1962. He was the first faculty member to do fundamental research in catalysis, concentrating his efforts on *in situ* IR spectroscopy of catalyst surfaces. Squires is a gifted educator, and is currently director of the school's Coop Program. **David P. Kessler** and **Roger E. Eckert** came in 1964. David's research interests are in transport phenomena, applied mathematics and biomedical engineering. He has also contributed to Purdue as an administrator, previously as associate provost and presently as the head of the Interdisciplinary Engineering Division. Roger has worked on polymer rheology and transport phenomena. His current research interests are in applied statistics and the design of experiments.

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Robert A. Greenkorn came to Purdue in 1965 after several years in industry and academia. His research is in thermodynamics and transport phenomena, more specifically flow in porous media. He is author or co-author of four books and is presently a vice-president of Purdue. **Henry C. Lim** joined Purdue in 1966 after several years at Pfizer. His early research was on process control. Since 1970 he has concentrated his efforts on modelling, control, and optimization of biochemical reactors. He is co-author of a book on environmental engineering. **K. C. Chao** also worked in industry and academia before joining Purdue in 1968. He directs a research program in theoretical and applied thermodynamics. Recently, he has concentrated on developing equations of state. In addition to the book with Greenkorn on thermodynamics, he has edited three ACS volumes on thermodynamics and equations of state.

In 1969 **Robert E. Hannemann,** a chemical engineer and physician (pediatrician), was added to the faculty as a "permanent" visiting professor. His research focuses on various biomedical engineering problems including the causes and treatment of the hyaline membrane disease, and the spectroscopic detection of jaundice. That same year **R. Neal Houze** came to Purdue from the University of Houston. His research interest is in two-phase flow. He is presently the director of the university-wide Coop Program.

Eleven of the twenty full-time faculty members were hired in the 1970's and 1980's. **Phillip C. Wankat** and **Gintaras V. "Rex" Reklaitis** came in 1970. Phil is doing research in various aspects of separation science, including chromatographic methods, membrane science, magnetic separations, and cyclic zone separation. A heralded educator, Phil is active in ASEE and has an MS in counseling along with his degrees in chemical engineering. Over the past fifteen years, Rex has developed computer-aided design into one of the school's major strengths. He also has written two textbooks, one on optimization and one on energy and mass balances. In 1985 he was appointed assistant dean of engineering for Graduate Studies and Research.

George T. Tsao and **W. Nicholas Delgass** joined Purdue in 1974. George was at Iowa State University and NSF before coming to Purdue. Here he has developed a large research program on biochemical and genetic engineering. He is founder and director of the Laboratory for Renewable Resources Engineering. Nick came from Yale University. His research centers on heterogeneous catalysis. He is co-author of a book on spectroscopic techniques in catalysis.

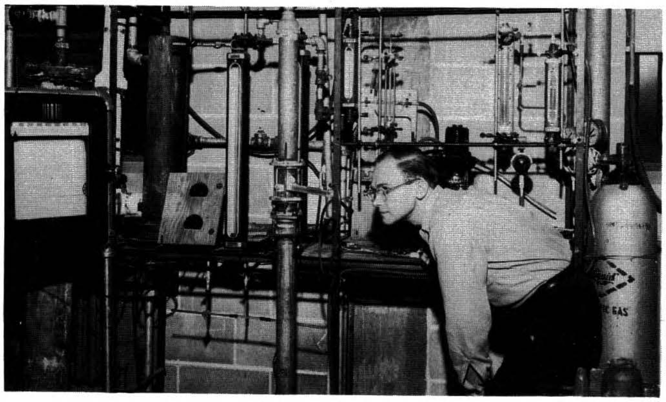
Three faculty members were added in 1976 and 1977. **Doraiswami "Ramki" Ramkrishna** came to Purdue after several years at I.I.T. Kanpur. He is well-known for his research in the application of mathematics to chemical engineering problems. He is co-author of a book on linear operator methods. **Nicholas A. Peppas** also joined the school in 1976. His research is on polymers and biomedical engineering. **James M. Caruthers** came to Purdue from M.I.T. in 1977 and has developed research programs in thermorheology and viscoelastic properties of polymers and in rheology and light scattering of colloidal dispersions.

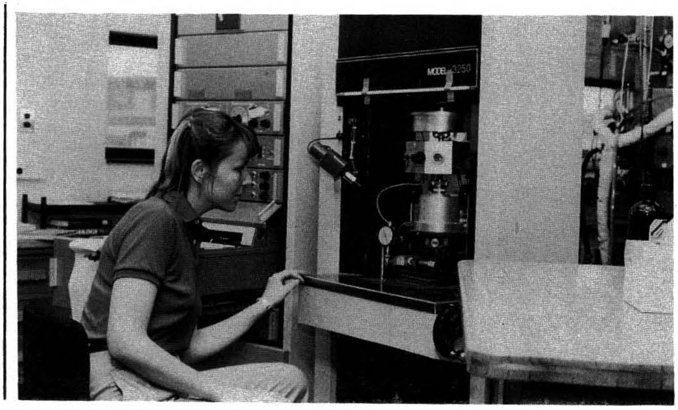
Elias I. Franses joined Purdue in 1979. His research centers on colloids and interfacial science with emphasis on the thermodynamic and transport properties of surfactants and the microstructure and stability of dispersions. **Linda N. H. Wang,** who joined the faculty in 1980, is doing research in ion-exchange theory, separation science, and applications of these to control the local environment of enzymes used in biomedical and biochemical engineering. **Christos G. Takoudis** joined Purdue in 1981. He has develped research programs in reaction engineering, catalysis, and chemical vapor deposition. The present head of the school, **Ronald P. Andres,** also joined Purdue in 1981, after 17 years on the faculty at Princeton University. His research interests are in the areas of chemical physics, aerosol science, and process control.

RESEARCH

Current research at Purdue covers a wide spectrum of activities. There is not space to discuss all of these activities here, but we will illustrate a few.

Biochemical Engineering • Biochemical engineering at Purdue dates back to the work of Lovell on production of 2,3 butane-diol from corn in the early 1940's. By 1970 a strong research program under the early leadership of Alden Emery and Henry Lim was in place. Among current studies are Emery's work on improving the efficiency of algae and plant cell growth and Henry Lim's work on adaptive control of bioreactors. Lim's work utilizes highly instrumented bioreactors interfaced to a hierarchical system of minicomput-





Left: Ray W. Fahien, current editor of this journal, doing research toward his 1954 PhD under the direction of J. M. Smith. Right: Kathleen M. Keville, a current graduate student, at a cone and plate rheometer in one of the polymer research laboratories.

ers for on-line data acquisition, analysis, optimization and control. The reactors can operate in the batch, semi-batch, continuous, or cyclic mode. On-line control and optimization allow Lim and his students to force bioprocesses to maximize production of biochemical products, such as penicillin, while regulating cell growth to maintain cell mass.

The Laboratory of Renewable Resources Engineering (LORRE) supports the bioprocessing research of approximately fifty professionals and students. Among the many projects that LORRE director George Tsao is involved in is the conversion of biomass to basic chemicals. This work involves all aspects of biochemical engineering including, for example, the use of genetic engineering to transfer xylose isomerase genes into yeast to create new cultures that can yield ethanol from both xylose and glucose.

Mike Ladisch and Martin Okos (faculty members in agricultural engineering with courtesy appointments in chemical engineering), Phil Wankat, and their students are addressing the problem of recovery of ethanol from the dilute aqueous solutions produced by bioprocesses. They have devised more energy efficient distillation methods, have found that extraction with gasoline can produce gasohol directly, and have developed new methods to produce pure ethanol by absorbing water from the ethanol-water azeotrope. This latter process, developed by Mike Ladisch, is being licensed commercially.

The behavior of cells in multinutrient media is governed by hundreds of microscopic chemical processes. Ramki Ramkrishna and his students have found that the internal regulation in cells can be modelled by assuming that cells seek to optimize their growth rate and respond to changing conditions accordingly. This cybernetic model has predicted cell responses to changing nutrients and provides a framework for control strategies for microbial fermentations.

Control of the local microenvironment in bioreactors requires chemical modification of the reaction medium. Linda Wang and her students have accomplished this control by immobilizing enzymes near ion exchange sites. In urea hydrolysis, for example, the local pH is maintained near the optimum for urease by removing the product carbonate ions by ion exchange.

Systems Engineering and Computer Aided Design • Perhaps nowhere in chemical engineering does the computer offer greater opportunities than in the area of process design and optimization. The university's Cyber 205 supercomputer, a CDC 6500, office and lab terminals linked to a powerful network of VAX 11/780 computers, as well as the recently funded NSF Engineering Research Center in Intelligent Manufacturing provide a most supportive environment for these studies at Purdue. In addition, the school has two unique facilities for education and research—the Shell Interactive Graphics Laboratory consisting of VAX 11/780 computer and 8 MEGATEK interactive graphics terminals and the IBM Computer-Aided Process Engineering Facility consisting of an IBM 4341 computer and 22 color graphics terminals.

Rex Reklaitis and his students use these facilities heavily in three separate areas of research. Their work in batch processing seeks to develop, implement, and demonstrate computer-aided methodology to support the design, scheduling and operation of batch systems. They pay particular attention to the role of intermediate storage in the operation of batch plants and are exploring methodology for automated planning and scheduling of multiproduct plants. Development of adaptive local approximation methods for physical property calculations has been a key to the effective simulation of the inherently dynamic processes encountered in batch systems. A second project is development of a process engineer's work station, integrating data base management, interactive computing, and computer color graphics. The present prototype allows interactive flow sheet drawing, material and energy balancing, and preliminary sizing and costing of equipment. Ultimately, the work station will

The 1986 plan of study includes a core curriculum and structured options in biochemical engineering, computer applications, engineering science, microelectronics, process management, and polymers.

allow generation and transmission of reports as well as the progressive development and evaluation of new process designs. Rex's research also encompasses the synthesis and operation of energy recovery systems. One of its aims is to develop energy management methodology for energy intensive processes and to test it under simulated conditions using the IBM facility and ACS (IBM's process control software).

Materials • Many of society's technological challenges past, present and future are closely linked to the development of new materials. The chemical engineer's role at this frontier is being increasingly recognized. Polymer materials and metal clusters are two areas of current research emphasis at Purdue. Jim Caruthers' research on the mechanical properties of polymer solids focuses on predicting the yield behavior of amorphous polymers. By carefully considering volume changes during deformation and combining a full three-dimensional linear viscoelastic constitutive equation with a statistical mechanical equation of state, he and his students are developing new models for predicting yield stress quantitatively over a wide range in strain rate. These models also identify mechanisms for pre- and post-yield behavior in polymer solids.

Another area of fundamental materials research is the work of Elias Franses, Jim Caruthers and their students on the properties of filled polymers. They have recently succeeded in preparing monodispersed spheroids of chosen aspect ratio. These unique materials, together with a new theory for interpreting light scattering from oriented, shaped particles will permit them to study particle orientation in suspensions under shear. Recent rheological measurements on suspensions of the shaped particles show that the particles do not interact directly but rather are associated by entanglements of polymer chains absorbed at the particle surface. The ultimate goal of these studies is a rheological constitutive equation for heavily filled polymers.

Particles of another sort are the focus of the research of Ron Andres and his students. Using a carefully arranged series of supersonic expansions they are able to separate the nucleation and growth of metal clusters. The result is the ability to produce metal aerosols with controlled cluster size from 5 to 500 atoms and with a size distribution of only $\pm 10\%$. This uniquely narrow distribution provides special opportunities for studying the effect of cluster size on the catalytic and electronic properties of metals.

Thermodynamics • In recent years, K. C. Chao, H. M. Lin, R. A. Greenkorn, and their research group have developed a new equation of state, the chain-of-rotators equation, that explicitly accounts for the rotational motion of polyatomic molecules. The cubic chain-of-rotators equation, derived from the original, represents vapor pressure and liquid density to within 2%. Chao and his students have turned their attention to combining group contribution, equation of state, and local composition concepts to describe polar fluids and mixtures. Particularly important to their recent success has been the effective use of Purdue's Cyber 205 supercomputer for the simulation of polar fluids and mixtures by averaging millions of microstates computed by Monte Carlo methods. Their experimental research of fluid phase equilibria at elevated temperatures and pressures has produced fundamental data of lasting value.

Other Research • Other research activities at Purdue span applied mathematics, biomedical engineering, chemical processes, colloid and interface science, kinetics and catalysis, reaction engineering, semiconductor processing, separations, and transport phenomena. Many of the experimental research programs are the direct beneficiaries of the expertise of David G. Taylor, our instrumentation specialist.

EDUCATION

The curriculum has changed substantially in recent years in response to changing technology and the broadened knowledge base underlying chemical engineering. Nevertheless, in comparing today's curriculum with that of the 1920's and 30's, one is struck by the continuity.

Today's undergraduates have the option of doing a semester research or design project in lieu of an elective course or of participating in an honors program which includes two semesters of independent research and a BS thesis. This option had its origin in an independent research-project course for undergraduates established by Peffer and Bray back in 1925.

Today's undergraduates have hands-on experience with a modern control computer (Honeywell TDC-2000) in their senior laboratory course and make use of real-time computer simulations supported on the IBM-4341 computer in their required process control course. A course in process control was established back in 1919 by George Sherman, existing first as an instrumentation course and since 1937 as a control course.

The undergraduate plan of study for 1936 included a core curriculum required of all students and structured electives for gas technology, general, metallurgy, and organic technology options. The 1986 plan of study includes a core curriculum and structured options in biochemical engineering, computer applications, engineering science, microelectronics, process management, and polymers. Throughout this period the school has stressed development of strong communications skills. This aspect of the program is now in the able hands of Frank S. Oreovicz, our communications specialist.

The current graduate curriculum consists of a core of four courses in applied mathematics, reaction engineering, thermodynamics, and transport phenomena. These courses follow general syllabi agreed upon by the faculty and have a rigor and depth that establishes the tone for graduate study. The remainder of a student's plan of study may be chosen from seventeen graduate electives (each course taught in alternate years), about a dozen graduate-undergraduate electives, or graduate courses from other departments. These courses are chosen in consultation with the student's thesis committee both to promote breadth and to support the student's research interests.

THE FUTURE

The school has had an illustrious past—one that is intertwined with the history of chemical engineering education and the chemical engineering profession. The impact of Purdue goes beyond its 6804 BS and 1208 advanced degrees. One-fifth of the more than 338 PhD graduates from Purdue have continued in academia, many achieving prominent positions. A recent survey by the school identified a total of 170 alumni that have become university faculty. The same 1984 survey identified over 300 alumni who are chief executive officers, presidents, or vice presidents of companies. The 1983 National Research Council Survey of graduate programs in engineering ranked the school second in the country in the "overall influence of scientific contributions of its faculty on chemical engineering."

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What can we predict for the future? What else except to repeat after Heraclitus, "Nothing is permanent except change." The 75th Anniversary of Purdue's School of Chemical Engineering finds both the chemical engineering profession and chemical engineering education in a period of rapid change.

From the perspective of the changes that have taken place at Purdue over the past 75 years the current situation is seen to be evolutionary rather than revolutionary. The National Research Council has recently charged a committee headed by Neal R. Amundson to look to the future of chemical engineering. The subcommittees for this undertaking: biochemical and biomedical engineering; chemical engineering aspects of advanced structural materials; chemical engineering aspects of electronic, photonic, and recording materials and devices; computer-assisted process and control engineering; energy and natural resources processing; environmental protection, safety and hazardous materials; and surface and interfacial engineering, have titles that qualify as headings for the research currently being undertaken at Purdue. Even more important than changes in research direction is maintenance of an environment in which students recognize, participate in, and generate excellence in research and a curriculum that is designed to prepare graduates for the needs of today as well as the continuing evolution of challenges that the profession will offer in the future.

The year 1986 finds the school stronger than ever. The presence of an ambitious and enthusiastic faculty and a dedicated undergraduate and graduate body, the support provided by a strong research university and by a large concerned alumni body, and the guidance provided by the history of the past 75 years, all point to a future even brighter than the past. □