Chapter 8

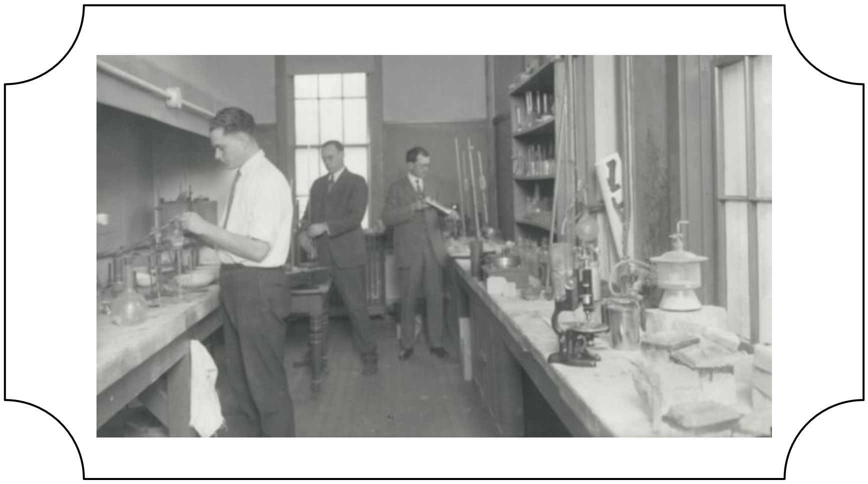
Chemical Engineering Research at Purdue

During the early years of the School of Chemical Engineering, research work *per se* was non-existent. Whatever research was done by Prof. H.C. Peffer was carried out by undergraduate students, who were required to write a B.S. thesis. This thesis was on a short research project performed in the last semester of the senior year. Experimental subjects were always selected and the work could be completed in two to three weeks.

Peffer, a metallurgist with Alcoa before he joined Purdue, was interested in new methods for production of metals. For the laboratory experiments his students used either the facilities of the Chemistry Department (especially of E.G. Mahin and P.N. Evans) or of the School of Mechanical Engineering. The first professional Ch.E. degree was awarded to Merle Robert Meacham (1887-1945) in 1916 for a thesis entitled "Potentials of the System H2-Pt-0.1N(HCl+KCl)-Hg2Cl2-Hg," supervised by Nathaniel E. Loomis, an instructor in the Chemistry Department. The first M.S. degree was awarded to Ernest H. Hartwig (1895-1992) for a thesis entitled "Effect of Segregation of Impurities upon Carbon Distribution in Steel," supervised by Prof. E.G. Mahin, of Chemistry.

Between 1911 and 1923 Peffer was occupied almost exclusively with teaching. Yet, he found the time for some original research. Thus, the first "publication" of the School appeared in 1923 in the form of a U.S. Patent (No. 1,465,173 issued August 14, 1923) on Electro-deposition of Co and Cr.

With the addition of Bray in 1923 and Maxwell in 1926 some research work was started in the areas of metallurgy and metallography, although the first true publication in a serious research journal did not appear until 1928 in the form of the article entitled "A Continuous Extraction Apparatus," authored by H.L. Maxwell (*Ind. Eng. Chem., 20*, 871-873 (1928)). Professor Peppas met Professor Maxwell during his last visit to Purdue in 1985. Maxwell was full of memories and recalled how he wrote his first paper here, and he indicated that there was very little research going on then. Serviss, who came in 1929, published no papers and supervised no graduate students.



Professor Peffer (right) and students in Peffer's first laboratory at Purdue Hall in 1925.

The graduate program in chemical engineering was established in 1924. Within the next six years 20 M.S. and Ch.E. theses were supervised by Peffer, Bray, Maxwell and Leckie. Most of these theses were in the area of metallurgy.

The year 1928 marks the beginning of serious research efforts in the School. Two events were responsible for this change: the establishment of the Indiana Gas Association grant and the collaboration of Peffer with R.L. Harrison of Rostone, Inc. At its annual meeting in May 1927, the Indiana Gas Association approved a five-year grant to Purdue University to enlarge its program of instruction, research and extensions in gas engineering effective 1928. As a result of this program, Prof. Robert B. Leckie was hired in 1928 to be in charge of the Gas Engineering program. Although Leckie was not a very active researcher, he did graduate four students (3 M.S. and 1 Ch.E. degrees) in the next eight years.

The Indiana Gas Association (IGA) was the sponsor of the longest research collaboration between the School and a funding agency. After the first funding period starting in 1928, funds were available on an annual basis and supported the salaries of professors and the stipends of many graduate students. Contributions were received from the public service companies of the state through the association. Some of the early research projects were on oxygen from air, and chemical methods of measuring large volumes of gas. Leckie was in charge of the program from 1928 to 1936, when J.L. Bray took over. He was in charge until 1952, when S. Hite started supervising the IGA projects. In September 1957 Lyle F. Albright became the faculty member in charge of this program until 1979 when this research was terminated. It is estimated that more than 25 graduate students were supported in the last 20 years of the IGA funding.

The second project is related to the development and characterization of a synthetic stone by Peffer. In 1923, Peffer started working on the use of a local shale as a raw material for construction. He was helped by Richard L. Harrison who did his M.S. thesis under Peffer in Civil Engineering (M.S. '23). A few years later, David E. Ross, at that time President of the Board of Trustees, started supporting Peffer's research on this raw material which outcropped in Attica, Indiana. The initial experiments were carried out in the Purdue Hall by Harrison, who became known as the "mud-pie maker." Gradually, Ross advanced more funds and the following four patents were issued to Peffer and his collaborators:

> H.C. Peffer, R.L. Harrison and D.E. Ross, Structural Material, U.S. Patent 1,852,672, April 5, 1932
>
> H.C. Peffer, R.L. Harrison and D.E. Ross, Artificial Structural Material Suitable for Ornamental Work, U.S. Patent 1,877,959, September 20, 1933.
>
> H.C. Peffer and P.W. Jones, Artificial Structural Material, U.S. Patent 1,877,960, September 20, 1933.
>
> H.C. Peffer and P.W. Jones, Use of Fly Ash for Making Molded Structural Material, U.S. Patent 1,942,769, January 9, 1934.

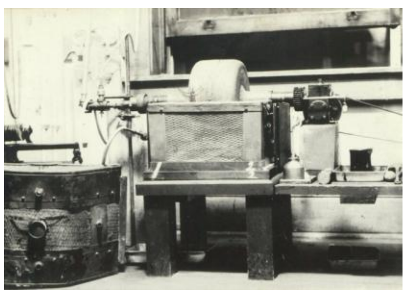
Eventually, Ross built a plant for the crushing, grinding, and processing of this shale. This project finally developed into Rostone, Inc., a local company where Peffer became Vice-President until his death in 1934. A research article1 by Peffer, Harrison and Shreve describes the properties and uses of this shale.

In 1930 the Organic Technology option was started under R.N. Shreve who became the most influential Purdue researcher of the 1930's and 1940's. His second M.S. student, John W. Olson, was the first ChE student to prepare a thesis on a subject related to organic chemicals instead of metals, gases or inorganic chemicals. The first Ph.D. theses of the School were awarded on May 21 and 24, 1935 to two of Shreve's students, William N. Pritchard, Jr., and Miller W. Swaney (see box).

Some of the early research projects of Shreve were on the synthesis and properties of certain drugs and dyes. The drug fl-phenyl-azo-a-a' diamino-pyridine hydrochloride was the subject of the Ph.D. thesis of Swaney and the M.S. thesis of Westcott C. Kenyon (1935). This drug was commercialized by Mallinckrodt as a genito-urinary antiseptic compound under the trade name Mallophene®. Work on barium, strontium and calcium salts was also done in the 1930's under the sponsorship of Mallinckrodt.

During his days as an independent consultant before he joined Purdue, Shreve had developed a strong interest in nitrogen-containing heterocyclic compounds because of their potential applications as dyes and explosives. He was very interested in the scientific studies of the Russian chemist Alexei Chichibabin (1871-1945), who had sent him many of his articles from 1916 to 1928 (see also Chapter 3). In 1928 they met in Russia, and the next year Chichibabin defected to France. A major figure in organic chemistry, Chichibabin became professor at the Collège de France in Paris. The studies of Shreve and Chichibabin were translated into short-lived commercial products in the 1920's. After Shreve's arrival at Purdue, the studies of the chemistry of these compounds became the basis of more than forty theses on dyes, under the sponsorship of Mallinckrodt and other companies. Other research areas pursued by Shreve in the 1930's and early 1940's were fur bleaching, preparation of plastics and coatings, hydrogenation of vegetable oils and esterification reactions.

Peffer's studies on the raw material to the development of Rostone, a construction material (photograph of 1926).



Above: One of the earliest pieces of equipment used in R.N. Shreve's work in 1932. A wrought iron ball mill used for the preparation of sodium amide by Abraham H. Goodman (M.S. '33). **Right:** The first distillation column for R.N. Shreve's research

It is appropriate at this point to examine the way research was done by graduate students in those days. The student was recruited and hired by the faculty member directly. There were no qualifying examinations for the Ph.D.; only a heavy course-load was required. The projects were sponsored by companies and the results were readily available to the companies for submission of patents (at least before 1937). In the School's Archives we found at least two letters by Shreve[2, 3] who offered 12 student reports in 1935 and 24 in 1937 to Mallinckrodt for the use of the company! Thus, graduate students were predominantly assistants in the laboratory and their work was not protected by any formal agreement. In one of the many letters written by an official of one of the many sponsoring companies of Shreve's work we find the following, which characterizes the prejudice of that period and the special obstacles that some graduate students had to overcome. The name and company of the author are omitted for obvious reasons.

> Enclosed herewith is also a letter just received this morning from one of your Purdue graduate students. The name sounds as if it might be Jewish but his record looks pretty good. Would you mind checking up on it and returning it for our files?

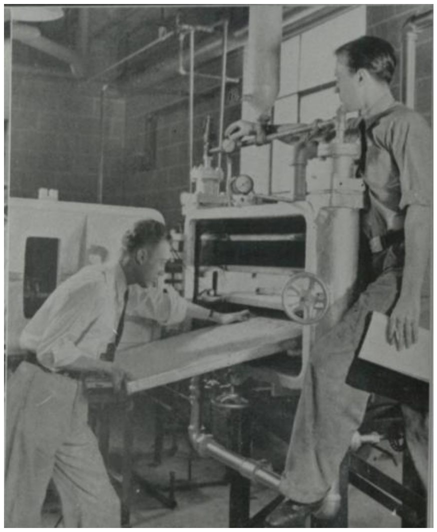
To his credit, Shreve did not reply.

In July 1937, things changed with the decision that the Purdue Research Foundation (PRF) would oversee the research contracts and grants of the various professors. This Foundation had been organized in 1929 with J.K. Lilly, Sr. as its first Director (1930-1948). Here are excerpts from an agreement signed by PRF and a company in September 1937.

> It is proposed that the research work may be done by graduate students working under the direction of Dr. Shreve; that the Company shall pay to the Foundation the sum of $1,500 to be used for the payment of salaries, overhead, and the cost of a limited amount of chemicals, such amount to be paid in full on or before October 15, 1937; and, that the Company shall pay any reasonable cost of special chemicals and equipment immediately after being billed for same. The materials and special equipment shall belong to the Foundation at the termination of the Fellowship...
>
> Upon establishment of the Fellowship, the Foundation will arrange so that all discoveries and inventions made by the research workers during the period of the Fellowship shall be assigned to and remain the property of the Foundation... The Foundation shall not publish the results of the research work of the Fellowship without full knowledge and advice of the Company and the Foundation in the results created.

After the arrival of Clifton L. Lovell, the first theses on fundamental chemical engineering were issued. Indeed, the first thesis on unit operations was the M.S. thesis of Forrest D. Stoops on “Entrainment Velocity Limits in Fractionation.” The first Ph.D. thesis of true chemical engineering content was that of William J. Burich on the “Influence of Free Convection Currents near Critical Values of Reynolds Number.”

Lovell's research addressed important aspects of chemical engineering within the framework of unit operations, and later fluid mechanics and mixing. In the 1930's he did research on distillation, heat transfer and mixing. In the early 1940's he expanded his research to the areas of fluid mechanics -where he became nationally known for his outstanding work in absorption and extraction. A true pioneer he examined many chemical engineering phenomena related to fluid flow. Unfortunately, his failing health did not allow him to publish most of his papers, and many of his significant results from his more than 35 theses remained unknown to the wider ChE community. It is interesting that Lovell had no research laboratories of his own; instead he used the equipment in the undergraduate unit operations laboratory, of which he was in charge.



Left: Research work in 1940.
Right: Graduate students in 1940.

The problem of research equipment was a serious one until 1940 when the School relocated to the CMET building. In the Annual Report of the President for 1924 we find that "the control laboratory is equipped and has been in use for sometime. The experimental laboratory is now provided with motor and line shafting, crushing and grinding machinery, filter press, flotation machine, centrifugal and a good-sized oil muffle furnace." The School did not have appropriate equipment for education and research but it did have "our museum of raw and finished products (which) could be extended to advantage."

Left: Graduate students in 1941.
Right: Organic Technology option in 1941.

In 1931, when the School moved to Heavilon Hall, equipment had increased significantly with the addition of metallurgical apparatus, furnaces, gas appliances and "a considerable number of standard pieces of equipment (which) have been loaned by manufacturers throughout the country," as the 1931 Report of the President states. By 1937 Shreve, Lovell and Bray had brought to the School old industrial equipment including a distillation column, crystallizers, evaporators and filters. Shreve had the most modern research facilities.

By 1936 the number of publications had increased to a respectable 1.2 publications per faculty per year (see Appendix T). Here is a description of the professional activities of the faculty from the 1937 Report of the President.

> Members of the staff attended meetings of the American Institute of Chemical Engineers, the American Chemical Society, the American Institute of Mining and Metallurgical Engineers, the American Society for Metals, the Society for Promotion of Engineering Education, and the American Society for Testing Materials, either to present papers or as members of standing committees. Doctors J.L. Bray, C.L. Lovell and Professor R.N. Shreve made a number of trips during this year in connection with the revision of the curriculum and the construction of the new Unit Operations Laboratory, in the course of which a large number of public contacts were made in the shape of addresses before groups at other universities, Purdue Clubs, and civic and professional organizations.

Left: Metallurgical Engineering in 1940.
Right: A ball mill reactor in the Heavilon Hall laboratories circa 1939.

Table 8-1 lists the contracts, grants and gifts of the School in June 1936. This list shows that seventy-five years ago there was already significant, externally supported research activity in chemical engineering at Purdue, but none of it was government supported.

Table 8-1. 1936 Research Projects

Funding Agency	Project	Funds ($)
Indiana Gas Association	Gas manufacture	4,500
Engineering Foundation	Dye technology	1,850
American Cyanamid Co.	Cyanamid studies	1,000
Various Gifts	Equipment	8,000
American Gas Association	Fellowship	1,350

The move to the new CMET building in 1940 led to a significant increase in funding. For example, in the fall of 1940 graduate research was supported by grants from J.G. Seagram & Sons, the Mixer Corporation, the Hill-Rom Company, Mallinckrodt, the American Welding Society, IGA, duPont, New Jersey Zinc Company, International Nickel Company, U.S. Steel Corporation, and the Calcium Chloride Association; these grants totaled more than $40,000. It was in 1940 that David E. Ross offered to Purdue 300 shares of Ross Gear and Tool Company which created a special fund from the income of which the first David Ross Fellowships were given.

In the mid and late 1930's one half of the graduate research projects were on unit processes (Shreve), the rest divided between metallurgy and unit operations. A single project on thermodynamics was supervised by Bray in 1938-39 but it did not yield a thesis. The first thesis on a heat transfer subject appeared in 1939. It was the M.S. thesis of Herbert F. Wiegandt, who became a professor at Cornell University, entitled “A Comparison of Thermocouple Installations Used in Heat Transfer” (C.L. Lovell, advisor). In the early 1940's research on distillation, mixing, absorption, fluid mechanics, heat and mass transfer, unit processes, organic chemical technology and (somewhat primitive) kinetics was performed. In 1942-43 Lovell achieved another first, by supervising the M.S. thesis of Ramon I. Lindberg on “Liquid-liquid Extraction of 2,3-Butanediol from Fermented Grain Mash.” This was the first thesis in biochemical engineering, a subject area that forty years later would be one of the strongest research areas of the School.

Synthesis of synthetic rubber in the Unit Processes laboratory in June 1944.

The School made significant contributions to chemical engineering problems and chemical production during World War II4. A training school to develop technically competent superintendents for the operation of munitions plants was established. Cresol, which was no longer available from the European chemical industries, was produced in the laboratories on a semi-commercial scale. It was needed to produce a flexible plastic for war material. A chemically pure mustard gas was produced in quantity for needed studies to compare with the commercial product. Quantitative studies of high energy chemical reactions which gave promise for improved rocket propellants were made for the government. Finally, in collaboration with the Chemistry Department, an extensive study was carried out of methods for analysis and control of production processes separating U235 and U238. The methods developed were used in production of materials for the atomic bomb.

As discussed in Chapter 3, in 1945 the School started hiring new faculty, prominent among which would be J. M. Smith and D. Holcomb. Clifton Lovell, a true pioneer of chemical engineering, would stay active only until 1946 when he took a leave of absence for health reasons. He had time to supervise one more biochemical engineering M.S. thesis on the "Clarification of Malt Converted Degerminated Corn Mash Prior to Fermentation" (Francis A. Hilinski, M.S. '45).

Shreve was extremely active in research from 1945 until his retirement in 1955. His research was gradually turning towards subjects such as kinetics, reactor design, fixed beds, absorption and even polymerization reactor design.

Joe M. Smith established in 1945 an ambitious research program with students working on kinetics, catalysis, thermodynamics and heat transfer. The first thesis on the subject of kinetics and reactor design was the M.S. thesis of Robert R. Cartnell on "Vapor Phase Hydration of Ethylene Oxide" (1947) supervised by Smith. The first thesis in thermodynamics was authored by Albert J. Barnes, Jr. supervised by Dysart E. Holcomb; its subject was "Phase Relations for the Two-Component System: Stearic Acid and Water."

By 1950 the School had a very active research program—15 M.S. and 11 Ph.D. degrees were awarded in 1950—and significant funding for research was available. For example, the Indiana Gas Association supported the research of J.L. Bray and S.C. Hite on hydrogenation of coal, control of mixed industrial gases, temperature and pressure-relief valves, electric ignition for gas appliances and venting of direct heaters. Starting in 1945, the same investigators supervised research on home humidity control sponsored by the American Gas Association.

Left: Filling sand bomb to be used in the Explosives laboratory (July 8, 1941 picture).
Right: The Explosives laboratory in 1941 (CMET building, room 213)

J.M. Smith was in charge of a variety of research projects. Studies of temperature gradients in continuous gas-solid catalytic reactors were supported by PRF, whereas from 1946 until 1950 the Research Cotrell Corporation supported his work on heat and mass transfer in fluidized gas-solid systems, and after 1950 his work on flow in fluidized systems. The Engineering Experimental Station was the sponsor of Smith's work on vapor-phase hydration of ethylene oxide, and in 1947 the Texas Company gave him a grant for the study of the radial temperature gradients of gas-solid catalytic converters. Finally, his studies on the reaction of sulfur vapor and methane were sponsored by the Eastman Kodak Company and the Pure Oil Company.

In his short time at Purdue, Holcomb studied the liquid-liquid extraction of fatty materials (work sponsored by Procter and Gamble Co. and Shell) and the thermodynamic properties of ternary hydrocarbon mixtures. In 1947 Doody had already started his work on vapor-liquid equilibria, which was supported by Shell, and on boiling phenomena, supported by PRF. Finally, soon after his arrival in 1949 Bennett started working on liquid-liquid equilibrium.

Shreve had the largest research program during this period. His work on alkylation was supported by the American Cyanamid Co. from 1946 to 1952. Lilly Varnish Company started supporting his work on surface coatings in 1946 and continued doing so for nine years. At one time eight graduate students were working on this project. The first thesis in the field of polymers at Purdue was the Ph.D. thesis of Brage Golding (1948) on “Oil Soluble Phenolic Resins and their Varnishes” supervised by Shreve. In 1950 Edwal Laboratories supported Shreve's work on dyes made from amino derivatives of toluene. Other companies supported his work on derivatives of methylnaphthalene and dyes from nitrogen-containing heterocyclic compounds.

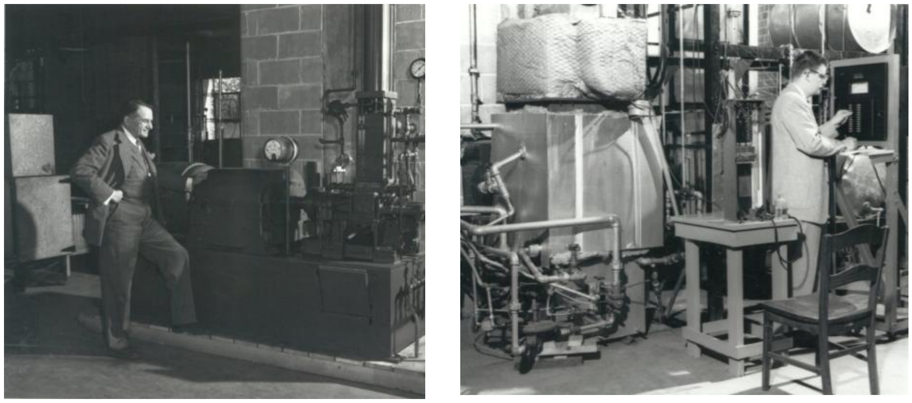
Table 8-2. The Kelly Lecture

The Arthur Kelly Lecture was established by a grant from alumnus Arthur Kelly (B.S. '24), a retired Vice-President of B.F. Goodrich Co. It is presented annually by outstanding engineers and scientists from the broad areas of chemical engineering. The recipients are selected by the faculty in recognition of their contributions to research. The Kelly Lecturers have included legendary figures in chemical engineering and two Nobel laureates.

1965	Warren L. McCabe (deceased)	North Carolina State University
1966	Arthur B. Metzner (deceased	University of Delaware
1967	Olaf A. Hougen (deceased)	University of Wisconsin
1968	R. Byron Bird	University of Wisconsin
1969	C. Judson King	University of California, Berkeley
1970	L.E. Scriven (deceased)	University of Minnesota
1971	Charles N. Satterfield (deceased)	M.I.T.
1972	Robert L. Pigford (deceased)	University of Delaware
1973	Andreas Acrivos	Stanford University
1974	John M. Prausnitz	University of California, Berkeley
1975	Michel Boudart	Stanford University
1976	Arthur E. Humphrey	University of Pennsylvania
1977	Rutherford Aris (deceased)	University of Minnesota
1978	James J. Carberry (deceased)	University of Notre Dame
1979	Warren E. Stewart (deceased)	University of Wisconsin

1980	Paul Flory (deceased)	Stanford University – Nobel Prize 1973
1981	Neal R. Amundson (deceased)	University of Minnesota
1982	William R. Schowalter	Princeton University
1983	Thomas J. Hanratty	University of Illinois
1984	Wolfgang M.H. Sachtler	Northwestern University
1985	Benjamin G. Levich (deceased)	City University of New York
1986	Alan S. Michaels (deceased)	North Carolina State University
1987	Morton M. Denn	City University New York
1988	Edward L. Cussler	University of Minnesota
1989	E. N. Lightfoot	University of Wisconsin
1990	H. Ted Davis (deceased)	University of Minnesota
1991	Reuel Shinnar (deceased)	City University of New York
1992	Robert S. Langer	M.I.T.
1993	Arthur W. Westerberg	Carnegie-Mellon University
1994	W. Harmon Ray	University of Wisconsin
1995	Douglas A Lauffenburger	M.I.T.
1996	John H. Seinfeld	Caltech
1997	Lanny D. Schmidt	University of Minnesota
1998	Matthew V. Tirrell	Univ. California-Santa Barbara
1999	George N. Stephanopoulos	M. I. T.
2000	Robert A. Brown	M.I.T.
2001	Gerhard Ertl	Fritz Haber Institute, Germany – Nobel Prize 2007
2002	Mark E. Davis	Caltech
2003	Gregory N. Stephanopoulos	M.I.T.
2004	William B. Russel	Princeton University
2005	40 Year Symposium:	
	Frank S. Bates	University of Minnesota
	Alexis T. Bell	University California-Berkeley
	Ignacio E. Grossmann	Carnegie-Mellon University
	Michael L. Shuler	Cornell University
	James Wei	Princeton University
2006	Frances H. Arnold	Caltech
2007	Manfred Morari	ETH-Zurich
2008	Pablo Debenedetti	Princeton University
2009	Carol K. Hall	North Carolina State University
2010	Rakesh Jain	Carnegie-Mellon University
2011	Stanley I. Sandler	University of Delaware

In the early 1950's C. O. Bennett and Joe Smith embarked upon important research in thermodynamics, and Jack Myers started his pioneering work on fluidized drying and heat transfer. A major Department of the Army contract supported the work of Comings and Myers on gas dynamics. Comings was also involved in high pressure research, and Van Ness was hired to contribute in the area of thermodynamics. In the early 1950's Lilly Varnish was supporting around eight different projects on polymers and coatings under the direction of Shreve and Visiting Professor Brage Golding.



Left: R.N. Shreve and a new Banbury mixer in 1951.
Right: The Indiana Gas Association provided research funds to the School for more than 50 years. Samuel C. Hite tests a gas furnace (February 26, 1953).

Major changes in the direction of ChE research at Purdue were observed in the period of 1955 to 1960. The number of projects in unit processes had gradually decreased and in the spring of 1956 the last two students working in this research field graduated. After 26 glorious years at Purdue, unit processes had been absorbed in the more modern areas of kinetics and chemical processes.

Table 8-3. The Shreve Prize for Chemical Processing

The Shreve Prize for Chemical Processing was established by R. Norris and Eleanor B. Shreve in 1960 to recognize outstanding research contributions in the area of chemical processing by a ChE faculty member. The recipient was selected by a committee consisting of Shreve, two alumni of the School working in industry, the Dean of Engineering, and one of the officers of the Indianapolis Section of AIChE. The award was accompanied by a check for $500. Considering that the typical salary of an Assistant Professor in 1960 was about $7,800 a year, the amount of $500 was significant. The recipients of this award were the following:

1960	Lyle F. Albright
1961	Brage Golding
1962	John M. Woods
1963	Robert D. Vaughn
1964	Charles E. Wales
1965	Roger E. Eckert
1966	Donald R. Coughanowr
1967	Leslie E. Lahti

1968	Theodore J. Williams
1969	Robert G. Squires
1970	Lyle F. Albright
1971	Robert A. Greenkorn
1972	David P. Kessler
1973	Henry C. Lim

In 1974 this award was changed to become *the teaching award* of the School (see Table 7-2). A less known Shreve Prize was established in 1958 at Cheng Kung University by Professor Shreve to recognize a faculty member of that School who had done outstanding ChE research in his early career. This award, sponsored by Shreve, consisted of a certificate and $300 in scientific books. We do not know how long this Shreve Prize was given. We are aware of one of its recipients, Prof. Jehn-Hwa Wang[5], who received it in 1960.

Table 8-4. Purdue University Research Awards

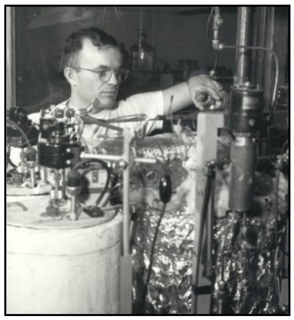
Nicholas Peppas won Purdue's highest research recognition, the **Herbert McCoy** research award, in 2000 and the **Sigma Xi** award in 2002.

The **University Faculty Scholar** designation is a faculty distinction started in 1998 intended to recognize exceptional achievement and promise of mid-career faculty. ChE recipients are Venkat Venkatasubramanian 1998, Joe Pekny 1999, Michael Harris 2003, Fabio Riberio 2006, Steve Beaudoin 2006, Ken Thomson 2007, Hugh Hillhouse 2009 and David Corti 2011.

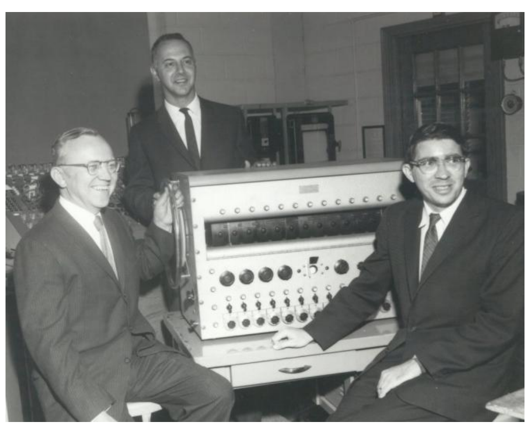
Purdue also has a **Sigma Xi** competition for outstanding graduate student research. ChE winners are: Richard W. Korsmeyer, 2nd Prize, 1982, Steven R. Lustig, 3rd Prize, 1985, Balaj Narasimhan, Most Outstanding Award, 1996, Antonios Mikos, 3rd Prize, 1985 and 2nd Prize, 1998, and Delai Dink, 1st place in poster competition (Engineering Sciences Category), 2004.

Left: Lilly Varnish of Indianapolis supported the ChE research on polymers and coatings for 8 years. On the occasion of a visit of officials of the company to the labs, R.N. Shreve and E.W. Comings welcome B. Golding - then Associate Director of Research of Lilly Varnish - and two other researchers (April 21, 1953).
Right: Joseph F. Gross (Ph.D. '56) and a fellow graduate student at a picnic in September 1955.

For more than 20 years the financial support for the graduate student research projects came from industry. Over the next 15 years (1956-1971) a major effort would be made to balance this financial support with funds from federal agencies. These grants were usually given for more fundamental research. The first two Purdue ChE grants from the National Science Foundation were awarded in the fall of 1955 to Edward W. Comings for a proposal on the "Thermal Conductivity of Gases at High Pressure" and to John M. Woods and Joe M. Smith for their proposal on the "Kinetics of Vinyl Chloride Production."



Left: Truman Storvick (Ph.D. '59), now professor emeritus at the University of Missouri - Columbia, as a graduate student (April 23, 1958).
Right: Gary W. Poehlien (B.S. '58, M.S. '63, Ph.D. '66) (on right) as a graduate student in September 1963. Gary had an illustrious career as a researcher and academic administrator including Director, School of Chemical Engineering at Georgia Tech from 1978-85 and Director, Chemical and Transport Systems Division, NSF, 1997-2000. He retired from Georgia Tech in 2002.



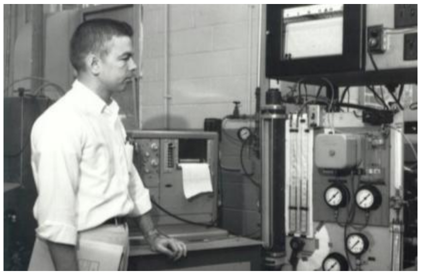
Brage Golding (middle) and Donald R. Coughanowr (right) with the donor of a new analogue computer (October 27, 1960).

John (Jack) E. Myers performed his classic research on heat transfer from 1950 to 1966.

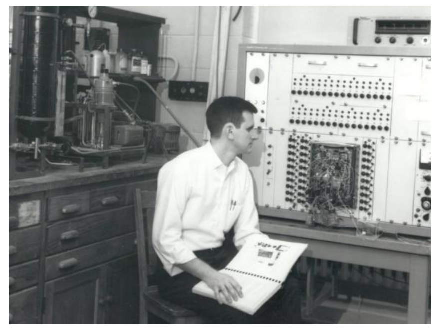
In 1959, of 58 research projects 12 were funded by federal agencies (Woods, Emery, L.C. Case and Myers by NSF, Bennett by DOD, and Sesonske by the Atomic Energy Commission), Rushton by ACS/PRF, 5 by the Indiana Gas Association, 22 by companies, nine by the Engineering Experimental Station, and 10 by the School. Major research emphasis was placed on heat transfer (Myers, Sesonske, B.D. Smith) and mass transfer (Bennett, Emery, B.D. Smith, Tucker). Work on fluid mechanics was performed by Bennett, Rushton and Shannon; and the thermodynamic properties of fluids were investigated by Bennett, Comings, Albright, Doody, Emery and B.D. Smith. Research in chemical processes was performed by Albright and in chemical reaction kinetics by Coughanowr and Woods. Finally, an ambitious polymer program was established by L.C. Case and Emery. The total research expenditures were $97,000 or 9% of the total engineering budget.

During the years of Golding's administration events occurred in the School which led to an unfortunate decrease in the research funds. With the exception of the area of optimization and control, all other research areas suffered a drastic decrease in the number of available projects. By 1966 ChE research expenditures (external support) had dropped to $41,000 (Appendix S) representing an all time low of only 1.6% of the total engineering funds for research. For a period in the early 1960's only one half of the faculty members were active in research. Prominent among them were Albright in chemical processes, Squires in kinetics and catalysis, Myers in heat transfer, Emery in polymer rheology, and Koppel and Coughanowr in process control.

After 1961 Koppel and Coughanowr established an ambitious research program that developed a national reputation in the area of process control. Support by NSF and various companies continued for over a decade. The addition of Lim and Weigand in the late 1960's further contributed to the recognition of this program. The first Purdue ChE thesis in the area of control was published in 1962 by Wayne E. Luetzelschwab. He was a student of Coughanowr and his M.S. thesis was entitled *An Analog Computer Simulation of a Steam-jacketed Kettle and Control System*. Luetzelschwab, who passed away on March 5, 2010 at the age of 72, was a leading authority in oil extraction. In 1963, the first purely theoretical thesis was accepted by the faculty. Supervised by Paul T. Shannon, this was the M.S. thesis of Martin R. Feinberg, now a distinguished professor at Ohio State University, on the *Thermodynamics of the Steady-state from an Information Theory Viewpoint.*



Left: Noel E. Moore (BS '56, PhD '67) in 1963 before he became a professor at Rose Institute of Technology (now Rose-Hulman Institute of Technology)



Right: Duncan A. Mellichamp (Ph.D. '64) now professor emeritus at the University of California-Santa Barbara in 1963. Mellichamp was one of the most influential control engineers of the last 40 years and a great friend of Purdue ChE.

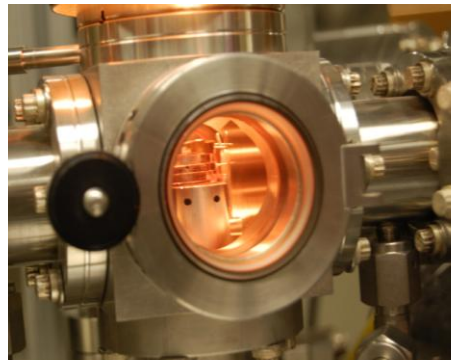
In the early days of Greenkorn's administration, the main research areas of emphasis were kinetics and reaction engineering, optimization and control, simulation and design, thermodynamics and transport phenomena. Comparison of the emphasis on research in 1970 with that of 1985 and 2010 (Table 8-5) shows the major research changes in the School. The table shows the percentage of projects that all graduate students were doing their research on each year.

Left: Robert G. Squires and graduate student in 1966. **Right:** Graduate students and visiting scientists from many foreign countries are educated at Purdue University. Here visiting scientists Yves Tayeb (left) from Rhone-Poulenc in Paris, France, and Pierre Cuille (right) from the University of Toulouse, France, use the computer under the approving eyes of postdoctoral fellow Sachindra K. Dash (1983 picture)

Table 8-5. Distribution of School's Research Projects

Research Field	Percentage of Research Projects		
	1970	1985	2010
Applied Mathematics		3.4	0
Biochemical Engr.		18.0	2.9
Biomedical Engr.		3.4	8.7
Catalysis		11.2	16.3
Chemical Processes		1.1	0
Colloid & Surf. Sci.		3.4	2.9
Energy:			
Batteries			2.9
Biomass			7.7
Solar			12.5
Systems			2.9
Environmental Engr.		1.1	0
Kinetics & React. Engr.	16.4	6.7	2.9
Materials (non-polymer)			4.8
Optimization &'Control1	17.9	5.6	0
Particulates			5.8
Polymers		18.0	6.7
Separation		4.5	8.7
Simulation & Design	10.5	11.2	9.6 (Pharma)
Thermodynamics	10.5	9.0	1.0
Transport Phenom.	44.7	3.4	3.8

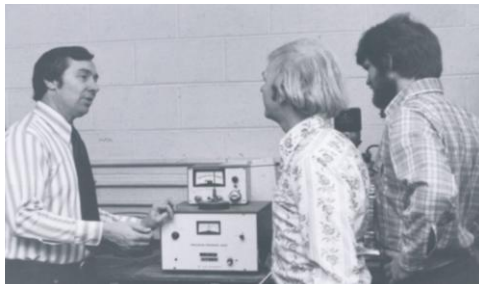
Between 1970 and 1985 there was a shift towards research projects in newer technological areas such as biochemical engineering, catalysis, polymers, and computer-aided design. There was a broader distribution and representation of research areas in 1985 than in 1970. Research in design/simulations and in thermodynamics stayed at approximately constant levels. At first glance, emphasis in kinetics and reaction engineering seems to have decreased, but this is a false conclusion since (i) a large number of projects in biochemical engineering address kinetic problems, and (ii) the projects in catalysis normally include kinetics as well. Research in optimization and control decreased somewhat, but not as much as it appears because some of the control work was applied to biochemical problems. Clearly, the major change in the research direction of the School during this period was the reduction in transport phenomena research from approximately 45% in 1970 to only 3% of the projects in 1985; however, there was still research in fluid mechanics that was performed within the framework of non-Newtonian fluids (polymers). Classical mass transfer (unit operations-type) research appeared to disappear, but parts were just renamed as separations and other significant research in this area was continued in polymers. Finally, heat transfer research was not an active research area in the School in 1985 or in 2010.



Sophisticated catalysis equipment has been used in the School for a number of years.
Left: William D. Kostka (B.S. '74, M.S. '78, Ph.D. '81), and Prof. W.N. Delgass discuss the operation of the secondary ion mass spectrometer (SIMS) in 1980.
Right: Experiments being conducted in Fabio Ribeiro's laboratory in 2008.

In the mid 1980s Purdue had strong programs in a wide range of research fields (see Appendix V). Biochemical engineering was a major research field and faculty involved included Tsao, Lim, Emery, Ramkrishna and Wankat. Biomedical engineering work was carried out by Wang, Hannemann, Franses and Peppas. Catalysis was another major research area for the School under the leadership of Delgass, Squires, Takoudis and Andres. Chemical processes were studied by Albright and Eckert, colloid science by Franses, and environmental engineering by Greenkorn and Lim. Reaction engineering problems were addressed by Ramkrishna, Takoudis and Andres. The areas of optimization, control, simulation and process design were the focus of Reklaitis, Koppel, Lim and Andres; but unfortunately Koppel left in 1986 and Lim in 1987. Polymer science and engineering was the research area of Caruthers and Peppas, and separation science that of Wang and Wankat. In addition to his other interests, Ramkrishna conducted research in applied mathematics. A strong thermodynamics group was run by Chao and Greenkorn. Finally, classical transport phenomena continued in the research of Greenkorn, Kessler and Houze. In 1987, with the help of Jim Schorr (BS 54, DEA 74, Hon. Doc 87) a capital fund drive to raise funds for research instrumentation facilities was started. This drive became part of New Directions (see box in Chapter 6) and eventually raised a significant amount of money for the School.

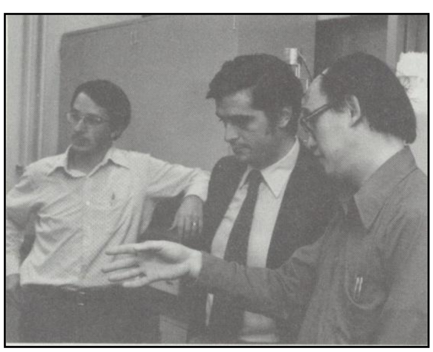
Christopher C. Creagan (M.S. '77, Ph.D. '81), now at Kimberley Clark, and E. Terry Papoutsakis (M.S. '76, Ph.D. '79), now a distinguished professor at University of Delaware, work with a new fermentor in Professor Lim's laboratory in November 1976.

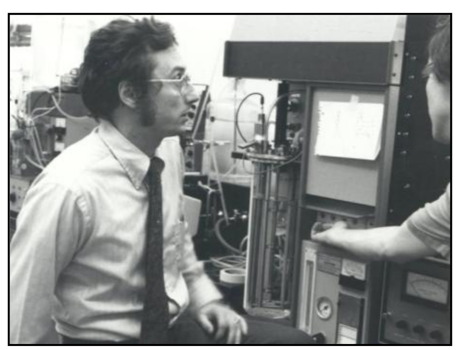


Robert G. Greenkorn with Edward A. Turek (B.S.' 73, Ph.D. '78) and David W. Arnold (Ph.D. '80), now professor at the University of Alabama, in December 1980.

The classification of research projects as it appears in Table 8-5 cannot show the wide range of interests of the faculty, and the unusual research subjects available to graduate students. For example, genetic engineering work was carried out by Tsao's group in the early 1980s, chemical vapor deposition and polymer research as related to microlithography were conducted by Takoudis and Peppas, aerosol science was studied by Andres, and coal research was of interest to several faculty members.

The research programs of chemical engineering departments clearly have a certain amount of inertia: faculty who have developed expertise and acquired specialized apparatus in one area are often loath to exit that area. On the other hand, when faculty leave, new professors are hired, or the funding available from the major government agencies waxes and wanes in different research areas; changes in research directions can be quite dramatic. Research universities hire new faculty who will help strengthen existing research areas, or lead the department into promising (in the sense of attracting both funds and graduate students) new areas, or (on rare occasions) for their leadership ability. Unfortunately for the undergraduates, teaching considerations in many research universities are, at best, secondary in the hiring decisions. On the other hand, some of the best researchers are also award winning teachers.

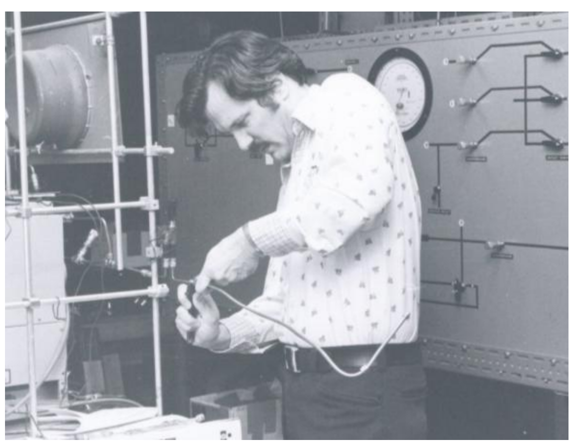




Left: George Tsao (right) nurtured international research collaborations. George is shown here in 1978 with Bruce Dale (Ph.D. '79), now distinguished professor at Michigan State University (left), and Prof. Francesco Alfani of the Department of Chemical Engineering of the University of Naples, Italy (center).
Right: William A. Weigand, shown here with Paul O. Hennigan (M.S. '79, Ph.D. '83), was instrumental in merging process control, and biochemical engineering (1979 picture).

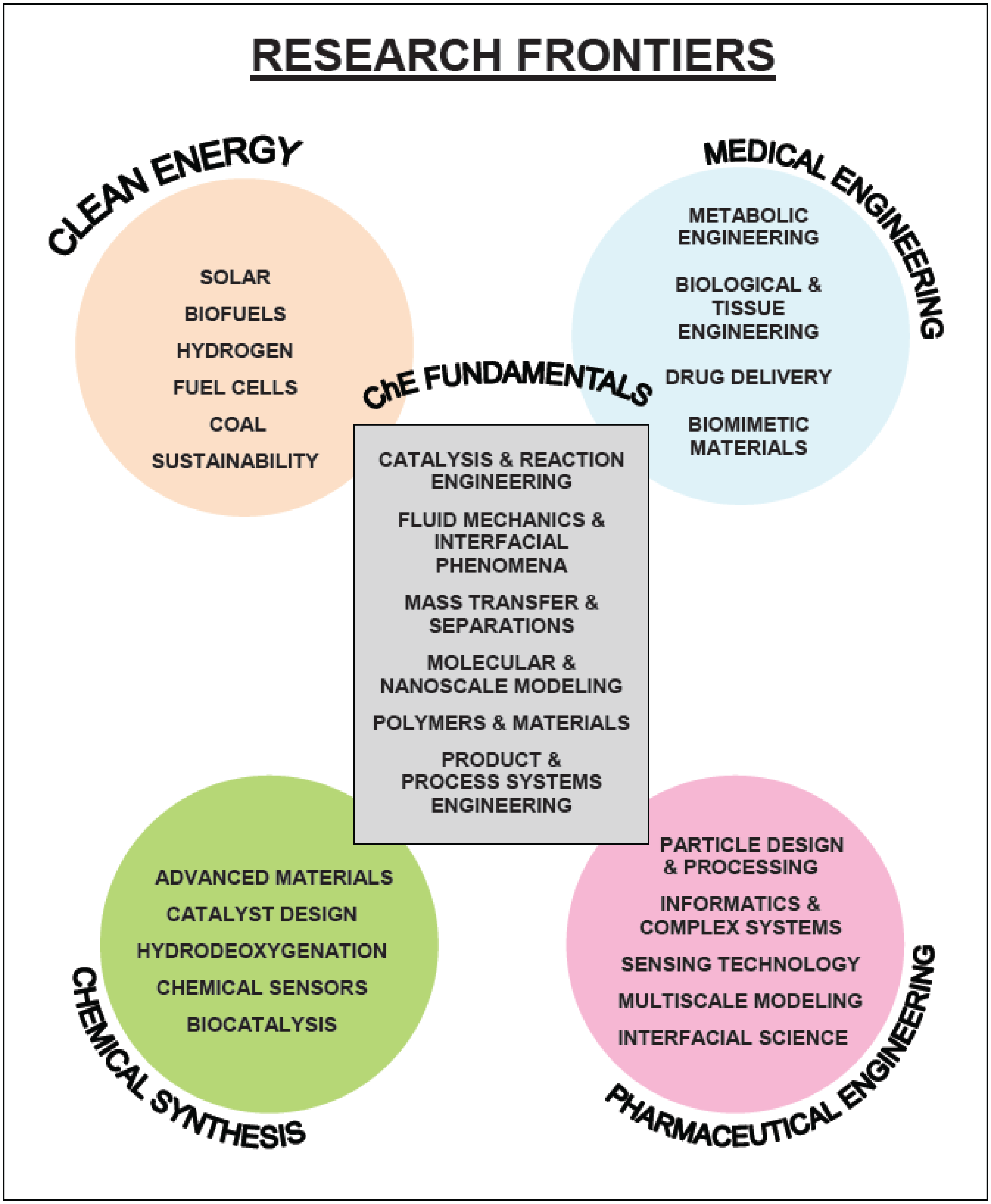
Looking at the evolution of research in the School in Appendix V and at the 2010 data in the Table, it is clear that there have been major changes in the research interests of the faculty. Reflecting national and Purdue interest and the availability of money, energy has become the largest single area. However, we could have classified many of these projects differently. A majority of the solar cell work involves nanotechnology and materials development (Agrawal, Chakrabarti and Wu), some of the biomass work is close to classical biochemical engineering (Morgan) while some is catalysis-based (Agrawal, Delgass, Ribeiro), and much of the battery work (Caruthers, Pekny) could also be classified as materials-oriented research. Catalysis has blossomed, partially from hiring faculty interested in this field (Ribeiro, Thomson), partly from development of centers (see Research Center box later), and partly from energy and other applications. Although there has been a reduction in kinetics/reactor research, part of the apparent reduction is classifying projects as catalysis instead of reactors.

Purdue ChE was one of the two pioneering programs on drug delivery during the 1970s to 1990s. In the last 10 years, the new area of Pharma has become very important because of the success of the Pharmaceutical Processing Research Center. Some professors (Reklaitis, Venkatasubramanian, Litster, Harris, Beaudoin, Basaran) have refocused their expertise and tools on the slightly different problems occurring in pharmaceutical manufacture. There is clearly an increase in biomedical research (now conducted by Franses, Hannemann, Liu, Ramkrishna and Yuan) which reflects the interest and success that earlier national and Purdue pioneers (Hannemann, Peppas, Barile, Franses, Ramkrishna and Wang) had in this area. Applied mathematics appears to have lost out, but it has really won the war since almost all projects use applied mathematics to attack problems in biomedicine, biochemicals, separations and so forth. Although unit processes are gone, unit operations research lives with new, more specific names: separations (Agrawal, Wang, Wankat), particulates (Harris and Litster), and pharmaceutical processes (Reklaitis, Venkatasubramanian).



W. Nicholas Delgass in his first catalysis laboratory in 1976.

The current (2011) research thrusts of the School are shown in the Venn diagram, and the faculty working in each area are listed in Appendix V.



For 88 of its 100 years of history, the School has been active in research. Since the publication of Peffer's first original research contribution in 1923, ChE faculty members have not stopped contributing to research. Some statistical facts will be presented which show the prominent position of the School in the American and world-wide ChE research.

From 1923 through 1985 more than $18,000,000 was received for support of research from external sources. From 1985 to 2010 the research expenditures had increased to a total of $172,000,000 or a grand total of $190,000,000 over the research life of the School. From 1975 through 1984, Purdue ChE was one of the top five ChE Departments in the country in research funds. For example, in 1983-84 Purdue ChE was fifth with $1,654,000 per year. M.I.T. was first with $2,851,000 but for almost twice as many faculty members. After 1984 research expenditures increased, but the School's position relative to other ChE departments slipped. In 1984-85 Purdue's $1,770,000 in research expenditures was seventh with MIT again first. In September 1997 *Chemical & Engineering News* ranked the School as 10th in total research expenditures among ChE departments. The October 4, 2010 issue of *C&EN* listed Purdue as 17th in ChE research expenditures (38th in federal funding) in 2007. The School was 18th in expenditures for ChE research (23rd in federal funding for ChE research) in 2008.

One difficulty comparing different universities is data bases differ. The *C&EN* article, which uses the NSF data base, lists Purdue expenditures as $9,275,000 in 2007 and as $9,882,000 in 2008. Neither of these numbers agrees with Purdue's data in Appendix S ($8,902,000 and $10,850,000). One difference may be the use of academic years versus calendar years. The C&EN article also lists the School's 2004 expenditures as number 1 in the US at $22,360,000. This amount clearly included expenditures for the Forney Hall addition. With the exception of 2004, the position of the School's research expenditures relative to other ChE departments has clearly slipped. However, the nature of ChE research has changed and some institutions concentrate on nanotechnology and biological research that is very expensive to perform and does not always reminds the authors of "chemical engineering".

The School has consistently ranked near the top Ph.D. producers in the country. During its 100 year history the School has awarded 750 Ph.D. degrees, 1130 thesis M.S. degrees, and 32 professional Ch.E. degrees (see Appendices N, O, P, and Q for complete listings). Because the size of Ph.D. cadres varies significantly and Ph.D. students do not stay for a set number of years, the number of graduates from a program varies significantly from year to year.

For 1983-84 Purdue[16] was ranked third in Ph.D. graduates behind the University of California at Berkeley and M.I.T. Purdue[16] was ranked 22nd in the number of M.S. graduates, a strong indication of the earlier faculty decision to de-emphasize the M.S. program and further strengthen the Ph.D. program. In the ratio of Ph.D./M.S. graduates the School was ranked 6th with a ratio of 1.00; Carnegie Mellon University was first with a ratio of 2.25. In 1986 Purdue ChE was fifth in the country after M.I.T., the University of Michigan, the University of Wisconsin and the University of Minnesota in total number of Ph.D. in chemical engineering awarded. From 1987-92 Purdue graduated 85 PhD (6th in U.S.)[17]. The top five schools were MIT (165), Cornell (153), University California-Berkeley (108), University Minnesota (98), University Texas-Austin (96). Below Purdue in top 10 were Delaware (75), Wisconsin (72), University of Illinois (67), and Princeton (65). In 1990-91 Purdue was 4th in number of Ph.D. graduates, and in 1991-92 the 22 PhD awarded placed the School 3rd nationally. The 20 PhD in 92-93 placed Purdue 5th nationally while the 21

Ph.D.s in 1994-95 was 3rd in the US. In 1995-96 we awarded 20 Ph.D. degrees (4th in US), and in 1996-97 we awarded 22 Ph.D. degrees (4th in US). During the five year period from 1992 to 1997 the School was fourth in number of Ph.D. degrees awarded. From 1990-98 the School was 4th in number of PhD graduates, and in 2002-03 the School was 2nd.

The School has increased the diversity of the graduate students.
Above: Rasika Prabhu, Ogebule Oluwaseyi , Coco Abbou Oucherif, and Heather Emady.
Below: Astronaut Mary Ellen Weber (center, BS '84) with Vincent Kispersky (grad student), David Taylor (Instrumentation Director), Andrew Smeltz (PhD '09), and Julie Renner (GSO president, 2009-10).

Unfortunately, more recently other programs have increased the size of their graduate programs and Purdue is no longer consistently in the top five. For example, in 2005-06 the 14 Ph.D. graduates tied ChE for 17th in US. The 17 graduates in 2006-07 tied Purdue for 11th, the 22 in 2007-08 placed Purdue 5th, and the 24 in 2008-09 placed Purdue as tied for 4th. The top three producers of Ph.D. degrees in chemical engineering in 2008-09 were MIT (43), Georgia Tech (37) and University of Texas-Austin (29). In 2009-2010 Purdue graduated 18 Ph.D.s and 12 MS, all of whom are continuing for their Ph.D. degrees.

Nationally, approximately 50% of ChE Ph.D. graduates from US schools are not US citizens. Purdue runs a bit higher than this and the international students are consistently from the top universities of the world, particularly India and China. Many of the best US graduates matriculate at schools that are ranked in the top 10. (Rankings of graduate programs are discussed at the end of this chapter.) In addition, because it is difficult for international students to obtain an industrial position in the US unless they have a Ph.D., international students are much more likely to earn a Ph.D. than an MS. The US percentages of international Ph.D. graduates reported by

C&EN (Oct. 31, 2005 and Oct. 4, 2010) and the percentages for the School are reported in Table 8-6. It should be noted that PhD degrees awarded are a lagging indicator of recruiting patterns. The School has made efforts to increase recruiting of US citizen graduate students in recent years. During the last two academic years, 64% of the incoming graduate students (37 out of total 58) were US citizens. The goal is to have about 2/3 graduate students in the School who are US citizens, with the remaining being top students from top international programs.

Table 8-6. Percentage of Ph.D. Degrees to International Students

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
US%	44	47	51	50.3	50.3	49.6	48.8	49.2	50.6	51.6	---	---
Purdue%	54	50	58	72	87	67	63	77	68	68	47	71

In 1985 with 77 (23%) of Ph.D. students having become professors, Purdue was second to the University of Michigan in the percentage of Ph.D. students continuing in academia. This fact was, of course, a surprise for those who believed for years that Purdue was only a good School for industrial preparation. In 1985 with a total number of 170 professors having received at least one degree from the School, Purdue was second only to M.I.T. in this category. Since 1985 many more Purdue graduates have become professors (see Appendix B), but the relative standing of the School in producing professors appears to have slipped.

Many graduates of the School at all levels have become professors.
Left: Professor Pedro Arce (left, PhD '87) now Head at Tennessee Technological University and David DiBiasio (PhD '80) now Head at Worcester Polytechnic Institute at the Chemical Engineering of the Future Symposium in 2009.
Right: Jennifer Sinclair Curtis (BS '83) now a professor and formerly Department Head at the University of Florida, presenting at the Women in ChE Conference in 2009.

Related to research achievements is the scientific output of the faculty and students. From 1923, when the first Purdue ChE publication appeared, through May 2009, Purdue faculty wrote or edited 134 books (listed in text boxes in Chapters 7 and 8), wrote over 140 educational publications (see Chapter 7), and wrote over 3500 refereed technical publications (Appendix T). The 1982 report *An Assessment of Research-Doctorate Programs in the United States: Engineering* published by the National Research Council ranked Purdue ChE first among all Schools in the number of publications and second in the "overall influence of scholarly work in chemical engineering".

Finally, if the number of refereed publications is an indication of faculty and student research productivity, then the School of Chemical Engineering of Purdue University peaked with 308 publications (6.4 publications per faculty per year) in 1995 and 1996 (see Appendix T-1). This high peak can be explained because by coincidence eleven of the 24 professors had the highest publication output in a two year period of their entire careers in 1995 and 1996. It is worrisome that the running average of three two-year periods peaked at 247 publications for the period from 1993-98, dropped steadily to 162 for 2001-06, and then rebounded slightly to 168 for 2003-08. These issues are discussed in more detail in the section on rankings at the end of this chapter.

Table 8-7. National Research Awards

National Medal of Technology and Innovation:
This highest Recognition of inventors given by the United States was conferred on Professor Rakesh Agrawal (2011).

American Institute of Chemical Engineers (AIChE) Awards:
William H. Walker Award for contributions to the literature of ChE was awarded to J. Henry Rushton (1952) and to former faculty members Edward W. Comings (1956), Joe Mauk Smith (1960) and Nicholas A. Peppas (2006).

Warren K. Lewis Award for research and educational contributions was awarded to alumnus Robert C. Reid (BS '50, MS '51) (1983) and to former faculty Carroll O. Bennett (1980), Joe Mauk Smith (1983), and Hank van Ness (1988).

Richard H. Wilhelm Award for chemical reaction engineering contributions was awarded to former professor Joe Mauk Smith (1977), to future professor Arvind Varma (1993), to Prof. Doraiswami Ramkrishna (1998), and to alumni Vern Weekman, Jr. (BS '53, Ph.D. '63) (1982), Martin Feinberg (MS '63)(1996) and Chris Bowman (BS' 88, Ph.D. '91)(2006).

Institute Lecture was presented by alumni Robert C. Reid (BS '50, MS '51) (1967) and Vern Weekman, Jr. (BS '53, Ph.D. '63) (1978), Professors J. Henry Rushton (1970) and Rakesh Agrawal (2005), and former professor Nicholas A. Peppas (2007).

Allan P. Colburn Award for outstanding contributions by a young member of AIChE was awarded to future professor and alumnus Robert D. Vaughn (BS '51) (1958), to future professor Sangtae Kim (1993), and alumnus Chris Bowman (BS'88, PhD '91) (2001) and alumna Kristi Anseth (BS '92) (2003).

Professional Progress Award for outstanding research under 45 years of age was awarded to alumna Kristi Anseth (BS '92) (2009) and alumnus Chris Bowman (BS' 88, Ph.D. '91)(2011).

Alpha Chi Sigma Award for research to Prof. Doraiswami Ramkrishna (1987)and alumni Terry Papoutsakis (PhD'79) (2003) and Tony Mikos (MS '85, PhD '88) (2007).

Founders Award for life contributions to ChE was given to Profs. J. Henry Rushton (1962) and Rakesh Agrawal (2011), and to former professor Nicholas A. Peppas (2008).

Chemical Engineering Practice Award for outstanding contributions to ChE industrial practice was given to Prof. Rakesh Agrawal (2006), to alumnus Jacob M. Giest (BS '40)(1976), to alumna Lisa Brannon-Peppas (PhD '88) (2008), and to future Prof. Jeff Siirola (2009).

F. J. Van Antwerpen Award for exceptional service to AIChE was awarded to Profs. J. Henry Rushton (1979) and Lyle F. Albright (2003).

Industrial Gases Award to future Professor Rakesh Agrawal (1998).

Computing and Systems Technology Award recognizing outstanding research contributions in computer systems technology was given to Prof. Gintaras V. Reklaitis (1984), Prof. Venkat Venkatasubramanian (2009) and future professor Gary Blau (1997).

CMA Stine, Materials Engineering and Science Award for outstanding research contributions to the materials and polymers area to Prof. Nicholas A. Peppas (1984) and to alumni Curry E. Ford (Chem BS '33) (1979) and Chris Bowman (BS '88, PhD '91) (2009) .

Food, Pharmaceutical & Bioengineering Award to Profs. Henry Lim (1987) and Nicholas A. Peppas (1994) and alumni Terry Papoutsakis (MS '76, PhD '79) (1995), Mike Ladisch (MS' 75, PhD '79) (2001) and Tony Mikos (MS '85, PhD '88) (2010).

Thomas Baron Award in fluid particulate systems to Prof. Doraiswami Ramkrishna (2004). Fluidization Lectureship Award to former professor and alumna Jennifer Sinclair Curtis (BS '83) (2007)

Nanoscale Science & Engineering Forum Award was awarded to Prof. Ronald Andres (2006).

Fuels & Petrochemicals Division Award awarded to Prof. Rakesh Agrawal (2008)

Clarence (Larry) G. Gerhold Award of the Separations Division was awarded to future professor Rakesh Agrawal (2001).

Michael Grimes Award for excellence in chemical engineering to Prof. Michael Harris (2005).

The following professors were named **AIChE Fellows:** Agrawal (2009), Greenkorn (1981), Peppas (1997), Ramkrishna (2008), Reklaitis (1994), Varma (2008), Venkatasubramanian (2011), and Wankat (1997).

American Chemical Society (ACS) Awards:

David Perlman Lectureship was presented by Prof. George Tsao (1986).

Marvin Johnson Research Award of the Microbial and Biochemical Technology Division given to Prof. George Tsao (1987) and alumni Terry Papoutsakis (MS '76, PhD '79) (1996) and Mike Ladisch (MS' 75, PhD '79) (2000).

The Heroes of Chemistry Award that recognized chemists and chemical engineers whose work led to successful innovation and development of commercial products based on chemistry was awarded to alumnus Donald R. Miller (PhD '83) of Wyeth for development of Mylotarg® (2004).

ACS Fellows: former professor Nicholas A. Peppas (2011) and alumni Mike Ladisch (2010) and Terry Papoutsakis (2011)

Separation Science & Technology Award presented to Prof. Phillip C. Wankat (1994).

James M. Van Lanen Distinguished Service Award to alumni Michael Ladisch (1990), Arindam Bose (1992), and Terry Papoutsakis (2007).

Victor K. LaMer Award in Colloids and Surface Chemistry for best doctoral thesis to alumnus Tony Mikos (MS '85, PhD '88) (1991)

Unilever Award for the most outstanding doctoral thesis in polymer chemistry to alumnus Chris Bowman (BS '88, PhD '91) and alumna Kristi Anseth (BS '91) (1996).

ASEE Research Awards:

ChED Lectureship Award was given to Professors Lowell B. Koppel (1982), Gintaras V. Reklaitis (1994) and Phillip C. Wankat (1997); to future professor Arvind Varma (2000); to alumna and former professor Jennifer S. Curtis (BS '83) (2008), and to alumni Robert Reid (1977) and Tony Mikos (2009).

Curtis McGraw Research Award for outstanding research in engineering under the age of 40 was awarded to Professors Nicholas A. Peppas (1988) and James M. Caruthers (1990), and to alumnus Chris Bowman (BS '88, PhD '91) (2000) and alumna Kristi Anseth (BS '91) (2003).

General Electric Senior Research Award was given to Prof. Nicholas A. Peppas (2000).

American Association for the Advancement of Science:

Arvind Varma elected as **Fellow** (2011).

American Institute of Medical and Biological Engineering (AIMBE) Awards:

Pierre Galletti Award for life contributions: to former professor Nicholas A. Peppas (2009)

AIMBE Fellows: elected are the following Professors Doraiswami Ramkrishna, George Tsao and Nien-Hwa Linda Wang, former professors Frank Doyle, Nicholas Peppas and Eva Sevick-Muraca, Alumni Chris Bowman, Mark Byrne, Prasad Dhurjati, Richard Korsmeyer, Mike Ladisch, Anthony Lowman, David Meadows, Tony Mikos, Balaji Narshimhan, Terry Papoutsakis and alumnae Kristi Anseth, Lisa Brannon-Peppas, Surya Mallapragada, and Julie Ross.

Society for Biomaterials Awards:

Founders Award for life contributions to the field to former professor Nicholas A. Peppas (2005) and alumnus Tony Mikos (2011).

Clemson Award for research in biomaterials to former professor Nicholas Peppas (1992), alumna Kristi Anseth (2008) and alumni Chris Bowman (2005) and Tony Mikos (2001).

Materials Research Society (MRS) Awards:

MRS Fellow: former professor Nicholas Peppas (2005)

MRS Outstanding Young Investigator Award: to alumni Tony Mikos (1996), Chris Bowman (1997) and Kristi Anseth (2001).

Chemical Engineering (CE) Magazine: **CE Personal Achievement Award** was awarded to former professor Lowell Koppel (1994).

American Physical Society (APS) Awards: The following professors were named **APS Fellows**: Osman Basaran (2008) and Nicholas Peppas (1998).

Gas Processors Association**: Donald L. Katz Award** for outstanding accomplishments in gas processing research to Prof. Emeritus K. C. Chao (1994).

Industrial Research Institute (IRI): **IRI Achievement Award** in 2007 to Prof. Rakesh Agrawal.

North American Catalysis Society: **Distinguished Service Award (Inaugural)** to Prof. W. Nicholas Delgass (2010).

9th International Symposium on Agglomeration: **Achievement Award for Excellence in Granulation Research** awarded to Prof. James D. Litster (2009).

U. S. Department of Energy: **John Ericsson Award in Renewable Energy** awarded to Prof. George Tsao (1988).

Table 8-8.

Members of National Academy of Engineering

Name	**Title**	**NAE Election Year**	**Purdue Connection**
Rakesh Agrawal	Winthrop E. Stone Distinguished Professor of Chemical Engineering, Purdue University	2002	Purdue faculty member 2004 to present
Kristi S. Anseth	Distinguished Professor and HHMI Investigator, University of Colorado	2009	BS '92
S. George Bankoff *	Walter P. Murphy Professor of Chemical and Mechanical Engineering, Emeritus, Northwestern University	1996	PhD '52
Robert C. Forney	Retired Executive Vice President, E. I. du Pont de Nemours & Company	1989	BS '47, PhD '50
Clifford C. Furnas *	President, State University of New York at Buffalo	1967	BS '22
Jacob M. Geist *	President Geist Tec.	1980	BS '40
William J. Harris, Jr.	Commissioner, Independent Consultant	1977	BS '40
Sangtae Kim	Donald W. Feddersen Distinguished Professor of Mechanical Engineering and Chemical Engineering,Purdue University	2001	Purdue faculty member 2003 to present
Michael R. Ladisch	Distinguished Professor & Director, LORRE, Purdue University	1999	MS '74, PhD '77

John C. Martin	Chairman and CEO Gilead Sciences	2008	BS '73
Nicholas A. Peppas	Fletcher Stuckey Pratt Chair in Engineering, University of Texas at Austin	2006	Purdue faculty member from 1976 to 2002
R. Byron Pipes	John Leighton Bray Distinguished Professor of Engineering, Purdue University	1987	Purdue faculty member 2004 to present
Michael P. Ramage	Executive Vice President ExxonMobil Research & Engineering Company	1996	BS '66, MS '69, PhD '71
Henry J. Ramey *	Keleen and Carlton Beal Professor, Stanford University	1981	BS '49, PhD '52
Doraiswami Ramkrishna	Harry Creighton Peffer Distinguished Professor of Chemical Engineering, Purdue University	2009	Purdue faculty member 1976 to present
Robert C. Reid *	Professor Emeritus of Chemical Engineering, Purdue University	1980	BS '49, MS '50
Gintaras V. Reklaitis	Burton and Kathryn Gedge Distinguished Professor of Chemical Engineering, Purdue University	2007	Purdue faculty member 1970 to present
Lloyd M. Robeson	Principal Research Associate Air Products& Chemicals, Inc.	2001	BS '64
Jeffrey J. Siirola	Professor of Engineering Practice	1994	Purdue Faculty member 2011 to present
Theofanis G. Theophanous	Director, Center for Risk Studies and Safety; Professor, Chemical Engineering & Professor, Mechanical Engineering, University of California, Santa Barbara	1998	Purdue faculty member 1969-75
Vern W. Weekman	Faculty Industrial Lecturer, Princeton University	1985	BS '53, PhD '63
William D. Young	Chairman and CEO Monogram Bioscience	1993	BS '66,
* Deceased			

Graduate Students: Organization, Research and Awards

An important part of research is communicating the results to a wide audience. In addition to writing papers, graduate students present both posters and papers. Many students have their first opportunity to present a poster and later a paper at the School's Graduate Student Organization Research Symposium. After a presentation in this relatively safe and friendly venue, students present posters and/or papers at various national meetings.

Graduate Student Organization

The Chemical Engineering Graduate Students' Organization GSO was founded in 1978 to promote interaction between the graduate students and the faculty. It operates partially as a social club, partially as a forum to present the difficulties of graduate students, and partially as a sponsor of a symposium to showcase graduate student research. In 1979 after considerable discussion the faculty agreed that GSO would have one voting and one non-voting representative to the Graduate Curriculum Committee. Every year these representatives are elected by the GSO. Professor Osman Basaran was the GSO advisor from 2004 to 2009 and Prof. Jim Litster from 2009 to present. The recent presidents are Dina Colucci (1991-1992), Matt Perkins (1994-95), Chris Williams (1995-97), Aaron Cote (1998-99), E. Nicholas Jones (1999-2000), Kevin Stavens (2000-01), Paul T. Fanson (2001-02), Jeffrey W. Kloostermann (2002-03), Jamey D. Young (2003-04), Charles L. Schaffer (2004-06), Nanette Boyle (2006-07), Bri-Mathias Hodge (2007-08), Hari Nair (2008-09), Julie Renner (2009-10), Sara Yohe (2010-11), and Laura Hirshfield (2011-12). On August 20, 1992, GSO conducted the first annual Chemical Engineering Graduate Research Symposium. Presentation of research at the Colloquium replaced the previous requirement (started in 1980) that graduate students present a 20 minute seminar during the normal seminar period on Tuesdays. Every year since the GSO has planned and run this major symposium of graduate student research with a number of industrial representatives present. Nanette Boyle, a former president of the GSO, believes the symposium is an important resource for students because "It gives our graduate students an opportunity to network with professionals in the field. Senior doctoral students are able to formally present their research to industry representatives, while the full breadth of research activities at Purdue is highlighted in a poster showcase." The symposium presentation and poster awards that we have information for are listed in Tables 8-8 and 8-9, respectively.

Sara Yohe (GSO president) explaining her research to President Cordova during President Cordova's visit to the School in April 2011.

Table 8-9. GSO Research Symposium Presentation Awards			
Year	**1st place**	**2nd Place**	**3rd Place**
2011	Dave Balachandran	Anirudh Shenvi	Julie Renner
2010	Meenesh Singh	Pei-Fang Sung	Anirudh Shenvi W. Damion Williams
2009	Intan Hamdan	Mahapradad Kar	Rugved Pathare
2008	Dana J. Gary		
2006	Vikrant Urade Qi Xu	Hariprasad Subramani	
2004	Scott McCllelan	Nicole M. Dingle	Jamey Young
2002	Jeff Kloosterman	Mark Byrne	Santhoji Katare
2001	Abhijit Namjoshi	Alvin Chen	Paul Fanson
1999	Eric Stangland	Aaron Cote	Jennifer Ward
1998	Sabrina Myrick Steve Richter	Christie Hassan Aaron Cote	
1997	Steve Honkomp Ted Pirog	Nancy Irwin Michael Ernest	
1996	Tamara Troy Philip Wisnewski	Chris Brazel Lalitha Balasubramanhya	
1995	Matthew H. Basset Bryon Maner Christine Hutchinson	Jeffrey D. Bielefeld Ramprasad Ramkrishnan Christopher Panczyk Christopher Brazel	
1994	Dina Colucci Scott Beck	Doug McWilliams William Mahoney	Adam Starry Stacey Fu
1993	Dan Stark Mike Masterov		
1992	Dina Colucci Kathy Jurman		

The GSO poster session in 2007 in Henson Atrium.

Table 8-10. GSO Symposium Poster Awards			
Year	**1st place**	**2nd Place**	**Honorable Mentions**
2011	Gautam Yadav & Haoran Yang	Shane Bates Rengy Sheng-Chuan Su	
2010	Julie Renner	John O'Grady Ahmad Al-Kukhum & Hyun-Tae Hwang	
2009	Wenbin Hu	Julie Renner Robert McCarty	
2007			Dana J. Gary
2006	Hari Nair, Joseph Gatt & Michael Liszka	Tom Manz, Krista Novstrup & Grisha Medvedev	J-S Lim, E. Royston, E. Widjaja, H. Yi, S-Y Lee, J. N. Culver Gowri Krishnamurthy Kevin Witte & Jae-Sung Lee Avantika Shastri & Sean Werner
2004	ChimY. Chin, Chi-Ming Yu, & Yi Xie	Ying-Chih Liao	Eric Sherer Charles Schaffer Kyung Jae Jeong
2001	J. Zach Hilt	Erika Hernandez	
1999	Paul Fanson Alan Thompson		

In addition to the awards from the GSO symposium, in 2010 the faculty started awarding a Faculty Lecture Award to a graduate student who has done outstanding research and Research Publication Awards to current graduate students and to very recent graduates whose research papers were extensively cited. In 2010 Nanette R. Boyle received the faculty lecture award and Robert Collins, Moiz Diwan, Qijie Guo, and Andrew Smeltz received research publications awards. In 2011 Vishesh Shah won the faculty lecture award and Nanette R. Boyle and Qijie Guo received research publications awards. Also, S. Mun in 2003, Rahul Kasat in 2008, and Vishesh Shah in 2010 won AIChE Separations Division Graduate Student Research Awards, Nyah Zarate won the AIChE Particle Technology Forum Outstanding Poster Award in 2010, and Grayson Ford won the very competitive best poster award at the IEEE Photovoltaic Specialists Conference (PVSC) in 2010.

Research Collaborations and Centers

Modern research is collaborative. Not only do professors advise graduate and undergraduate students in research, they also work with post-doctoral researchers and with other professors. Based on joint publication of papers (see Appendix U) the number of collaborations of Purdue professors with other Purdue professors in the time period from 1971 to present ranged from zero to 14 with an average of 4.4. Assistant professors who have less than four years at Purdue are not included since they did not have enough time to develop collaborations, do the research and publish the results. These numbers undercount the number of collaborations for professors who were at Purdue for a number of years before 1971 because most had collaborations with professors who were not at Purdue in 1971. For example, Albright collaborated with L. C. Case, Doody, Golding, Morgen, Sesonske, Shannon, Shreve, and Tucker in addition to the four collaborations shown in Appendix U. Thus, over his career Albright collaborated on papers with a total of twelve Purdue professors.

Modern research is also collaborative in that professors commonly work with faculty in other departments at Purdue and at other institutions. Faculty collaborate with faculty in every School of Engineering, and with faculty in many other departments including Agronomy, Biochemistry, Chemistry, Child Psychology, Consumer Sciences and Retailing, Earth and Atmospheric Science, Education, Horticulture, Pharmacy, and Veterinary Medicine among others. In addition to the research laboratories of individual faculty members, several research centers have been established in the School of Chemical Engineering, in collaboration with other schools, and in Discovery Park. In these research centers (see box) graduate students and faculty members cultivate strong collaborative research activities of an interdisciplinary nature.

The Pharmaceutical Engineering team won the College of Engineering Team Award in 2010. Osman A. Basaran, Michael T. Harris, Carl Wassgren, Rodolfo Pinal, Martin Okos, Venkat Venkatasubramanian, James D. Litster, Lynn Taylor, Stephen P. Beaudoin, Teresa Cadwallader, Teresa Carvajal, and Rex Reklaitis (Doraiswami Ramkrishna not shown).

RESEARCH CENTERS

Laboratory of Renewable Resources Engineering (LORRE)

Established in 1978 within the School of Chemical Engineering and under the directorship of Prof. George T. Tsao, this research center has since become independent. After George retired, Prof. Michael Ladisch became the director. Although the original mission of LORRE was to do research on converting renewable resources to liquid fuels, the mission has broadened so that LORRE now is an integrative biotechnology and engineering center that conducts research related to bioprocessing, bionanotechnology, bioenergy, enzyme engineering, applied microbiology, molecular biology, and biorecovery. Engineers and scientists from many Purdue Colleges and from other university do collaborative research under the LORRE umbrella. LORRE has extensive laboratories in the Potter building and employs approximately fifty professionals and students. The two directors, George Tsao and Michael Ladisch, are to be congratulated for keeping an externally funded research center viable for 33 years—a very difficult task. In addition to Tsao and Ladisch, ChE faculty members who have collaborated with LORRE at some period since 1978 include Nancy Ho, Ramki Ramkrishna, Roger Eckert, Jim Caruthers, Martin Okos, Linda Wang and Phil Wankat.

Pharmaceutical technology & Education Center

This Center was formed on July 1, 2006, and is jointly operated by Chemical Engineering and the Department of Industrial and Physical Pharmacy. "The mission of this center is to advance pharmaceutical technology and pharmaceutical manufacturing throughout the world." Rex Reklaitis is the co-director from the School. Other engineering faculty involved in the center are Pekny, Venkatasubramanian, and Kim from ChE and Wassgren from ME. Industrial partners are Eli Lilly and IBM. One of the activities of the Center is teaching 597D and 597E (see Chapter 7).

Engineering Research Center for Structured Organic Particulate Systems

This NSF-sponsored Center is a collaborative effort of Rutgers University, Purdue University, NJIT, and the University of Puerto Rico-Mayaguez that was funded in 2006. Structured organic particulate systems are multicomponent organic systems where the microstructure determines the performance as a drug delivery system. At Purdue faculty from Chemical Engineering, Industrial and Physical Pharmacy, and Mechanical Engineering are involved. The Chemical Engineering professors are Basaran, Beaudoin, Harris, Litster, Okos, Pekny, Reklaitis (Deputy Director) and Venkatasubramanian. The School is taking a lead in thrust areas on design, scale-up and optimization of manufacturing processes (Litster-thrust leader) and on integrated systems science (Venkatasubramanian-thrust leader). Purdue has research project leadership on drop formation and layering (Basaran), surface interactions and surface modification (Beaudoin), optimization and design modeling for continuous roll compaction granulation (Litster), ontological informatics (Venkatasubramanian), and real-time process management (Reklaitis).

George Tsao developed impressive research laboratories for biochemical engineering in the Laboratory for Renewable Resource Engineering (LORRE) housed in the A.A. Potter building. LORRE is now under the direction of Michael Ladisch (Ph.D. '77). Shown, among others, are former graduate students Norman B. Jansen (Ph.D.'81) and John J. Cannon (M.S. '77, Ph.D. '80).

RESEARCH CENTERS IN DISCOVERY PARK

"Discovery Park is the heart of large-scale interdisciplinary research and innovation at Purdue, building on the university's strengths in science, technology, engineering, and mathematics." Started in 2001, Discovery Park has grown into a $500M enterprise with a number of new buildings on what used to be called the Ag Campus in the area where Terry Courts used to be. All projects done through Discovery Park are interdisciplinary and are done through a number of centers. Professor Joe Pekny was instrumental in the planning and development of Discovery Park as the Mann Director and Founder of the e-Enterprise Center. In this role Pekny founded projects which ultimately led to the Center for Advanced Manufacturing in Discovery Park, Purdue Homeland Security Institute, and the Regenstrief Center for Healthcare Engineering. Many professors from the School are involved in the Discovery Park research centers listed below.

Bindley Bioscience Research Center in Discovery Park

The Bindley Bioscience Research Center focuses on interdisciplinary life science research with emphasis on diet & disease prevention, drug discovery/delivery, health & disease biomarkers, nanomedicine, instrument development, and infectious disease & interventions. The Center has extensive laboratory facilities with specialized equipment such as flow cytometry and cell separation, protemics, and an imaging facility. Professors Morgan, Pekny, and Ramkrishna are participating faculty. Hannemann served on the Executive Committee in 2002-03.

Birck Nanotechnology Center in Discovery Park

The Birck Nanotechnology Center opened in July 2005 in a state-of-the-art 187,000 square foot facility connected by an enclosed walkway to Bindley. Birck cost $58M and provides office and research space for 45 faculty and up to 180 graduate students. The Center focuses on interdisciplinary nano-engineering and nano-science research. The Center contains a 25,000 sq. ft. cleanroom with research spaces rated at 1, 10 and 100 microparticles per cubic foot. Specialized equipment includes an electron beam lithography system capable of patterning lines as narrow as 6 nanometers and an electron microscope capable of imaging the atomic structure of nanocrystals in a high-temperature reactive atmosphere. Chemical engineering faculty who are or have been affiliates of Birck include Andres, Baertsch, Basaran, Beaudoin, Caruthers, Corti, Delgass, Franses, Harris, Hillhouse, Gil Lee, Pipes, Ribeiro, Thomson, Varma, Won and Wu.

Discovery Learning Research Center in Discovery Park

The Discovery Learning Reseach Center (DLRC) has a 22,000 square foot facility housed in a new, state-of-art building in Discovery Park. The mission of the DLRC is to advance research that revolutionizes learning in the STEM disciplines. The DLRC works to achieve its mission by catalyzing large-scale, interdisciplinary research programs in teaching and learning, by promoting use of teaching and learning research in actual classroom practice, and by providing leadership in influencing Science, Technology, Engineering and Mathematics (STEM) public literacy and educational policy. Programs for students include a DLRC internship program, Interns for Indiana, Cancer Prevention Internships, Midwest Crossroads Alliance for Graduate Education & Professoriate (AGEP) that focuses on students from groups that are underrepresented in STEM disciplines, and the Louis Stokes Alliance for Minority Participation. School faculty who are affiliates of the DLRC are Basaran, Houze, Pekny, Venkatasubramanian, and Wankat.

Oncological Sciences Center in Discovery Park

The mission of the Oncological Sciences Center is to forge interdisciplinary partnerships and research to advance cancer research beyond the laboratory. The Center is located in the Burton D. Morgan Center for Entrepreneurship in Discovery Park. The Center currently focuses on cancer prevention, cancer diagnosis, and cancer care engineering. School faculty who are or have been members include Beaudoin, Hannemann, Gil Lee, Morgan, Ramkrishna, and Won.

Regenstrief Center for Healthcare Engineering in Discovery Park

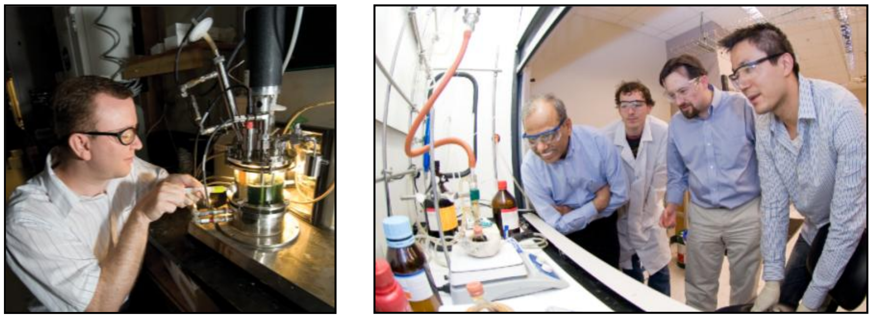
The mission of this Center is to "catalyze the transformation of healthcare-delivery systems by applying the principles of engineering, management and science." The Regenstrief Center uses a systems analysis approach to develop an engineering solution for better healthcare delivery. Joe Pekny was the Founding Director during start-up and while the Center was searching for a permanent director, and Robert Hannemann served on the Launch Committee and currently serves on the Center's Executive Committee. School faculty who are part of the Regenstrief Center include Hannemann, Pekny and Ramkrishna.

The Energy Center at Discovery Park

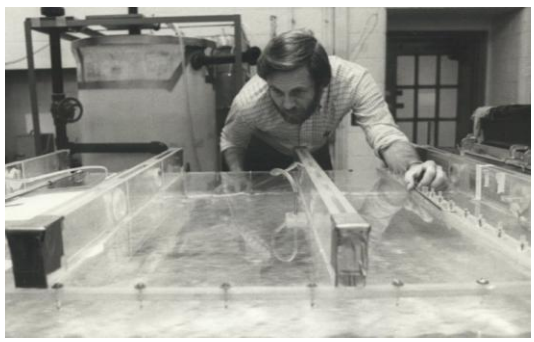
The mission of the Energy Center is to strengthen interactions among the energy engineering and sciences research community on campus and to increase the collaboration between academia, government laboratories and industry. The Center started in 2005 with start-up funds from the Lily Endowment. The Center facilitates faculty energy proposals including the $6.1M government grant made in 2009 for the Indiana Advanced Electric Vehicle Training and Education Consortium directed by Jim Caruthers to develop electrical vehicles and advanced batteries for these vehicles. School faculty involved in the Energy Center include Agrawal, Caruthers, Delgass, Pekny and Varma. In addition, Mike Ramage (BS '66, Ph.D. '71) is a member of the external advisory council.

Center for the Direct Catalytic Conversion of Biomass to Biofuels (C^3Bio) in Discovery Park

C^3Bio is an Energy Frontier Research Center funded by the US Department of Energy at an expected level of approximately $20M. Dr. Maureen McCann of Biology is the Director. The mission of this highly focused center is to conduct high-risk, but potentially very high reward research on direct conversion of lignocellulosic biomass to biofuels and other bioproducts. Successful completion of the Center's mission would decrease the US dependence on foreign energy sources. C^3Bio is located in the Bindley Bioscience Center. Professors Agrawal, Delgass, Ribeiro, and Thomson from the School are involved in C^3Bio research.



A number of professors are conducting energy research.
Left: John Morgan studying the growth of algae.
Right: Solar cell research in the School being conducted by (left to right) Rakesh Agrawal, Grayson Ford (PhD '11), Hugh Hillhouse, and Qijie Guo (PhD '09)



From 1970 to 1978 R. Neal House performed important research on the flow characteristics of two-phase systems using a specially constructed channel; the research was supported by NSF (1978 picture).

Historical Research Centers

Research Centers, particularly those that are externally funded, usually have a finite life—often around ten years. LORRE has proven to be an exception to this rule. Some of the Centers that were at one time quite important locations of interdisciplinary research including chemical engineering faculty are listed here.

Materials Research Laboratory (MRL) and Materials Research Science and Engineering Center (MRSEC)

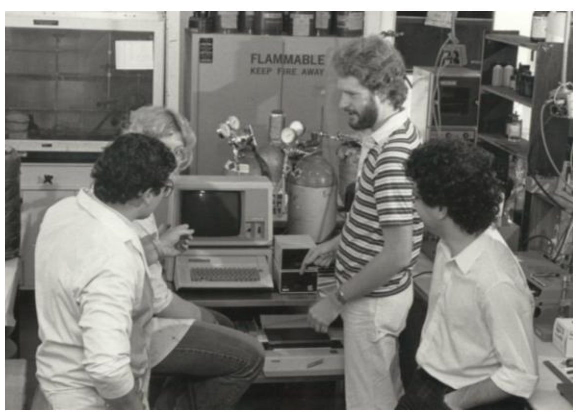
The MRL was one of fourteen NSF-funded centers for interdisciplinary research on materials. It supported a wide range of experimental facilities and brought together faculty and students from chemistry, physics, chemical engineering, electrical engineering, and materials engineering. Professors R.P. Andres, W.N. Delgass and C.G. Takoudis were active research participants in the MRL. The MRSEC program replaced the MRL program. The current MRSEC for Technology-Enabling Hetero-structure Materials is housed in the School of Electrical and Computer Engineering and does not have any involvement from ChE faculty. However, many ChE professors are involved in materials research including polymers and nanomaterials.

Coal Research Center (CRC) and Center for Coal Technology Research (CCTR)

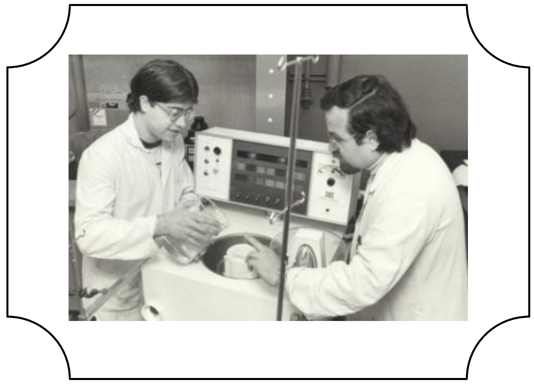
This center was established in 1980 to consolidate University efforts in coal research and to assist participants in exchanging information in this vital research area. Approximately sixty professors and graduate students were associated with CRC including ChE participants Professors K.C. Chao, W.N. Delgass, R.A. Greenkorn, N.A. Peppas, G.V. Reklaitis, R.G. Squires, and C.G. Takoudis. The Center closed in the 1990's when it appeared that natural gas was the solution to the US energy problems. In 2004 the State of Indiana formed the CCTR as a state agency which was placed at Purdue. Currently, only A. Varma from ChE is involved in the CCTR.

Computer Integrated Process Operations Consortium (CIPAC)

The Computer Integrated Process Operations Consortium (CIPAC) was a collaborative research effort between a number of major corporations and the process systems engineering faculty of the School. The goal of CIPAC was "to investigate integrated approaches to process operations management in order to improve safety, efficiency, quality, flexibility, responsiveness, and the overall competitive posture of batch and continuous process industries." Professor Reklaitis was the founding director in May 1992 with six industrial partners who each paid a membership fee of $25,000/year. The founding faculty members were Doyle (until September 1997), Pekny, Reklaitis and Venkatasubramanian. Gary Blau of Dow Elanco, who had been an active participant in CIPAC, joined the faculty in January 1998 and immediately became a faculty member of CIPAC. In August 1998 Jay H. Lee joined the School and was a faculty member of CIPAC until he left in 2000. In 1999 Reklaitis became too busy raising funds for the new ChE building to continue as director of CIPAC, and in May 1999 Gavin Sinclair became the director. In 2000 the 12 member companies were: Air Products, Dow Chemical, DowElanco, DuPont, Eli Lilly and Co., Gensym, ICI, International Business Machines, Mitsubishi Corporation, Searle Corp., Westvaco and Weyerhaeuser. Unfortunately, by 2002 two of the key faculty members Pekny and Reklaitis, were too busy to continue with CIPAC and CIPAC was closed in May 2002.



The polymer laboratories also had up-to-date equipment. The differential scanning calorimeter, thermomechanical and thermogravimetric analyzers are shown with students (from left to right) Phillip L. Ritger (M.S. '85), Barbara D. Barr-Howell (M.S. '85), John Howell (B.S.Chem. '84), and Antonios G. Mikos (M.S. '85, Ph.D. '88).



Left: Linda N.H. Wang, shown here in 1980, has made significant contributions in ion-exchange resins, simulated moving beds, separation science, and biomedical engineering.
Right: Biomedical engineering has been an active research area of several faculty members since 1969. Here G.W. Raymond Davidson, III (M.S. '82, Ph.D. '85) and Nicholas Peppas operate an artificial kidney in the facilities of the School of Veterinary Medicine (1979 picture).

Above: Robert F. Kamrath (M.S. '81, Ph.D. '84) and Elias I. Franses (right) in the Colloid Science laboratory.
Below: Faculty members working on polymer science and engineering in 1980. From left to right: J.M. Caruthers, N. A. Peppas, and M.F. Malone

Textbooks by Purdue faculty were discussed in Chapter 7. The text box below lists monographs, professional books and edited collections done by Purdue professors during the period they were on the Purdue faculty. Books done while professors were in emeritus status are also included.

Table 8-11. Monographs, Professional Books, Handbooks, and Edited Collections by Purdue Faculty

1968

L.F. Albright, *Modern Chemical Engineering*, special publication – collection of articles from *Chemical Engineering*, McGraw Hill, N.Y., 1968.

K.C. Chao, (Ed.), *Applied Thermodynamics*, ACS, Washington, D.C., 1968.

1971

T.J. Williams, *Interfaces with the Process Control Computer*, IF, AC, 1971.

1972

G.V. Reklaitis and J.E. Goldberg (Eds.), International *Symposium on Systems Engineering, Vol II: Contributed Papers*, Purdue University, 1972.

1974

L.F. Albright, *Processes for Major Addition-Type Plastics and their Monomers*, McGraw-Hill Co., N.Y.,1974; (2nd ed., Krieger Pub. Co., Melbourne, FL 1985).

1976

L.F. Albright and C. Hanson, (Eds.), *Industrial and Laboratory Nitrations*, ACS Symposium Series, Vol. 32, ACS, Washington, D.C., 1976.

L.F. Albright and B.L. Crynes, (Eds.), *Industrial and Laboratory Pyrolyses*, ACS Symposium Series, Vol. 36, ACS, Washington, D.C., 1976.

1977

L.F. Albright and A.R. Goldsby, (Eds.), *Industrial and Laboratory Alkylations*, ACS Symposium Series, Vol. 55, ACS, Washington, D.C., 1977.

G.T. Tsao and M. Ladisch, (Eds.), *Advances in Enzyme Engineering*, Vol. I, 1, ASM, Washington, D.C., 1977.

G.T. Tsao, (Ed.), *Advances in Enzyme Engineering*, Volume II, ASM, Washington, D.C., 1977.

1979

W.N. Delgass, G.L. Haller, R. Kellerman and L.H. Lunsford, *Spectroscopy in Heterogeneous Catalysis Research*, Academic Press, N.Y., 1979.

K .C. Chao and R.L. Robinson, Jr., (Eds.), *Equations of State in Engineering and Research*, ACS Symposium Series, ACS, Washington, D.C., 1979.

1981

R.G. Squires and G.V. Reklaitis, (Eds.), *Computer Applications in Chemical Engineering*, ACS Symposium Series, Vol. 124, ACS, Washington, D.C., 1981.

1982

R.S.H. Mah and G.V. Reklaitis (Eds.), *Selected Topics in Computer Aided Process Design and Analysis*, AIChE Symp. Ser. 78, No.214, 1982.

S.L. Cooper, N.A. Peppas, AS. Hoffman and B.D. Ratner, (Eds.), *Biomaterials: Interfacial Phenomena and Applications*, ACS Advances in Chemistry Series, Vol. 199, ACS, Washington, D.C., 1982.

L.F. Albright and R.T.K. Baker, (Eds.), *Coke Foundation on Catalysts and in Pyrolysis Units*, ACS Symposium Series, ACS, Washington, D.C., 1982.

1983

L.F. Albright, B.L. Crynes and W.H. Corcoran, (Eds.), *Pyrolysis: Theory and Industrial Practice*, Academic Press, N.Y., 1983.

G.V. Reklaitis and J. Siirola (Eds.), *Data Base Implementation and Applications, AIChE Symp. Ser. 79*, No. 231, 1983.

1985

N.A. Peppas and R.J. Haluska, (Eds.) *Proceedings of the 12th International Symposium on Controlled Release of Bioactive Materials*, CRS, Lincolnshire, IL, 1985

1986

N.A. Peppas, *History of the School of Chemical Engineering*, Purdue University, 1986

N.A. Peppas, *Hydrogels in Medicine and Pharmacy*, (three volumes), CRC Press, Boca Raton, FL, 1986.

P.C. Wankat, *Large Scale Adsorption and Chromatography*, (two volumes), CRC Press, Boca Raton, FL, 1986.

1987

G.V. Reklaitis and H.D. Spriggs (Eds.), *Proceedings of the First International Conference on Foundations of Computer Aided Process Operations*, CACHE and Elsevier, 1987.

Stroeve, P., and Franses, E.I., (Eds.), *Molecular Engineering of Ultrathin Polymeric Films*, Elsevier, 1987.

1988

LeVan, M.D., K. S. Knaebel, S. Sircar and P. C. Wankat (Eds.), *Adsorption and Ion Exchange: Fundamentals and Applications*, AIChE Symp. Ser., 84(264), 1988.

1989

A. Gürsoy, B. Dortunc, E. Piskin and N.A. Peppas, *Controlled Release Technology*, Ciba-Geigy, Istanbul, Turkey, 1989

N.A. Peppas, (Ed.), *One Hundred Years of Chemical Engineering*, Kluwer, Dodrecht, The Netherlands, 1989

1990

Venkatasubramanian, V., and L. Ungar, *Advanced Reasoning Architectures for Expert Systems*, CACHE Corporation, 1990

1993

N.A. Peppas and R.S. Langer, (Eds.), *Biopolymers I & II, Advances in Polymer Science*, 109 (1993)

A.B. Scranton and N.A. Peppas, *Modern Hydrogel Delivery Systems, Advances in Drug Delivery Reviews*, 11 (1993)

R. Gurny, H. Junginger and N.A. Peppas, *Pulsatile Drug Delivery: Current Applications and Future Trends*, Wissenschaftliche, Stuttgart, Germany, 1993

T.J. Roseman, N.A. Peppas and H.L. Gabelnick, (Eds.), *Proceedings of the 20th International Symposium on Controlled Release of Bioactive Materials*, CRS, Deerfield, IL, 1993

1994

A.G. Mikos, R. Murphy, H. Bernstein and N.A. Peppas, (Eds.), *Biomaterials for Drug and Cell Delivery*, Materials Research Society, Pittsburgh, PA, 1994

F. Buchholz and N.A. Peppas, (Eds.), *Superabsorbent Polymers: Science and Technology*, ACS Symposium Series, Volume 573, American Chemical Society, Washington, DC, 1994

1995

L. Drzal, R. Opila, N.A. Peppas and C. Schutte, (Eds.) *Polymer/Inorganic Interfaces*, Materials Research Society, Pittsburgh, PA, 1995

1996

G.V. Reklaitis, A. Sunol, D.W.T. Rippin, and O. Hortacsu, (Eds.), *Batch Processing Systems Engineering*, NATO ASI Series F, Volume 143, Springer Verlag, Berlin 1996

Davis, J.F., Stephanopoulos, G. and Venkatasubramanian, V., (Eds.), *Proceedings of the International Conference on Intelligent Systems in Process Engineering*, AIChE Symposium Ser., Vol. 1992, 1996.

Hightower, J. W., W. N. Delgass, E. Iglesia, and A. T. Bell, (Eds.), *11th International Congress on Catalysis - 40th Anniversary*, Elsevier, Amsterdam, 1996.

1997

J. Mockus, W. Eddy, A. Mockus, L, Mockus, and G.V. Reklaitis, *Bayesian Heuristic Approach to Discrete and Global Optimization*, Kluwer Academic Publisher, the Netherlands, 1997

N.A. Peppas, D.J. Mooney, A.G. Mikos and L. Brannon-Peppas, (Eds.), *Biomaterials, Carriers for Drug Delivery, and Scaffolds for Tissue Engineering*, AIChE, NY, 1997.

1998
Caruthers, J.M., Chao, K.C., Venkatasubramanian, V., Sy-Siong-Kiao, R., Novenario, C.R. and Sundaram, A., *Handbook of Diffusion and Thermal Properties of Polymers and Polymer Solutions*, Design Institute for Physical Property Relations, AIChE, NY, 1998.
J. F. Pekny and G. E. Blau (Eds.), *Proceedings Third International Conference Foundations of Computer-Aided Process Operations*, AIChE Symp. Ser., No. 320, Vol. 94, 1998.
2000
G.V. Reklaitis and J.J. Siirola (Eds.), *Proceedings of the 7th Int'l Symposium on Process Systems Engineering, Computers & Chemical Engineering*, Vol 24, 2000.
Ramkrishna, D., *Population Balances. Theory and Applications to Particulate Systems in Engineering*, Academic Press, San Diego, Cal., 2000.
D.L. Wise, L. Brannon-Peppas, A.M. Klibanov, R.L. Langer, A.G. Mikos, N.A. Peppas, D.J. Trantolo, G.E. Wnek, and M.J. Yaszemski, (Eds.), *Handbook of Pharmaceutical Controlled Release Technology*, Dekker, New York, NY, 2000.
2001
J. Siepmann and N.A. Peppas, (Eds.), *Mathematical Modeling of Controlled Drug Delivery*, published as *Advances in Drug Delivery Reviews*, 48 (2001).
2002
Achenie, L., Gani, R. and Venkatasubramanian, V., (Eds.), C*omputer-aided Molecular Design: Theory and Practice*, Elsevier, November 2002.
Wankat, P. C., *The Effective Efficient Professor: Teaching, Scholarship and Service*, Allyn & Bacon, Boston, 2002.
2009
H. Alfadala, G.V. Reklaitis and M. El-Halwagi (Eds.), *Proceedings of the 1st Annual Gas Processing Symposium*, Advances in Gas Processing Series, Elsevier, the Netherlands, 2009
L. F. Albright (Ed.), *Albright's Chemical Engineering Handbook*, CRC Press and Taylor and Frances Group, Boca Raton, FL, 2009.

The polymer research laboratories including the the rheology laboratory (shown) were located in the A.A. Potter building in the 1980s

Evaluation/Rankings of Graduate Programs

Since about 1965 a wide range of rankings of universities and of the engineering programs of universities has appeared in various educational and other journals. It is not clear whether these rankings are of real significance, and doubtful that they can actually be correlated with outstanding education or research. Often they are lagging indicators. Some of the early rankings were based on a small sample of questionnaires or no survey at all! But it is a fact that they are used by administrators, and quoted by faculty, students and alumni, especially when their favorite School appears in a respectable rank. They are also heavily used by potential graduate students, particularly international students who cannot easily visit schools, to decide which schools to apply to. Rankings of undergraduate programs are discussed at the end of Chapter 7.

In the Roose-Anderson report[6] of 1966, the Purdue School of Chemical Engineering was ranked 17th in quality of graduate faculty and was included last in the category of "distinguished and strong" departments. The University of Wisconsin was first, followed by the University of Minnesota and the University of California at Berkeley.

In the 1974 survey[7] of the journal *Change*, the Schools of Engineering of Purdue were ranked seventh. MIT was first followed by the University of Illinois and Stanford University.

The 1976 report[8] of *New Engineer* was a thorough evaluation of engineering and chemical engineering programs around the country. The survey was conducted among more than 1000 department heads. Purdue Chemical Engineering was ranked second to M.I.T. in positive responses to the question: "In your field, which graduate school's degrees are most valuable in landing good jobs in non-academic positions?"

The 1976 Gill report[9] was widely circulated among departments and created major dissatisfaction throughout the country because of the small number of respondents used to rank the various programs. The School was ranked 19th in quality of graduate faculty; University of Minnesota was first.

The 1978 Griskey report[10], published in Chemical Engineering Education, used a complicated formula that included data on M.S. and Ph.D. degrees awarded, extramural funds obtained, and refereed publications published, to rank ChE departments. Purdue was ranked 15th; Stanford University was first. In 1986 Prof. Peppas discovered that the data used by Griskey for Purdue were incorrect. Had he used the correct data, Purdue would have been ranked 7th.

As noted in Chapter 7, the methods to rank institutions are only limited by one's imagination. Noble[11] used the replies of department heads to rank ChE departments according to "users' preference". According to user's preference, the School's graduate program was ranked sixth and the University of California Berkeley was first.

The 1983 report of the National Research Council[12] was the most thorough analysis of relevant data that had been published up to that time. The School of Chemical Engineering was ranked 12th in "scholarly quality of faculty" - University of Minnesota was first -, Purdue was second in "improvement in program quality in the last five years" behind the University of Houston, and first in the number of publications per faculty member. It was ranked second in the "overall influence of scholarly work on chemical engineering".

Soon thereafter, the Gourman report[13], which is often criticized as a one-man evaluation, ranked Purdue ChE 11th in the country with a "score of 4.86".

Probably the most important ranking of graduate programs in the last 25 years was the 1993 analysis of the National Research Council released in 1995[14]. In this ranking the School was 16th sandwiched between Northwestern University (15th) and Houston. The top five schools were Minnesota, MIT, University California-Berkeley, Wisconsin and Illinois. This report was roundly criticized or cheered depending on where one's program landed in the ratings. One problem with the rankings was that there were separate rankings for program effectiveness and faculty quality, but they were closely correlated ($R^2 = 0.97$)[18] and larger faculties received higher ratings. Based on extensive rankings (total numbers)15 the School was 8th in publications, 9th in citations, 15th in support, and 32nd in honors for a 14th ranking overall. [To the "totally unbiased" eye of the author (PCW) the honors ranking does not appear to be in line with the other rankings.] In a recalculation of the scores based on intensive ratings[15] (per faculty for publications, citations, support and honors) Purdue ranked 36th. The difficulty with intensive rankings is they include professors who are not involved with the graduate program and a program that is too small will be quite narrow. A composite index of both extensive and intensive rankings[15] put the School 25th.

The 2005 *US News and World Report* graduate rankings placed the School tied for 12th with three other schools, in 2006 the School was tied for 16th with Northwestern, in 2007 the School was ranked 14th, and in 2008 the School was tied for 15th, with Cornell and Northwestern. In the 2009 *US News and World Report* graduate rankings the School was tied for 14th and in 2010 the School was ranked 15th. Thus, after years of effort there is essentially no change in the ranking. The College of Engineering as a whole fared better in 2010. In the College ranking the peer assessment stayed level at 4.2, which tied for 10th, in 2009 the College was 11th in this category. The College's recruiter assessment score was 4.1 in 2010, also tied for 10th; in 2009 the College was 8th. College quantitative scores for graduate student selectivity, NAE membership, research expenditures, research expenditures per faculty member, and PhDs granted all improved compared to 2009. Wildavsky[16] discusses the origins of the US News and World Report's ranking system and of other ranking systems that followed. While the College rankings are based on several quantitative criteria along with peer assessment, the disciplinary (e.g. chemical engineering, mechanical engineering, etc) rankings are purely based on peer assessment. This is frequently cited as a drawback of the *US News and World Report rankings*.

It appears that a college or program can be ranked about anywhere one wants by changing the criteria. For example, the 2010 Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU) for engineering[17], Purdue University ranked 13th out of 100 universities. The top 15 universities in this ranking are in the U.S. with MIT as the top school. In the Shanghai Jiao Tong University's overall rankings[18] Purdue University was ranked 69th. In the *Times Higher Education* global ranking of world universities in engineering and technology[19] Purdue University was tied for 34th with the University of Wisconsin. Caltech was top ranked and MIT was second in this ranking. In the *Times Higher Education* global ranking of world universities (all areas)[20] Purdue University ranked #106.

The long-awaited, overdue 2010 NRC rankings[21] essentially capitulated to the reality that programs can be ranked on a variety of criteria. Instead of providing a single number for each program these rankings list a range from the highest to the lowest possible rankings. In addition, the data are provided to allow one to create a ranking based on whatever criteria are most important. Probably the most quoted rankings are the S-score and the R-score. *The S-score is the Survey based quality* which is the score based on a survey of 20 key factors with the weight of each factor adjusted by the weights assigned by experts in the field. The *R-score is the Research*

Productivity which is a composite measure of research productivity, based on publications per faculty member, citations per publication, percent of faculty holding grants, and awards per faculty member. The relative importance of these variables was determined by the direct assessments of some 50 faculty in each field.

The PhDs.org[22] web site uses the NRC data and automates the process of generating scores. For example, if one decides to put 100% of the weight in the survey quality one obtains the S-scores (a range showing the uncertainty in the ranking from the highest ranking (low numbers since top ranking is #1) to the lowest possible ranking). Based on the NRC rankings the School's 12-43 S-score moved the School down to 21st compared to 16th in 1993. Considering the efforts the School has put into research and that from 1999-2003 the School was ranked first in papers in the Thomson Scientific database with 183 [Penn State (2nd) 177, University of Minnesota (3rd) 171, Texas A&M and University of California-Berkeley (tied for 4th) with 155, and Delaware (6th) 142], this result is difficult to fathom.

The PhDs.org[22] web site can also be used to obtain the R-score (set 100% of weight on research productivity). As expected, the School's R-rating is lower since per faculty scores invariably rate large departments with large undergraduate programs lower. The student outcomes measure is[22] "a composite of other measures of student support and outcomes, including 6-year graduation rates, time to degree, job placement within academia, percentage of first-year students with full financial support, and whether a program collects data about the employment outcomes of its graduates." For a large school (supposedly impersonal) the School did very well with a 10th place ranking that was the highest in the Big Ten. In *professional development* Purdue tied 32 other programs for the top score with 18 professional development programs available for students. In *diversity*[22] ("a composite measure of diversity that includes data on percent of faculty and students from underrepresented minorities, percent of female faculty and students, and percent of international faculty and students.") the School's score was 55-86, which implies that we still have work to do on diversity (see box on Underrepresented Groups in Engineering in Chapter 7).

What can the School do to improve its graduate program ranking? Like all difficult questions, there is a simple answer, and it's wrong. First, one needs to decide which rankings are most important. If we pick the NRC or *US News & World Report* rankings, then we need to emulate the top Schools and focus on research, more money, more awards for faculty and so forth. If we choose the 2010 poll of top corporate recruiters by the *Wall Street Journal*[23] that asked the recruiters which schools produced the best graduates overall, Purdue Engineering is ranked second and other schools should emulate us. This poll was focused on undergraduates, but there is no reason to believe it does not also apply to graduate students.

Unfortunately, the generally accepted pecking order of graduate programs focuses much more on the NRC and *US News & World Report* type rankings than on recruiters. These rankings are pushed hard by the organizations that produce them (particularly *US News & World Report* because the rankings are big money makers) and thus are better known throughout the world. Potential graduate students, particularly international students who cannot visit graduate schools, tend to rely heavily on these rankings in deciding where to apply. Also, because the schools that are currently highly ranked benefit from their rankings, they also push (sometimes quietly and sometimes brashly) the validity of the rankings. Assuming that Purdue ChE decides to follow the pack, what needs to be done to increase the School's ranking?

Surprisingly, facilities improvement (Purdue ChE now has world-class facilities) had no discernable effect on the rankings. We can continue to invite opinion shapers to the School because the US News disciplinary rankings are entirely based on opinion. The advice24 developed based on regression analysis of the NRC and US News & World Report ranking procedures is given in Table 8-12. Some of this advice is obvious (items 1, 5, 8 and 9) and some is counter-intuitive (items 2 and 3) because of the methods used to collect the data used in the rankings.

The current School facilities are world class.
Above: Industrial Advisory Council (on left ChE alums Jim Marek (PhD '84) and Michael Ott (BS '74) visiting the solar energy lab in 2009.
Below: Even the older part of Forney Hall has first class laboratories. Dr. Varma (right) with Wenbin Hu (PhD '11) (center) and graduate student Gregory Honda

Table 8-12. Advice for Improving Rankings[24]

1. Make sure correct data is given to the ranking agency.
2. Publish papers in journals included in the Science Citation Index (SCI) data base. [Ranking agencies often use the SCI data base and do not cast a wider net.]
3. Encourage co-authorship of research papers with other Purdue ChE professors. [One paper by two authors at the same school will usually be double counted because it appears under both names in the SCI data base. In addition any citations of this paper will also be double counted.]
4. Cite papers by Purdue ChE faculty.
5. Encourage faculty to publish all research. [Communication is part of the research process. Clifton Lovell would have been nationally famous if he had published everything.]
6. Enforce publications by graduate students before they leave. [Research that is not published does not help rankings. Fortunately, this step is also good for graduate students as it builds their resumes, and is part of the communication part of research.]
7. Never stop with symposium preprints. [Papers at meetings may affect the opinion portion of the rankings, but rarely count in the hard data used in the rankings. This step is also part of the communication part of research.]
8. Write more proposals and obtain more grants. [Some rankings include research expenditures in the ranking formula. In addition, money is needed to get more graduate students (item #9).]
9. Recruit more talented graduated students.
10. Do pioneering work in new technologies.

Unfortunately, Steps 1 to 4 do not increase the actual amount or impact of research even though they massage the rankings. A more positive way to look at affecting the rankings is to consider strategies for prominence presented at the ChE faculty retreat[25].

Table 8-13. Strategies for Prominence[25]

1. Bring Research Expenditures near $500K/FTE faculty/yr. In 2008-09 the number was $389,600. In 2009-10 the number was $518,600 – so we have reached the goal. The challenge now is to stay at this level.
2. Increase number of graduate students (particularly domestic) to 5+ per FTE. for the 2010-11 year, the number is 4.7.
3. Continue to maintain ~1 PhD graduated/FTE faculty/yr. The average for the last 3 years is 0.9.
4. Increase grad students who receive NSF, NDSEG, etc Fellowships.
5. Increase number of PhDs who enter academic positions.
6. Write articles in high-impact journals, with particular focus on authoritative review papers that will continue to be cited long after they are published.
7. Increase nominations of faculty for awards.

Author's Closing Comments on Rankings. I (PCW) am going to exercise the author's prerogative and present my take on rankings. I believe that Purdue's School of Chemical Engineering should focus on continuing Purdue's Land Grant Heritage and prepare both undergraduates and graduate students to lead productive lives. According to the poll of top corporate recruiters by the *Wall Street Journal*,[23] our graduates are well prepared for industrial careers, and according to our history of placing graduates in university faculties they are also well prepared for academic careers. Thus, the School should not spend its energy chasing what other schools do well, but should continue to sell that what it does well is important. As part of our Land Grant Heritage it is important to develop unique programs, in both education and research, that satisfy societal needs and excite the students' imaginations.

References and Bibliography

1. H.C. Peffer, R.L. Harrison and R.N. Shreve, Ind. Eng. Chem., 25, 719 (1933).

2. Letter of R.N. Shreve to V.H. Wallingford, May 29, 1935.

3. Letter of R.N. Shreve to V.H. Wallingford, August 25, 1937.

4. H.B. Knoll, A Record of a University in the War Years: 1941-45, The Archives of Purdue, Vol. 4, 1947.

5. Letter of Dean C.T. Chuang of the Cheng Kung University to R.N. Shreve, July 13, 1960.

6. K.D. Roose and C.J. Andersen, American Council on Education, Washington, D.C., August 1966.

7. Anonymous, *Change*, 45 (Winter 1974).

8. Anonymous, *New Engineer*, 21 (December 1976).

9. W.N. Gill, unpublished report, 1976.

10. R.D. Griskey, *Chem. Eng. Educ.*, 12, 65 (1978).

11. R.D. Noble, paper No. 2208, ASEE Meeting, June 19-22, 1978.

12. An Assessment of Research Doctorate Programs in the United States: Engineering, National Research Council, Washington, D.C., 1983.

13. J. Gourman, A Rating of Graduate and Professional Programs in American and International Universities, National Education Standards, Washington, D.C., 1983-84.

14. Goldberger, M. L., B. A. Maher, and P. E. Flattau (Eds.), *Research-Doctorate Programs in the United States: Continuity and Change*, National Academy Press, Washington, D. C., 1995.

15. Angus, J. C., R. V. Edwards, B. D. Schultz, "Ranking Graduate Programs. Alternative Measures of Quality," *Chem. Eng. Educ*., 33 (1), 72-83 (Winter 1999).

16. Wildavsky, B., *The Great Brain Race: How Global Universities are Reshaping the World*, Princeton University Press, 2010.

17. 2010 Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU) for engineering, http://www.arwu.org/FieldENG2010.jsp Accessed March 30, 2011.

18. 2010 Shanghai Jiao Tong University's Academic Ranking of World Universities (ARWU) http://www.arwu.org/ARWU2010.jsp Accessed March 30, 2011.

19. *Times Higher Education global ranking of world universities in engineering and technology* http://www.timeshighereducation.co.uk/world-university-rankings/2010-2011/engineering-and-it.html Accessed March 30, 2011.

20. *Times Higher Education global ranking of world universities*, http://www.timeshighereducation.co.uk/world-university-rankings/2010-2011/top-200.html Accessed March 30, 2011.

21. National Research Council, http://sites.nationalacademies.org/pga/resdoc/index.htm, Accessed March 1, 2011.

22. http://graduate-school.phds.org/rankings/chemical-engineering Accessed March 1, 2011.

23. T. Evans, "State Schools Lure More Employers," *Wall Street Journal*, p. B1, Monday, September 13, 2010.

24. Blau, G. E., Y. Huang, and P. C. Wankat, "Forecasting the National Ranking of Purdue's Chemical Engineering Graduate Program," presented at New Directions Executive Committee Meeting, May 6-7, 2002.

25 Varma, A., "Strategies for Prominence," presented at Purdue School of Chemical Engineering Faculty Retreat," May 2010.