Chemical Engineering at . . .

Purdue University

Arvind Varma and
Cristina Farmus

Recent Purdue ChE Graduates celebrate at the university's main entrance sign.

Following the same arduous pace and diverse trends as the profession of chemical engineering itself, the School of Chemical Engineering at Purdue University has evolved and matured in the last century since it was established on June 14, 1911. Even though much has changed since 1969 when the last article about our school was published in *CEE* [*Chem. Eng. Ed.*, **3** (1), 32 (1969)], the ChE academic landscape still needs to balance education, research, theoretical training, hands-on applications, interdisciplinary collaborations, and fundamentals. The challenges faced five decades ago are just as pertinent today, but with new considerations such as global impact and other layers of complexity including diminished state funding.

FACULTY AND RESEARCH

One way our school has handled these increasingly varied challenges is by recruiting the best possible faculty in strategic areas of research. Since 2000, our school has grown from 21 to 33 faculty members, attracting world-class talent in established areas such as process systems, transport, and separations, while building a critical mass in new areas such as bio- and nanotechnology. While assembling arguably the best catalysis and reaction engineering group anywhere, we are also pioneering new work in energy, and building a strong materials and polymer team. The table on the facing page lists the current school faculty members.

With six members of the National Academy of Engineering, 13 distinguished and named professors, 151 graduate students, and 591 sophomores-to-seniors, we have successfully balanced the quality versus quantity challenge. In 2014,

Purdue ChE Faculty List			
Name	**Title**	**Education**	**Joined Purdue**
Rakesh Agrawal	Winthrop E. Stone Distinguished Professor	ScD, MIT, 1980	2004
Osman Basaran	Burton and Kathryn Gedge Professor	PhD, Minnesota, 1984	1995
Stephen Beaudoin	Professor	PhD, NC State, 1995	2003
Bryan Boudouris	Associate Professor	PhD, Minnesota, 2009	2011
James Caruthers	Gerald and Sarah Skidmore Professor	ScD, MIT, 1977	1977
David Corti	Professor	PhD, Princeton, 1997	1998
Elias Franses	Professor	PhD, Minnesota, 1979	1979
Rajamani Gounder	Assistant Professor	PhD, UC-Berkeley, 2011	2013
Jeffrey Greeley	Associate Professor	PhD, Wisconsin-Madison, 2004	2013
Robert Hannemann	Professor of BME & ChE	MD, Indiana, 1959	1984
Michael Harris	Robert and Virginia Covalt Professor	PhD, Tennessee-Knoxville, 1992	2001
Neal Houze	Professor	PhD, Houston, 1968	1969
Sangtae Kim	Distinguished Professor & Associate Head	PhD, Princeton, 1983	2003
Carl Laird	Associate Professor	PhD, Carnegie Mellon, 2006	2014
Julie Liu	Associate Professor	PhD, Caltech, 2006	2008
Jan-Anders Manson	Distinguished Professor of MSE & ChE	PhD, Chalmers, 1981	2016
Enrico Martinez	Professor of Engineering Practice	PhD, Notre Dame, 1972	2009
Jeffrey Miller	Professor	PhD, Oregon State, 1980	2015
John Morgan	Professor	PhD, Rice, 1999	2000
Zoltan Nagy	Professor	PhD, Babes-Bolyai, 2001	2012
Joseph Pekny	Professor	PhD, Carnegie Mellon, 1989	1990
R. Byron Pipes	John L. Bray Distinguished Professor of Engineering	PhD, Texas-Arlington, 1972	2004
Vilas Pol	Associate Professor	PhD, Bar-Ilan, 2005	2014
Doraiswami Ramkrishna	Harry Creighton Peffer Distinguished Professor	PhD, Minnesota, 1965	1976
Gintaras Reklaitis	Burton and Kathryn Gedge Distinguished Professor	PhD, Stanford, 1969	1970
Fabio Ribeiro	R. Norris and Eleanor Shreve Professor	PhD, Stanford, 1989	2003
Jeffrey Siirola	Professor of Engineering Practice	PhD, Wisconsin-Madison, 1970	2011
Kendall Thomson	Associate Professor	PhD, Minnesota, 1999	2000
Arvind Varma	R. Games Slayter Distinguished Professor; Jay and Cynthia Ihlenfeld Head	PhD, Minnesota 1972	2004
Linda Nien-Hwa Wang	Maxine Spencer Nichols Professor	PhD, Minnesota, 1978	1980
Phillip Wankat	Clifton L. Lovell Distinguished Professor	PhD, Princeton, 1970	1970
You-Yeon Won	Professor	PhD, Minnesota, 2000	2003
Chongli Yuan	Associate Professor	PhD, Cornell, 2007	2009
Emeritus Professors			
Ronald Andres	Professor Emeritus	PhD, Princeton, 1962	1981
Nicholas Delgass	Maxine Spencer Nichols Professor Emeritus	PhD, Stanford, 1969	1974
Robert Greenkorn	R. Games Slayter Distinguished Professor Emeritus	PhD, Wisconsin, 1957	1965
Nancy Ho	Research Professor Emerita	PhD, Purdue, 1968	1971
George Tsao	Professor Emeritus	PhD, Michigan, 1960	1974

we ranked seventh in Ph.D. and fifth in B.S. degrees awarded in the United States. With Rakesh Agrawal and Nancy Ho receiving the National Medal of Technology and Innovation in 2011 and 2016, respectively, and others with various recognitions, we could not be prouder of the accomplishments of our faculty. Our younger generation is equally promising, with Assistant Professors Bryan Boudouris and Raj Gounder receiving NSF CAREER awards this spring.

These accomplishments are possible only in the context of a highly functioning and collegial atmosphere coupled with sustained, collaborative, well-funded research efforts. Our Pharma group, led by Rex Reklaitis, is central to the Engineering Research Center for Structured Organic Particulate Systems (CSOPS) involving four universities—which has brought more than $10M to Purdue from NSF and industry since 2006. The Purdue Catalysis Center, led by Fabio Ribeiro, is now in the process of preparing an NSF ERC proposal for the Center for Innovative and Strategic Transformation of Alkane Resources (CISTAR). Purdue ChE is the leader among five institutions in this initiative, which has the potential to transform the world's energy and chemicals production outlook for the future.

Research Poster Session in the Henson Atrium.

JOURNEY THROUGH HISTORY

When AIChE celebrated its centennial in 2008, a series of lists were created to recognize several categories of accomplishments. Purdue ChE was one of only two U.S. schools honored to have alumni and current and former faculty included on each one of these lists. Dr. Henry Rushton (Purdue ChE faculty member, 1955-71; AIChE President 1957) was named one of the "50 Eminent Chemical Engineers of the Foundation Age." Paul Oreffice (BSChE '49, former CEO, Dow Chemical Co.) was among the "Top 25 Industrial Executives." Three out of the 30 "Groundbreaking ChE Books" were written by authors while they were on the Purdue ChE faculty: D.R. Coughanowr and L.B. Koppell, "Process Systems Analysis and Control"; J.M. Smith and H.C. van Ness, "Chemical Engineering Thermodynamics"; and R. Norris Shreve, "Chemical Process Industries." As an astronaut, Dr. Mary Ellen Weber (BSChE '84) was listed among the nine "Chemical Engineers in Space." Henry T. Sampson (BSChE '56), co-inventor of gamma-electric cell technology used in cell phones, was listed among the "Twenty Chemical Engineers in Other Pursuits." Professor Sangtae Kim was listed among the "100 Chemical Engineers of the Modern Era," along with school alumni Kristi Anseth (BSChE '92), Mike Ladisch (MSChE '74, PhD '77), and Vern Weekman (BSChE '53, PhD '63.)

In 2011, our school celebrated its centennial. It is noteworthy that throughout our long history, we have always maintained the maximum period of accreditation from ABET, with the most recent review in 2013. Through a series of centennial seminars, lectures, lab visits, and a dinner with more than 300 attendees, we were able to engage many students, alumni, and academic and corporate partners, and give them a glimpse into our outstanding programs and facilities. To commemorate the occasion, two books were published: *100 Years of Chemical Engineering at Purdue University, 1911-2011*, by Phillip Wankat and Nicholas Peppas, and *A Pictorial History of the School of Chemical Engineering at Purdue University*, by Phillip Wankat and Cristina Farmus. The school centennial

Left and above: Students at work in some of the school's research laboratories.

was a great opportunity to showcase our accomplishments and pause to celebrate our school's evolution.

UNDERGRADUATE EDUCATION

The mission of our school is to "Provide students with a rigorous and relevant education, conduct field-defining research, and enhance the school's global impact." In his 1969 *CEE* article, Professor Robert A. Greenkorn wrote that "We believe students must be given an education solidly rooted in the fundamentals of science and engineering [...] they must be taught how to apply fundamentals to new problems." To address this aspect, our school introduced the Fundamentals Laboratory in 2006, designed to provide juniors with opportunities to engage in hands-on learning activities. This is accomplished through a series of experiments that demonstrate fundamental chemical engineering principles associated with three core chemical engineering courses: Chemical Reaction Engineering, Momentum Transfer, and Heat and Mass Transfer. Twelve experiments are currently available, of which several were developed on portable setups that can be moved in and out of the lab and can also be used for classroom demonstrations. This setup provides flexibility for the lab to be reorganized at the end of each week, according to a schedule that follows the principles presented in the course lectures. With eight copies for each experiment, the Fundamentals Lab can accommodate a total of 24 students in one session. Among the experiments we have are viscosity of fluids in laminar flow (Stokes' Law), mass transfer in agitated vessels, heat transfer in shell and tube exchangers, and kinetics of a catalytic reaction. All of the experiments and setups were designed and built and are maintained by our faculty and staff. The Fundamentals Laboratory ensures that we recruit and educate outstanding students, provide them with opportunities early in their chemical engineering career to work in teams, develop their oral and written communication skills, challenge them to think creatively, and develop them into valued employees for their future employers.

ChE undergraduates hold an excellent co-op record, with 26% of our students engaged in three- or five-term co-op assignments—the highest participation percentage in the College of Engineering at Purdue. An impressive 20% of our undergraduates participate in research for credit. Among these young future engineers are some exceptional researchers; two of them, Haefa Mansour (BSChE 2015) and Alisha Tungare (BSChE 2015) presented their work in Washington, DC, as part of the "Posters on the Hill" events in the past two years. In terms of national student leadership, Austin Tackaberry (BSChE 2015) served as the 2014-15 Chair of AIChE's Executive Student Committee. While their activities expand outside of the classroom, our students maintain excellent academic records, with 70% of our undergraduates maintaining a GPA of 3.2 or above as of Fall 2015, in the context of Purdue registering only a modest grade inflation over the past 40 years (<http://www.gradeinflation.com>).

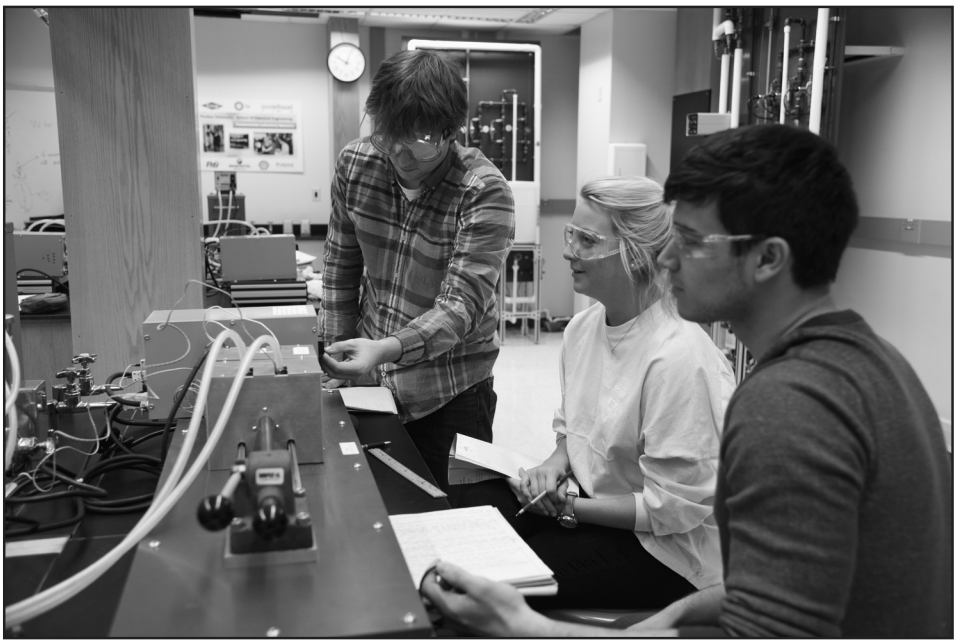
GRADUATE PROGRAM

The graduate program has also seen significant changes in the last decade. A first step was to decrease the number of required courses for the Ph.D. degree from 13 to 10. In conjunction, we reduced the number of core classes from five to four. The second step was to eliminate the written qualifier examination, which was largely redundant with the material in the core courses. In addition, the school moved up the deadline for passing the preliminary examination. As a result, overall Ph.D. graduation times have been shortened by approximately one semester, to about four years and a semester following the B.S. degree.

Significant effort from the faculty and the graduate committee has been invested into increasing the quality of the graduate program. Because of the growth in faculty size and expertise in cutting edge research areas, more graduate elective courses have been introduced and the average size of our incoming classes has increased from around 20 to now 28 students per year. Finally, to increase the impact of our students' research, we have recently added a minimum publication requirement for every graduating Ph.D. student.

PROFESSIONAL MASTER'S PROGRAM

The School of Chemical Engineering launched a new Professional Master's Program in 2015, with five concentrations: Biochemical Engineering; Energy Systems Fundamentals and Processes; Kinetics, Catalysis & Reaction Engineering; Particulate Products and Processes; and Pharmaceutical Engineering. This is a student-paid, full-time, non-thesis, 12-month program on the West Lafayette campus. The concentrations provide advanced technical education combined with development of professional management skills in key areas of chemical engineering related to industry sectors of regional, national, and international importance. Most courses are offered in the School of Chemical Engineering, but there is also a wide variety of electives in related disciplines. During the summer, students will undertake six credits of independent project work in our world-class laboratories. As part of the program, students are required to take nine credits through the Krannert School of Management in finance, marketing, operations, and management—enabling them to be successful in management roles in addition to engineering.



Thermal Conductivity of Solids Experiment in the Fundamentals Laboratory.

NEW INITIATIVES

The last decade has been prolific in terms of creating new programs across the board. In the undergraduate program, we have implemented the ChE Student Ambassadors and the ChE Study Abroad programs. The student ambassadors group is comprised of 10-12 undergraduates who help the school in many ways, from assisting with visits by prospective students and their families, to presenting to first-year engineering students what it means to be a ChE student, to representing the school at dinners and other university events such as Homecoming and Family Day. While the advantages to the school are obvious, the students also benefit from this initiative: They get to practice public speaking in a low-risk environment, meet interesting alumni and corporate executives, and are showcased as part of an elite group of students. Each of these students benefits from a Student Ambassador scholarship, appropriately provided through an endowment created by our alumni Ambassadors.

In the 2015-2019 Strategic Plan, the school established a goal of 20% of our graduates to participate in an international experience. Through course equivalencies at strategic partner institutions, ChE-specific short-term experiences during spring break and Maymester, and sustained financial incentives for those who participate in study abroad, we are well on track to achieve this objective. A short-term study abroad course counts as a technical elective and involves lectures at a partner university and industrial visits. Started in 2015, this program is attractive to many students who can still pursue co-ops or summer internships; for example, 26 students went to Singapore/NUS in May 2015, 13 students to Colombia (EAFIT, Universidad de Cartagena) during spring break 2016, and 26 students to Switzerland (ETH, EPFL) in May 2016. The school organizes these trips and offers incentives of $250 (spring break), $500 (Maymester), and $1,000 (semester) per student, while the university provides a one-time $1,000 per student stipend for any study-abroad experience.

To assist graduate students interested in academic careers, some years ago we created the Future Faculty Program, through which faculty with a talent for mentoring nurture graduate students who aspire to become professors. This program entails regular meetings and discussion and is an effective tool to increase the number of students who pursue academic careers.

Our school has a vision of contributing to an environment where women in chemical engineering are encouraged and supported to reach their full career potential. To achieve this goal, our school has just launched the Women in Chemical Engineering Center with the mission to collaborate with professional, academic, and industrial partners to implement programs that enable women in chemical engineering to be successful in their careers, pursue leadership roles, and make a difference in their profession. While the center is in its incipient stages, we will continue to incorporate our annual

Industrial Advisory Council Members inaugurate the newly renovated Alan H. Fox Unit Operations Laboratory, September 2013.

Women in Chemical Engineering Seminars, which have been taking place for the last eight years. The Women in ChE Center will focus on women in chemical engineering but will include men in all activities as partners in achieving the center's vision. This is a unique initiative in the ChE academic environment that places Purdue Chemical Engineering in a leadership role.

SAFETY

Our safety record has always been strong, but in recent years we have been ahead of the curve, first by implementing a required undergraduate Process Safety Management and Analysis Course at the senior level, and second by starting to teach in-house the graduate safety course. At the request of our graduate students, in 2013 we launched the Chemical Engineering Safety Seminars, which involve a series of talks and webinars on the topic of safety. In 2013, we also launched the Purdue Process Safety and Assurance Center, which aims to carry out research to address and solve problems having applied as well as fundamental importance in the safe and reliable operation of industrial processes in diverse fields. The center's research projects are supported with funds provided by industrial partners. Not surprisingly, our faculty, graduate students, and staff have been recipients of the campus-wide Purdue Presidential Safety award for the past three years since it was first initiated.

FACILITIES

All these activities take place in our world-class facilities in Forney Hall. The Chemical Engineering building, in its current state, was dedicated on Oct. 22, 2004. At that time, the original CMET building (1940) and the newly completed addition were renamed the Forney Hall of Chemical Engineering to honor alumni Robert (BSChE '47, MSChE '48, PhD '50, HDR '81) and Marilyn Forney (BSChE '47), who donated $10M toward the capital campaign. The combined space is comprised of over 177,000 gross sft; at the heart is a central atrium—named after Robert T. Henson (BSChE '36)—which is a three-story multi-purpose space used for studying, receptions, poster sessions, and numerous other events. Shortly after the dedication, a renovation campaign began to bring the original part of the building to modern and efficient standards. The work included everything from new plumbing, air handling, and electrical systems to a new roof, paint, hardware, and furniture. One major upgrade was the renovation of the Unit Operations Laboratory (UOL), completed in summer 2013. Besides the much-needed structural improvements that were implemented, this was a great opportunity to refresh the set of experiments offered by the UOL to align them with current industrial trends. Through the generosity of Alan Fox (BSChE '55), the UOL was endowed with a $1M fund to ensure that all operating expenses and future upgrades can be carried out in perpetuity.

When the East Wing (also known as the stacked labs) renovation is completed this summer, the school will have spent $19.5M for building the addition and $18M on renovating the older space. The outcome is a modern, efficient, and vibrant space worthy of a top chemical engineering program. The results of careful planning, tireless fundraising, and flawless execution can be seen in every corner of Forney Hall.

INDUSTRIAL ADVISORY COUNCIL

Throughout all these improvements, our school has benefitted from the strong support of our Industrial Advisory Council (IAC), initiated in 1988 through the leadership of senior executives from Abbott Laboratories, Air Products and Chemicals, Amoco, Dow Chemical, and Quantum Chemical.

Through semi-annual meetings and interactions with the school administration, faculty, and students, the IAC has provided invaluable advice, such as the idea for the hands-on Fundamentals Laboratory and the need to introduce statistics and safety courses in the undergraduate curriculum. The timely input and relevant feedback from the council members ensures that our school is the premier source of well-educated and well-prepared chemical engineers in the world. In addition, these corporate partners provide financial support for our programs and start-up support for new faculty.

ALUMNI AND FUNDRAISING

Mirroring the successful connections developed with industry, our school has cultivated extraordinary relationships with alumni. The Forney Hall addition was the first academic facility at Purdue to be financed entirely with alumni, corporate, and foundation support, with no contributions from the state or the university. The renovation project was just as resource-intensive and alumni were the major contributors there as well. There are many other examples that demonstrate how generous alumni support puts us in a class of our own. In 2012, the ChE Headship was endowed by Jay (BSChE '74) and Cynthia Ihlenfeld, creating a recurring annual fund to support the school's areas of greatest need. In 2011, Purdue's College of Engineering had a fundraising campaign providing matching funds to establish endowments in areas of strategic importance; our alumni response was overwhelmingly positive and resulted in the creation of 43 new Strategic Initiative Funds supporting critical activities within the school. The income from these endowments will be used in perpetuity to fund scholarships, fellowships, facilities upgrades, seminars, travel grants, study abroad, and other student activities. An important and never-ending task for the school is the recruitment of young faculty; to support this goal, our school has started a new initiative and over the past three years has created nine assistant/associate professor endowments that will be used to attract and retain the most brilliant early- and mid-career faculty members. What more could we offer our students than the best instructors and role models? We are very grateful for the support we receive from our graduates and are pleased that the initiatives we are championing resonate so well with them.

Given the extraordinary fundraising success made possible by our alumni and corporate partners, and also due to strategic vision and a prudent expenditure policy, Purdue Chemical Engineering reached a significant goal this year. Effective with the 2015-16 cohort, our school will support the stipend and tuition for all incoming graduate students for the first full academic year. In 2004, only one month was supported; gradually, over the interim period we were able to add more months and give students additional time to select an advisor. Finally, through endowment income, this year we secured recurring resources to fully cover the first nine months, a practice which brings us in line with a handful elite ChE programs in the United States.

WORK AND STUDY ENVIRONMENT

Another measure of the success of our school is reflected in the results of the annual Work & Study Environment Satisfaction Survey conducted annually since 2009. The satisfaction index continues to improve year after year; most recently, the undergraduate students were invited to take the same survey and their responses matched the high results reported by faculty, staff, and graduate students. The School of Chemical Engineering at Purdue continues to seek ways to improve, implements feedback from all stakeholders, and continually becomes a better place to work, conduct research, and study.

CONCLUDING REMARKS

Through our recent strategic plans, one constant prevails: to continue to be widely recognized among the premier ranks of chemical engineering programs in the world. Our integrity, excellence, leadership, diversity, and sustainability values prevail despite the pressures imposed by trends, polarized interests, incessant demands on time, and limited resources. From all aspects—human capital, programs, facilities, and finances—Purdue Chemical Engineering is in the best possible shape. Arvind Varma has served as the school head since January 2004 and plans to leave the position just as this issue of *CEE* goes to press. Thus in the coming months, our school will undergo a significant transition as we conclude the search for a new head, who will have the most advantageous starting point to lead us into a brighter future. The motto for our school's centennial was "A Century of People and Progress." This has stood the test of time since, through our people—faculty, staff, students, alumni, and corporate partners—we have reached our current privileged position. We are committed more than ever to best educate our students, push the boundaries of knowledge through field-defining research, and be a global leader in academia.

ACKNOWLEDGMENTS

We are grateful for the editorial enhancements and comments by Purdue School of Chemical Engineering's Senior Director of Development David Williams. ❐