ChE at...

The University of Houston

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Chemical engineering at the University of Houston has reflected the growth and diversification of the field: from traditional petrochemicals to advanced materials to energy and sustainability to the use of bioengineering principles for the betterment of human health.

The University of Houston is a young university, founded in 1927 about 3 miles south of downtown Houston. Starting as a junior college, it became a university in 1934, changing hands in 1945 to become a private university and finally becoming a part of the State of Texas system in 1963. In 1953 UH gained national recognition when it established KUHT, the world's first educational television station. Today, the University of Houston is the flagship of the University of Houston System and is considered one of the most ethnically diverse campuses among U.S. universities.

The Department of Chemical & Biomolecular Engineering (ChBE) at the University of Houston started as a program during the late 1940s and by the 1952/'53 academic year, a full-time faculty of chemical engineering was formed. During the next three years, under the leadership of **Joseph Crump**, a vision emerged with three short-term goals: (i) establishment of a graduate program comprising M.S. and Ph.D. degrees supported by an internationally recognized research program, (ii) establishment of an accredited undergraduate program with strong industrial ties, and (iii) growth of a department supported by university administration. During the next 15 years, under the leadership of **Frank Tiller** (Dean of Engineering, 1955 to 1963) and **Abe Dukler** (Chair), UH Chemical Engineering emerged as the young upstart department. Under the leadership of **Dan Luss** from the mid '70s, through the '80s, UH Chemical Engineering became one of the top departments in the United States (ranked 8th by the National Research Council in 1982). The leadership was passed to **Jim Richardson**, who chaired the department from 1996-1998. After a challenging period of budget pressures in the mid 1990s, UH attracted one of its former faculty members, **Ray Flumerfelt**, to serve as dean of the Cullen College of Engineering. One of Flumerfelt's primary goals was to invest in the Chemical Engineering Department to re-establish its prominence. In 2000 Flumerfelt hired one of UH's own, **Mike Harold** (Ph.D., 1985) who chaired the department from 2000 to 2008 when it underwent the name change to include Biomolecular. The injection of resources has led to a new period of growth and resurgence of the department, now under the leadership of **Ramanan Krishnamoorti**—transforming itself from its unit operations and transport focus to sustained excellence in reaction engineering, and new strengths in materials and biomolecular engineering. The full-time faculty is now approaching 20 in number while enhancing its reputation and impact. The most recent 2010 NRC review has the department ranked 18th (based on the more objective "S" ranking).

Joseph Crump

MISSION AND DEGREE PROGRAMS

It is this strong foundation and standard that the UH Chemical & Biomolecular Engineering Department strives to sustain and build upon. The mission of the department is to produce graduates of the highest scholarship and with skills that will enable them to prosper in their careers and to adapt to a field that continually evolves and transforms. The department has three specific aims:

1. *To provide a high-quality education for undergraduate and graduate students in chemical engineering through a comprehensive curriculum that emphasizes basic science, mathematics, engineering science, and engineering design. UH ChBE faculty members are expected to maintain their reputation as superior teachers and to provide a stimulating educational environment.*
2. *To engage in research programs that train graduate students, procure support for this research on a continuous basis, and contribute to the development of fundamental knowledge in the field of chemical engineering. The department's varied and aggressively pursued research ensures that our faculty members remain at the technological forefront of their respective areas of specialization.*
3. *To be of service to the community at large and, in particular, to the City of Houston and the State of Texas, and to provide the local engineering community opportunities for advanced and continuing education.*

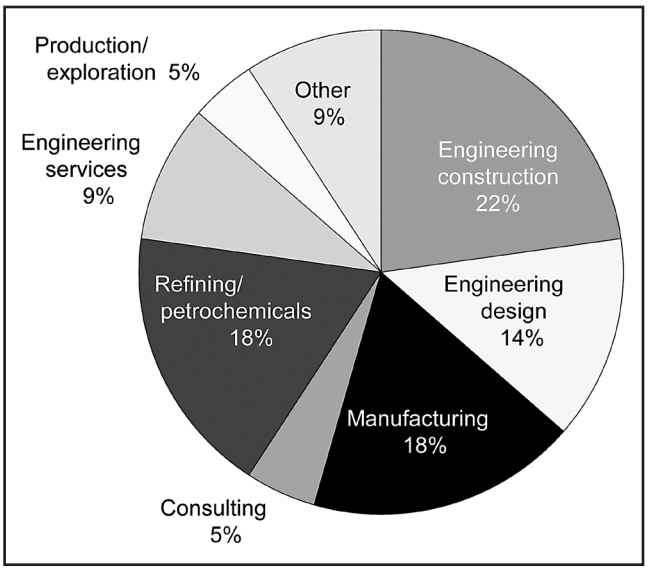
The department currently confers the following degrees:

- *Bachelor of Science in Chemical Engineering (B.S. ChE)*
- *Master of Chemical Engineering (non-thesis; MChE)*
- *Master of Science in Chemical Engineering (thesis and non-thesis M.S. ChE)*
- *Doctorate in Chemical Engineering (Ph.D. ChE).*

In addition, the department has administrative responsibility for a Petroleum Engineering program that confers the following degrees:

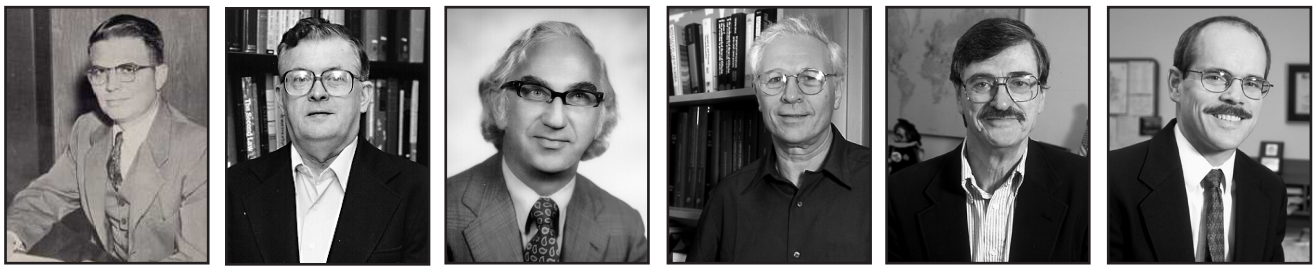
- *Bachelor of Science in Petroleum Engineering (B.S. PE)*
- *Master of Science in Petroleum Engineering (M.S. PE)*
- *Master of Petroleum Engineering (non-thesis, MPE).*

The department has traditionally attracted excellent undergraduate students who are among the best at UH. Reflecting the diversity of the UH student body as a whole, our undergrads are a very diverse group, with under-represented students (African-American, Hispanic, Asian) making up about 60% of the total. Moreover, the department does very well in attracting female students and provides a flexible program for working part-time students. Currently there are about 400 students in the program with recent graduation rates of about 35-45 per calendar year. The graduate program numbers approximately 100 students, about 25 of whom are part-time students (most have full-time employment and are MChE students). Current enrollment in the Petroleum Engineering program numbers about 130 students, equally divided among undergraduate and Master's students, the majority of whom are part-time working professionals.



Areas of graduate employment.

At the undergraduate level, the department has been effective in educating students for productive careers in the chemical process industry, process design firms, and the energy industry, particularly the upstream sector in recent years. Feedback obtained from local employers reveals that the UH ChBE students are top-performing, typically more mature students from the start. This is testimony to the fundamental focus of the curriculum, the standards of the instructors, and the diversity—including age—of the student population. Undergraduate enrollments in the program generally follow national trends influenced by the hiring dynamics in the chemical and petrochemical industries. The strong reputation



Left to right: Frank Tiller, William Prengle, Abe Dukler, Dan Luss, Jim Richardson, and Mike Harold.

of the department, however, has provided a steady stream of high-quality undergraduate students. Recent changes to include biomolecular engineering principles and materials science and engineering in the core undergraduate training along with development of minor options in petroleum engineering and nanomaterials engineering have diversified the education and training of the students.

THE EARLY YEARS

The department was founded in the late 1940s when the University of Houston was at that time a small, private undergraduate university principally attended by white students from more affluent families of the greater Houston area. Crump, the first department chair, recruited several key faculty members who were, as Jim Richardson refers to them, "the instigators." These were **William Prengle**, Dukler, and **Frank Worley**. Prengle and Dukler were hired from Shell Oil Company and at first were part-time lecturers and became full time faculty in 1952.

Dr. **Larry Witte**, Professor of Mechanical Engineering at UH, recalls the important impact that Crump, Dukler, and Prengle had on the department. "These three scholars were role models for the rest of the college," says Witte. "They showed us how to transform an undergraduate program into a successful graduate research program. In the 1960s they won a National Science Foundation (NSF) matching excellence grant that enabled them to expand and bring in more research. Other departments wanted to emulate their success."

An important step for the department and college occurred in 1955 when Frank Tiller was hired from Lamar University as the first dean of the College of Engineering. Dean Tiller set out to expand the college, enhance the quality of the faculty, and gain accreditation for the college programs. On arrival only 14% of the engineering faculty had doctoral degrees. Tiller actually sent some of them back to school to earn their Ph.D.'s. By 1963, 40% of the college faculty had doctorates.

As critical of a leadership role as Dean Tiller provided to the young college, he also became one of the stalwart researchers in the university. Tiller established himself as one of the leading academicians who used mathematical methods to solve chemical engineering problems.[1] His primary interest was in advancing the understanding of solid-liquid systems with application to separations, notably filtration. A long string of doctoral students would study with Tiller and were coveted by industry to improve the many processes involving solids and their purification. Tiller helped to establish and grow the American Filtration and Separations Society (AFS) as evidenced by the AFS Tiller Award which annually honors a top engineer in the field.

Complementing Tiller was Dukler, who established himself as the leading expert in multiphase flow. Dukler advanced the high-speed laser Doppler velocimetry method for flow of gas and liquid in vertical pipes. Dukler was elected to the National Academy of Engineering in 1977 for his pioneering advances in high Reynolds number multiphase flow.

The department hired **Ernest Henley** from Columbia University in 1961. Henley has distinguished himself for decades as being an innovator in his research, teaching, and extramural business pursuits. For a period of over two decades and ending a few years ago upon his retirement, Henley taught the two-course capstone design course to UH senior undergraduates. This was one of the main reasons why UH graduates were coveted by industry: UH graduates knew chemical engineering design and process economics. Henley's book with J.D. Seader and D. Keith Roper, *Separations Process Principles*, is in its third edition and has established itself as the text of choice for unit operations and separations at chemical engineering departments in the United States and internationally.[2]

During this period, the strong industrial ties to the department's research and educational activities were established. As department chair from 1966-1974 and dean of the college from 1976 to 1982, Dukler accelerated the department towards becoming an upstart among chemical engineering departments in the United States. In 1968 Dukler landed a $600,000 "Center of Excellence Departmental Development Grant" from the National Science Foundation, a highly competitive program. These monies were used to hire faculty members and build world-class research laboratories. Prof. **Osman I. Ghazzaly**, a faculty member in the Department of Civil and Environmental Engineering since 1966, points out that: "The real quantum jump in the direction of research came when Dukler took over. He wanted us to really show a change in direction, and he emphasized that research was the number one pursuit."

Says **Stuart Long**, Professor of Electrical and Computer Engineering and currently Interim Vice President for Research at UH, "Dukler was willing to take the heat for making this transition. He was willing to sacrifice his popularity to do the right thing." Around 1975 the department recruited **Alkis Payatakes**, an expert in transport phenomena, from Syracuse. Payatakes would join forces with Flumerfelt to start a center in enhanced oil recovery, which used theory of low Reynolds fluid dynamics to understand the movement and recovery of oil ganglia in porous media. Their approach changed the way the oil industry looked at petroleum recovery and helped to forge closer ties between the upstream energy industry and the department. The department's tradition in multiphase transport would receive a boost with the hiring of two junior faculty in the early 1980s, **Vemuri Balakotaiah** in 1983 and **Hsieh Chia Chang** in 1984. Balakotaiah was one of UH's own, a student of Dan Luss, while Chia was recruited away from UC Santa Barbara. While Bala and Chia had roots in chemical reaction engineering and nonlinear analysis, both applied their skills to the inherent nonlinearities of wavy flows

and flows in porous media, among other systems. During the 1990s the department recruited **Kishore Mohanty** away from the oil industry. Mohanty would further solidify the ties with the upstream energy industry with his fundamental focus on transport in porous media applied to oil and gas recovery. Complementing Mohanty's efforts was **Michael Economides**, hired from Texas A&M in 1998, who brought more practical aspects of petroleum engineering to the program.

THE REACTION ENGINEERING COMPETENCY

The hiring of Luss in 1967 was arguably the most important hire in the department's 60+ years. Luss, a highly accomplished student of Neal Amundson at Minnesota, was an expert in chemical reaction engineering. In the same period the department attracted Richardson, an accomplished expert in heterogeneous catalysis, from Exxon. Together their hiring ushered the emergence of chemical reaction engineering as the area in which UH chemical engineering would become the recognized national leader. In 1971, UH attracted **Jay Bailey** as an assistant professor with primary research interest in reaction engineering, and broadened the impact of the pioneering research. Bailey applied the principles of chemical reaction engineering and mathematical methods developed in chemical engineering first to enzyme catalyzed reactions and later to biochemical engineering, becoming one of the pre-eminent biochemical engineers.[3,4]

Luss became chair of the department in 1975, a position that he held until 1996. It was during Luss' tenure as chair that the department would ascend dramatically, thanks to the seeds planted by Dukler, strategic hires by Luss, and a sustained focus on research excellence in chemical engineering science. Indeed, it was Luss who stunned chemical engineering academe in 1976 when he attracted his former Ph.D. advisor, **Neal Amundson**, "The Chief," to Houston. Amundson brought his expertise in applied mathematics and reaction engineering to the department, and proceeded to graduate about 10 more doctoral students during his second career at UH.

Collectively, the department trained a new generation of students who would primarily join industrial research organizations and help to change the way that chemical reactors in particular would be analyzed, modeled, and designed. In the late '80s the department hired **Demetre Economou**, an expert in electronic materials processing. Economou helped to bridge the gap between reaction engineering and materials, and has become one of the leading researchers in gas-solid reactions in plasma processes. In 2000 another of Luss' students, Mike Harold, was recruited to become the sixth department chair. Harold had established a strong reputation first as an academic at the University of Massachusetts at Amherst, then as a researcher, then a manager at the DuPont Company's Engineering Research labs at the Experimental Station. Additional hires included **Roy Jackson** from Rice in 1977.

In recent years the department has emerged as a leading center for environmental reaction engineering and catalysis. Balakotaiah focused on transport and reaction in catalytic monoliths used in emission aftertreatment systems such as three-way catalytic converters. Harold founded a clean diesel testing and research facility in the early 2000s, now called the Texas Diesel Testing and Research Center and managed by Dr. **Charles Rooks** who was recruited from industry by Harold. The creation of the diesel center was in response to the regional need to reduce emissions of NOx ($NO + NO_2$) from the exhaust of diesel vehicles and equipment. The Houston area had the dubious distinction of being one of the worst offenders of the Clean Air Act's ozone standard. Harold attracted a City of Houston grant of $4 million to create a diesel vehicle testing facility and a few years later a $12 million grant to expand the operation.

Today Harold and Rooks lead a team of 15 engineers and staff and collaborate with other faculty members in the ChBE and Mechanical Engineering on basic research and technology development focused on clean diesel. The center has capabilities spanning bench-scale development of emerging technologies to full-scale testing of diesel vehicles. The main focus of the testing activities is on retrofit technologies to decrease NOx and particulate matter emissions from on-road and off-road vehicles and equipment. More recently the department has attracted **Jeff Rimer** from the University of Delaware, an expert in the synthesis of shape-selective crystalline materials such as zeolites. Rimer and Harold are joining forces to discover new zeolitic materials with enhanced activity and selectivity for the aforementioned lean NOx reduction. Joining the faculty in 2011 will be **Bill Epling** as an associate professor and **Lars Grabow** as an assistant professor. Epling, with earlier industrial experience from Cummins, Inc., and an established academic from the University of Waterloo, will be a perfect fit in the department's efforts in environmental reaction engineering. Grabow brings his expertise in molecular modeling of catalysts to apply to a wide range of problems including environmental reaction engineering, biofuels, electrochemistry and development of a new generation of catalyst materials.

MATERIALS AND BIOTECHNOLOGY

Materials-related research in colloidal, polymeric, and nano materials along with biotechnology and biomolecular engineering have become significant strengths of the department over the last three decades and in part reflect the changing nature of the discipline.

The discovery of high-temperature superconductivity at the University of Houston sparked a materials revolution on campus and the department became a leader in the area of oxide materials. The significant investments in materials characterization, developed in part as a result of the NSF Materials Research Science and Engineering Center, led

to the growth of not only inorganic materials but also to the growth of polymeric and nanoscale materials. In 2002, **Vince Donnelly**, a leading plasma physics expert, joined the department after two decades at AT&T's Bell Labs. Since then Donnelly and Economou have established the pre-eminent plasma physics and processing laboratory, with both of them receiving the highest honors from the American Vacuum Society. **Michael Nikolaou**, an expert in process control, works closely with them to provide robust control for industrial plasma processes.

The proximity of the petrochemical industry and the growth of advanced materials during the last quarter of the 20th century were reflected in the UH Chemical Engineering department's focus. Starting with **Raj Rajagopalan**, an expert in colloids recruited from Syracuse in the mid '80s, and **Jay Scheiber**, a theoretician working on polymer dynamics, the efforts in soft materials were strengthened by the addition of Ramanan Krishnamoorti and most recently of **Manolis Doxastakis**, **Gila Stein**, **Jacinta Conrad**, and **Megan Robertson**. These faculty have also led the advancement of nanotechnology research at UH with Krishnamoorti becoming a pioneer in the area of polymer nanocomposites. Doxastakis has developed expertise in applying molecular and multiscale modeling to understand entangled polymers, nanocomposites, and lipid-protein interactions. Stein is an expert in polymer thin films, working on developing materials for optoelectronics, advanced optical lithography, and organic photovoltaics. Conrad is studying the interaction between complex fluids such as polymers and colloids and the surfaces that confine or support them with potential applications in petroleum engineering, environmental engineering, and materials engineering. Robertson's research combines novel synthetic polymer chemistry and elucidation of polymer physics to design nanostructured materials to develop a new generation of materials based on renewable resources and in some cases with biomedical applications. Additionally, the development of a ~ 4000 ft^2 class 10/100 nanofabrication facility at UH has enabled the rapid growth of nanoscale soft materials research. Ongoing research to develop advanced materials for energy applications including improved hydrocarbon recovery, solar energy capture, and wind energy—along with a focus on sustainability by using natural biodegradable alternatives to petroleum-based materials—is representative of the efforts of the department to address many of the grand challenges facing humanity.

The growth of the Texas Medical Center over the last 30 years, starting from the pioneering efforts to produce the first artificial heart to the latest innovations in treating cancer, has triggered growth of biomolecular and biochemical engineering in the department. Jay Bailey's evolution from chemical reaction engineer to the pre-eminent biochemical engineer by the time he left UH in 1980, was the precursor for the current growth in biomolecular research in the department. **Richard Willson**, an expert in biomolecular recognition and nucleic acid purification, joined the department in the late '80s and is currently the theme leader for the diagnostics thrust of the NIH Western Regional Center of Excellence. Along with Mike Nikolaou (drug delivery), **Peter Vekilov** (an expert in phase transitions that occur in protein solutions with implications for deadly diseases including sickle cell anemia and Alzheimer's and for pharmaceutical drug preparation), and most recently **Navin Varadarajan** (quantifying functional human immune responses by integrated single cell analysis and developing new cancer therapeutics and vaccines) and **Patrick Cirino** (protein and metabolic engineering and biocatalysis toward cost-effective "green" chemistry and renewable fuels, bioremediation, and "next-generation" therapeutics), the department is well-positioned to grow biomolecular research and find solutions to challenging issues involving human health.

FEATURES AND OUTLOOK

The unique location of the University of Houston and the close relationship between the petroleum, petro-chemical, and materials industry along with the relation with NASA and, more recently, advanced materials companies and the Texas Medical Center, have positioned the department to be at the forefront of chemical engineering. The department has a unique relationship with the chemical industry and medical center through the graduate and research programs as well as the industrial advisory board. The continued vitality of the short course on heterogeneous catalysis and the significant interest in the short course on polymers, along with the renewed interest in the MChE program for working professionals and the significant interest in the part-time Ph.D. program (with doctoral candidates working in the numerous research and development centers in the greater Houston area), demonstrate the close relationship.

These strategic partnerships will continue to drive the success of the students and faculty of the Department of Chemical and Biomolecular Engineering at the University of Houston. The analytical, quantitative, and systems-based approach that was pioneered by Tiller, Dukler, Amundson, and Luss will continue to be the hallmark of the research performed at UH and will be integrated into the developments in cutting-edge applications in materials, human health, and energy. These will also help shape our evolving undergraduate and graduate curricula and maintain excellence in our teaching, service, and research missions.

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