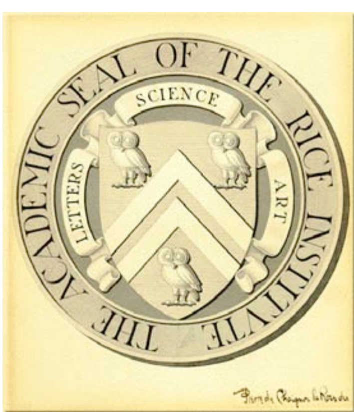
Chemical Engineering @ Rice University

Kyriacos Zygourakis
Rice University
Houston, TX 77251-1892

When Rice Institute opened its doors to the first class of students on September 23, 1912, a bachelor's in chemical engineering was among the degrees offered. Establishing an educational model for engineers that stayed in place for more than fifty years, the first Rice catalog stated: "*...Courses will be offered in chemical, civil, electrical and mechanical engineering. A complete course in any one of these branches will extend over five years. A student who has successfully completed the first four years of a course will be awarded a bachelor's degree, and after successfully completing the remaining year of his course he will be awarded an engineering degree...*"



On June 12, 1916, three chemical engineering graduates (James L. Bramlette, William M. Standish, and Herbert W. Wilber) received their bachelor's diplomas from President Lovett along with the 33 other members of the Rice Class of 1916. They were the first in a long line of Rice chemical engineering graduates who went on to have successful professional careers.

EXPLOITING AN OPPORTUNITY

The arrival on campus of Arthur J. Hartsook in 1921 marked the true beginning of an independent program in Chemical Engineering at Rice. Hartsook was educated at MIT and his choice of Rice and Houston was not an accident. At MIT he had gathered information that convinced him that the city and its vicinity would, in time, grow into one of the foremost chemical engineering centers in the country and the world. "The opportunity was right here, even then, back in 1921," remarked Hartsook in a 1970 interview. "Houston was already showing signs along its ship channel of developing into a major processing center for oil, lumber, cotton and sugar... It did not take much vision to see a splendid future for the entire area."

In 1928, Hartsook officially assumed the leadership of chemical engineering, a post he held until 1956. The department facilities expanded to occupy half of the first floor and the basement of the Chemistry Building (the current Keck Hall). An annex was added for the installation of a very complete Unit Operations Lab. By the late 1930's, chemical engineering had the largest enrollment in engineering, awarding between 15 and 29 B.S.Ch.E. degrees every year. Efforts to get the chemical engineering program accredited by E.C.P.D. (the precursor of A.B.E.T.) were initiated in 1938. Chemical engineering ceased to be a part of the department of chemistry that year and became one of the four branches of the department of engineering. And in 1941, Rice had the first chemical engineering department in the state of Texas accredited by E.C.P.D.

Hartsook's and Rice's investment in chemical engineering paid off handsomely. By the 1940s, Houston had become the petrochemical and energy capital of the world. And Rice graduates began to fill many of the positions created by the growing industrial establishment

Arthur J. Hartsook in a 1970 photograph

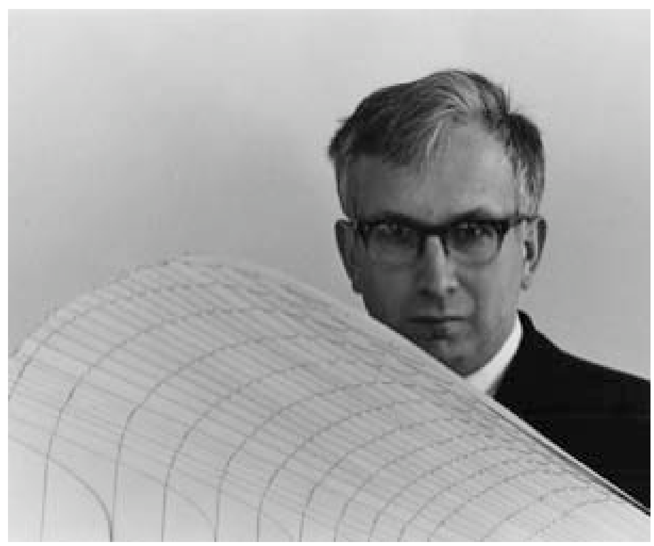
along the Houston ship channel. For many of these graduates, the ship channel became the launching pad for important leadership positions, first in corporate headquarters in New York or other major U.S. industrial centers and, subsequently, to key posts all over the world.

BUILDING A STRONG RESEARCH BASE

In 1947, the chemical engineering department received a mandate from Rice's President Houston to start a full-scale graduate program. The department responded to the challenge by hiring several professors (Bill Akers, Riki Kobayashi, Tom Leland and others who became leaders in their fields) and by expanding its research output. The 1950s and 1960s were years of almost exponential growth. In 1955, the department became a major player in the emerging field of nuclear energy, securing a grant from the Atomic Energy Commission to develop a program in nuclear engineering, supported by a radiation laboratory and a 10-watt operating reactor. Chemical engineering also "annexed" a sanitation laboratory program in Civil Engineering and began to address the broader problems of environmental pollution.

In the 1960s, the department was ranked among the top seven in the country. Capitalizing on Rice' location, a strong thermodynamics group led by Tom Leland and Riki Kobayashi developed new theories and an extensive database of thermophysical properties for the petrochemical industry. The appointments of Fritz Horn, Roy Jackson and several other young faculty members helped the department build strong programs in reaction engineering, catalysis and applied mathematics. Chemical engineering purchased the first digital computer ever installed at Rice (an LGP-30) and later acquired Rice's first solid-state programmable computer (an IBM 1620) that could be programmed with a (then) new language called FORTRAN. Also, Fritz Horn was one of the founding fathers of Rice's applied mathematics department (originally named Department of Mathematical Sciences) and served as the first chairman of that department from 1967 until 1969.

Perhaps the most significant example of a bold move into new areas, however, is the artificial heart project and the establishment of the Biomedical Engineering Laboratory in the mid '60s. In partnership with Baylor's Department of Surgery, Rice chemical engineers led by Bill Akers were instrumental in developing the first left ventricular heart bypass device and carried out a large number of pioneering studies that solidified Rice's national reputation in the field of biomedical engineering. Among their early successes was the development of an implantable artificial lens for the eye that restored sight to hundreds of patients. During the late 70's and 80's, however, the Biomedical Engineering lab shifted its research efforts away from medical devices to become one of the strongest centers of applied cellular engineering research.



Fritz Horn in an undated photograph

The 80's and early 90's were a period of continuous growth. Many new faculty joined the department to strengthen the areas of thermodynamics (Chapman, Robert), interfacial phenomena and petroleum engineering (Miller, Hirasaki), reaction engineering and applied math (Zygourakis), process control (Badgwell), biochemical engineering (Papoutsakis, San, Shanks) and biomedical engineering (Glacken, Mikos). New laboratories were built in 1982 to house the expanding research programs in bioengineering, catalysis, reaction engineering, and thermodynamics. In 1992, the chemical engineering faculty forming the core of Rice's bioengineering group (Hellums, McIntire, Mikos, San, Shanks, and Zygourakis) moved their offices and laboratories to a new research facility (George

R. Brown Hall), especially built to promote inter-disciplinary research between biologists and engineers.

Like the chemical engineering profession, the department reached a major crossroad as it prepared to enter the 21st century. Faculty retirements and the move in 1997 of four faculty members (McIntire – now at Georgia Tech, Mikos, San, and Shanks – now at Iowa State) to a new Bioengineering department forced the department to redefine its research and educational missions.

CHARTING NEW DIRECTIONS: FROM MOLECULES TO SYSTEMS

The mission of our department is shaped by the same forces that are redefining the chemical engineering profession. On one hand, revolutionary advances in nanoscale science and molecular biology open exciting new avenues for developing new materials, biological products, and medical therapeutics. At the same time, economic and social forces are driving a transition towards more sustainable and environmentally-friendly production methods. Chemical engineers are uniquely qualified to play leading roles in these revolutions. For more than a century, we have been very successful in developing and refining the tools necessary for translating molecular-level discoveries into new and cost-effective products. To meet the challenges of the new century, however, we must integrate molecular biology and nanoscale science into the scientific foundation of our discipline. Such an expanded knowledge base will enable us to engineer new products by scaling up processes from the molecular to the system level.

These challenges and needs form the foundation of the strategic plan formulated in 1998 to guide the future growth of our department. The plan provided a blueprint for research directions, faculty and graduate student recruitment, curriculum development, and facility renovation. At its heart was a dual research and education mission that called for:

- conducting world-class research in the areas of **advanced materials** & **complex fluids**, **biosystems engineering**, and **energy** & **environmental systems**;
- educating outstanding undergraduate and graduate chemical engineers to rise to leadership roles in academia, industry, law, business, medicine and government; and
- promoting interdisciplinary collaborations and forming bridges linking Rice innovations to applications in the chemical, energy, biotechnology and materials industries.

The strategic plan also calls for complementing the department's internal research thrusts with strategic alliances on **pollution control** with faculty from the Civil and Environmental Engineering Department, and on **biomaterials for tissue engineering** with faculty from the Bioengineering Department. Because both these departments grew from programs initiated within Chemical Engineering, our faculty members already have many strong connections through research collaborations, joint participation in university-wide research centers and joint faculty appointments. Our new undergraduate curriculum, a very flexible schema which encourages students to build interdisciplinary skills, also calls on these departments as teaching resources, thus solidifying these alliances.

Chemical Engineering faculty. **Back Row**: Miller, Garrett (visiting faculty), Hightower, Zygourakis, Armeniades, Cox, Hirasaki. **Front row**: Mantzaris, Wong, Pasquali, Chapman

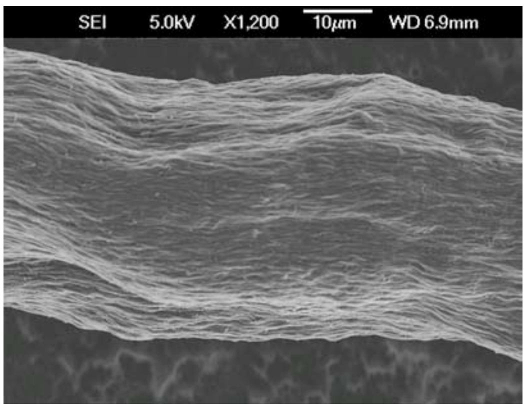
The implementation of the strategic plan began in 1998 with the help of a select Advisory and Development Board whose members include academic, industrial and professional experts. Over the past five years:

- Four new faculty members were hired in the areas of materials and biosystems.
- Over 14,000 sq. ft. of laboratory and office space were renovated. The renovated space houses state-of-the-art facilities for research on complex fluids, catalysis and nanomaterials that were equipped using external and start-up funds.
- A fundraising campaign for endowed graduate student fellowships has raised more than half a million dollars.
- We restructured our undergraduate curriculum by introducing four **focus** or **specialization areas**, by integrating courses or updating their content, and by introducing a biology (or biotechnology) requirement for our B.S. degree. The focus areas in biotechnology, environmental engineering, computational engineering and materials science are very popular among our undergraduates.

FACULTY RESEARCH

Hiring new faculty was a top priority and four new colleagues joined our department after 2000 to strengthen the materials and biosystems areas.

Matteo Pasquali joined the department as an assistant professor in January 2000 after receiving his Ph.D. from the University of Minnesota in 1999 and completing his postdoctoral studies at the same University. His research focuses on processing flows of microstructured liquids that are ubiquitous in the chemical, polymer processing, coating, food, and biomedical industries. Current projects include the computational modeling of process flows with mesoscopic rheological properties, the solution of microscopic transport equations, and the visualization of single DNA molecules in process flows. He recently led a



Aligned fiber extruded under anhydrous conditions from a 10 wt % solution of single-walled carbon nanotubes[1,2,3] (Pasquali lab)

team of researchers who discovered that a sulfuric acid-based superacid makes an excellent medium for dispersing single-walled carbon nanotubes (SWNTs) at concentrations that are useful for industrial processes[1,2,3]. This enabled them to process the dispersion into the first continuous fibers of aligned, pristine SWNTs. Fibers like these might be used to make ultralight, and yet ultrastrong materials with remarkable electronic, thermal, and mechanical properties.

Michael Wong joined our faculty as an assistant professor in July 2001 after receiving his Ph.D. from MIT in 2000 and completing a year of post-doctoral studies at UC Santa Barbara. Mike's research program focuses on designing new and improved materials for catalytic and encapsulation applications. His approach is based on the concept that the macroscopic properties of materials may be manipulated and engineered for target applications if their structural features can be controlled at the nanometer scale. Current efforts focus on the development of: (a) supported nanoparticle-based metal oxide catalysts for solid acid and oxidation reactions; (b) metal-supported nanoparticles for the breakdown of environmentally-unfriendly organic compounds; (c) "quantum dots" for photocatalysis, and (d) nanoparticle-based hollow microspheres and microshells that can be engineered to encapsulate either enzymes to form micro-bioreactors or drug molecules to form drug delivery devices.

Nikos Mantzaris also joined our department as assistant professor in July 2001. He received his Ph.D. from the University of Minnesota in 2000 and completed his two-year post-doctoral studies on mathematical biology at the same university. His research lies in the emerging area of biosystems Engineering and it aims at understanding, optimizing and controlling the behavior of biological systems with the use of mathematical modeling and dynamical studies. Specific systems of interest include recombinant *E.coli* cell populations, tumor-induced migration of endothelial angiogenetic cells and astrocytic signal transduction systems in the mammalian brain. The fundamental question Nikos is trying to answer for each of these systems is how *single cell events lead to the complex behavior and patterns exhibited by cell populations exhibiting heterogeneous phenotypes*. The common thread in these studies is the methodological framework used to accomplish these tasks. This framework includes the development of (a) simplified models that can capture the essential, experimentally observed features of the system under consideration, and (b) sophisticated two- and three-dimensional numerical algorithms that, in combination with the understanding gained from the simplified model results, serve as the basis for studying the asymptotic and transient behavior of the detailed model.

Holy cow! Dedicating a new research lab in the Indian tradition.

Paul Laibinis joined our department as associate professor in January 2003. He received his Ph.D. in organic chemistry from Harvard University in 1991 and was a member of the MIT faculty from 1993 to 2002. His laboratory employs methods of self-assembly and chemical modification for generating interfaces with enhanced properties. These efforts include the generation of molecular and polymeric thin films that are tailored through

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1 "Coming: Superthreads from Nanofibers," *New York Times*, Science Section, December 9, 2003.

2 "Acid Route to Nanotube Fibers," *Chemical & Engineering News*, **81**(50), 9 (December 15, 2003)

3 V.A. Davis et al., "Phase Behavior and Rheology of SWNTs in Superacids," *Macromolecules*, **37**, 154-160 (2004).

chemical synthesis to afford specific molecular architectures on surfaces as needed to alter and control surface events. The approach is general and reveals the ability to manipulate macroscopic interfacial events through nanoscopic changes at surfaces. Current research projects include approaches that control the interactions of biological species with surfaces, both to avoid their adsorption and to direct the adsorption of specific agents from solution. Such properties are important in the area of biodiagnostics, where selective recognition of targets in conjunction with the avoidance of non-specific adsorption events determine the performance of many sensor and microarray technologies.

The research efforts of the new faculty nicely complement the work of the senior faculty in the areas of materials, energy systems and biosystems.

Walter Chapman uses tools such as molecular simulation, computer visualization, statistical mechanics, and NMR to discover how material properties and structure depend on molecular forces. His current research program focuses on polymer solutions and blends, associating fluids, confined fluids, and natural gas hydrates.

George Hirasaki conducts research in fluid transport through porous media ranging from the microscopic scale intermolecular forces governing wettability to the megascopic scale numerical reservoir simulators for field-wide modeling. A reoccurring theme throughout this research is the dominance of interfaces in the determination of fluid transport processes.

Clarence Miller's research focuses on interfacial phenomena, especially those involving surfactants and their applications in detergency, pharmaceutical and food products, petroleum production, ground water cleanup, agricultural chemicals, and personal care products. His current projects include studies on surfactant dissolution rates, foam flow in porous media, and transport in emulsions.

Marc Robert conducts theoretical, experimental and computer simulation studies of the properties of matter. His current efforts focus on magnetic nanoclusters and carbon nanotubes, polymer, colloidal systems, ferroelectrics and disordered systems.

Kyriacos Zygourakis studies the mechanisms through which cell migration and proliferation affect the growth of three-dimensional tissues. Experimental data and large-scale simulations are used to analyze the dynamic behavior of large cell populations proliferating on 3-D scaffolds and find how tissue growth rates are modulated by the culture conditions.

INTERDISCIPLINARY RESEARCH

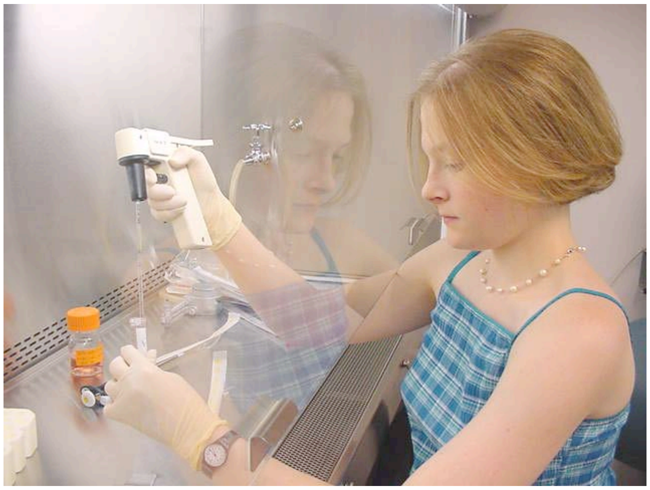
Over the past two decades, Rice has established several institutes and centers to promote interdisciplinary research on nanotechnology, biological sciences and engineering, information technology, and environmental engineering. Almost all our faculty members play key roles in these research efforts because a culture of collaborative research continues to be an integral part of our departmental tradition.

Center for Biological and Environmental Nano-technology (CBEN): Established in 2001 as one of six Nanoscale Science and Engineering Centers funded by the National Science Foundation, CBEN is the first to focus on applications of nanotechnology to human health and the environment. The Center's research activities explore the wet/dry interface between nanomaterials and aqueous systems at multiple length scales, including interactions with solvents, biomolecules, cells, whole-organisms, and the environment. Collaborations with industry, entrepreneurs, and the Jones Graduate School of Management are integral to the Center's mission of creating sustainable nanotechnology.

Many chemical engineering faculty members have formed strong collaborations with other CBEN researchers. In collaboration with Richard Smalley and other chemistry researchers, **Pasquali** is studying the rheological properties of suspensions of single walled carbon nanotubes and is working on the production of fibers from concentrated, strong-acid solutions of nanotubes. **Wong** and his collaborators are developing new and improved materials for catalytic and encapsulation applications. Their approach is based upon the concept that the macroscopic properties of materials may be manipulated and engineered for target applications if their structural features can be controlled at the nanometer scale. **Laibinis** is exploring methods of self-assembly and chemical modification for generating interfaces with enhanced properties. Finally, **Mantzaris**, **Zygourakis**, **Pasquali**, and **Wong** are developing transient population balance models and apply them to design reactors and develop optimal control policies for the large-scale production of high-quality nanoparticles (quantum dots).

Institute of Biosciences and Bioengineering (IBB): This institute was established in 1986 in recognition of the revolutionary advances in biotechnology and molecular biology. Its purpose is to foster interdisciplinary interactions among scientists, engineers, and clinicians from Rice and neighboring institutions.

Mantzaris and **Zygourakis** are collaborating with faculty from Biochemistry and Cell Biology, Bioengineering, and Chemistry, to develop a novel framework that combines experimental, theoretical and computational tools to study heterogeneous cell populations as complex, and highly interconnected *systems* with interacting components. This system-based approach will change the design principles used to develop effective drugs, tissues with desirable structure, materials with novel properties, and other bio-based, environmentally-friendly, and sustainable technologies. **Zygourakis** also collaborates with other IBB members on research focusing on tissue engineering and biomaterials. A Biotechnology Training Grant from NIH and an IGERT grant from NSF provide stipend support for graduate students working in these and related areas.



Jessica Dunn, an undergraduate student, works on her cell migration research project

Shell Center for Sustainability: Chemical Engineering played a key role in the creation of the Shell Center for Sustainability. *This* Center embraces the central theme of Rice's environmental initiative: that implementation of a strategy for sustainable development requires both new tools and a transformation in our understanding of society's needs.

Administered through Rice's Environmental and Energy Systems Institute, the Center has a three-pronged mission of education, research, and community service to:

- create the knowledge required to remove current technological barriers to sustainability and to enable development of novel "sustainable" processes and products,
- promote an interdisciplinary approach to sustainability that integrates research, education & public policy, and
- serve as an independent forum for open discussions on sustainable development issues and policies.

One of the first projects funded by the Center involves research on gas hydrates that offer a vast, untapped energy source and may have played crucial roles in past global warming events. **Chapman** and **Hirasaki** are collaborating with geoscientists to develop mechanistic models describing the accumulation and dissociation of gas hydrates that exist in deep ocean sentiments or in Arctic permafrost. Also, **Hirasaki** and **Miller** are working with faculty members from the Civil and Environmental Engineering department to develop and test new methods for bioremediation of aquifers.

UNDERGRADUATE STUDIES

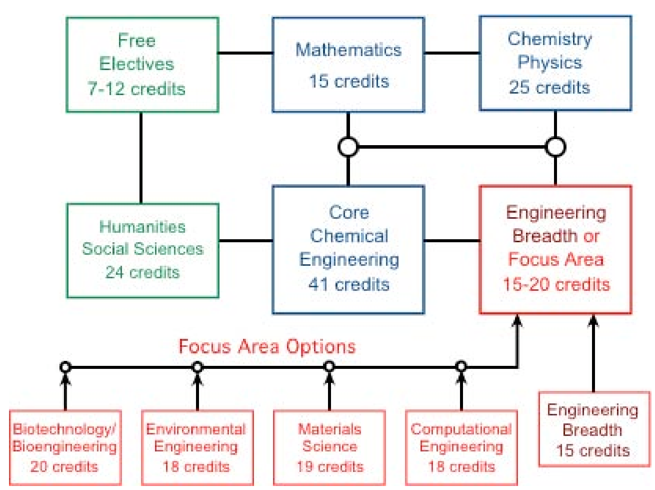
Over the past five years, our department has awarded 146 B.S. (A.B.E.T. accredited) and 18 B.A. degrees, for an average of about 33 graduates per year. After a significant decrease between 2001-03, our enrollments are increasing again and our current sophomore class has about 30 students. The percentage of female students in our classes ranges between 40% and 50%.

Industry employs the majority (about 61%) of our students who graduate with a bachelor's degree. Of the remaining students, about 18% continue their education in graduate schools to prepare for academic careers and industrial research jobs, 12% attend medical or law school, and 9% take government or other jobs.

In today's rapidly changing business climate, industrial sectors from petrochemicals to biotechnology and semiconductor manufacturing offer a multitude of employment opportunities to our graduates. As a result, our graduates get involved with (among others):

- product and process development for the chemical industry;
- exploration, production, and refining of petroleum and natural gas;
- design and optimization of fabrication facilities for semiconductors or magnetic storage devices;
- production of advanced materials (from plastics and fibers to catalysts and biomaterials);
- design of water and air pollution control devices;
- production of pharmaceuticals and biologic devices used for medical applications.

What opens all these career options to our graduates is a broad education that encompasses both fundamentals and technical grounding for further development in a variety of professional environments.



B.S. curriculum in chemical engineering

Courses in mathematics, chemistry, physics and computational engineering provide the foundation for the chemical engineering core, which introduces students to chemical process fundamentals, fluid mechanics, heat and mass transfer, thermodynamics, kinetics, reactor design, process control and process design. Chemical engineering curricula place an emphasis on chemistry not found in other engineering disciplines. This background allows chemical engineers to tackle the wide variety of technical problems arising in the chemical, electronic, pharmaceutical and biotechnology industries.

To complete their technical education, Rice students seeking a B.S. degree in chemical engineering take course electives in at least two other engineering disciplines to satisfy a "breadth" requirement. Or, they can use their electives to create a **focus** or **specialization area** in one of the following four disciplines:

- biotechnology and bioengineering,
- computational engineering,
- environmental science & engineering, and
- materials science and engineering.

The graphic above shows the components of the chemical engineering B.S. degree with their credit requirements. A total of 132 credit hours are required for the B.S. degree. The B.A. program is more flexible, making it even easier for a student to pursue a double major. Chemical Engineering specifies 77 semester hours for the B.A. degree, including prerequisites and laboratory courses. In addition to these requirements, students must also satisfy the University Distribution requirements (24 semester hours) and complete no fewer than 31 semester hours of free electives for a total of at least 132 semester hours.

GRADUATE STUDIES

Our department offers programs of graduate study leading to both the Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees, with the primary emphasis on the latter. A professional master's degree (M.Ch.E.), involving only course work, is also offered.

Currently, the department has about fifty graduate students. All our students are engaged in research activities and receive full financial aid (stipend plus tuition). During the past five years, the department has graduated an average of 7.5 PhDs each year, making it first in per faculty production of PhD graduates among the eight departments of the Rice School of Engineering. In its latest report published in 1995, the National Research Council ranked our department 16th in the United States in educating Chemical Engineering PhD students.

Graduate education is aimed at developing each student's ability to conduct independent creative scientific research. To ensure the versatility of our graduates, our curriculum provides a solid background in chemical engineering fundamentals (Applied Mathematics, Thermodynamics, Transport Phenomena, Kinetics and Reaction Engineering). It also provides a mastery of engineering tools and ability to set clear goals of professional development so that our graduates become productive and successful in their professional careers.

The first year of the Ph.D. program is flexible and allows entering students time to develop a sound basis in advanced areas of chemical engineering and to prepare them for the Ph.D. qualifying examinations. Typically, students take eight of the twelve courses required for the Ph.D. degree during their first two semesters at Rice.

One of the most important criteria in choosing a graduate school is the assurance of finding one or more faculty members within a department who can provide stimulating guidance and help the student develop independent research ability. Entering graduate students attend a seminar series in which members of the faculty discuss their research programs. After attending these seminars the students discuss possible Ph.D. thesis projects with individual faculty members with whom they have an interest in conducting research. Towards the end of their first semester, all entering graduate students submit a list with their three top choices of research projects. The final decision on research topic assignments is made during a departmental faculty meeting. This selection process is coordinated by the Graduate Studies committee in an effort

Time out for some barbecue!

to match the wishes and needs of the students to those of the faculty and to the available research projects. Over the past twenty years, about three quarters of all entering students were assigned to their first choice of research project.

Our graduate program is large enough to offer research topics in several important areas of chemical engineering and related fields, but small enough to retain an atmosphere where student and faculty can have extensive personal contact. In addition, interdisciplinary research projects provide ample opportunities for students to interact with researchers from other disciplines, especially through the interdisciplinary institutes.

FORWARD PATH

The Rice chemical engineering department grew from its embryonic beginnings as an adjunct to the chemistry department to a major research and educational center by the 1990's. To a large extent, this success was due to the foresight of its faculty and the ability to exploit opportunities in emerging areas. The artificial heart projects also demonstrated, perhaps for the first time, the importance of interdisciplinary work.

These past achievements set a precedent for the departmental rejuvenation that's occurring today. Faithful to its tradition, our department is refocusing its research and teaching efforts on areas that address the evolving needs of our society. These efforts are already receiving national recognition as evidenced by the recent journal and newspaper articles[1,2,3] describing Pasquali's work on producing fibers made from single-walled carbon nanotubes. The belief that chemical engineering is an **enabling discipline**, however, continues to shape our mission. Like our predecessors, we continue to use the same quantitative, systems-based approach in our research, adapt our curricula to meet the evolving needs of our students, and apply the same commitment to excellence.

ACKNOWLEDGMENTS

Our special thanks go to Bill Akers, Professor Emeritus and the staff of the Woodson Research Center, Fondren Library, Rice University.

THE UNIVERSITY AND ITS CITY

The university attracts a diverse group of highly talented students and faculty with outstanding graduate and professional programs in the humanities, social sciences, natural sciences, engineering, architecture, music, and business. With just 1,600 graduate students and 2,700 undergraduates, it offers an unusual opportunity to form close relationships with eminent faculty scholars and researchers and the option to tailor graduate programs to specific interests.

Only a few miles from downtown Houston, Rice occupies an architecturally distinctive, 300-acre campus shaded by nearly 4,000 trees. Surrounded by upscale residential neighborhoods, the Rice campus is adjacent to the Texas Medical Center, a large municipal park (Hermann Park) and the tree-lined museum district that features 11 museums exhibiting art, nature, medicine, science, and history.

Hermann Park

Houston is the fourth-largest U.S. city and home to a diverse blend of ethnic groups and cultures. It is the world's energy capital, an international business hub and a center for the visual and performing arts. Houston is the home of the Texas Medical Center, the largest concentration of medical schools, hospitals and research facilities in the world. Several other major universities are also located here. Rice has cooperative programs with the University of Houston, Baylor College of Medicine, the University of Texas Health Science Center, and Texas Southern University. Houston is one of the few U.S. cities with top-notch resident companies in all four major performing arts — ballet, opera, symphony, and drama. In addition to their wonderful permanent collections, Houston's museums routinely feature exhibits of national and international prominence.

As urban as it is, Houston is also a surprisingly green city. Its abundantly green landscape is sprinkled with parks and traversed by many bayous and waterways. Houstonians enjoy the outdoors in over 300 municipal parks and 120 open spaces, and many frequent the beach at Galveston Island, only a 45-minute drive away. Other short trips include Austin, the state's capital, and historic San Antonio, both of which are a little more than three hours away.

Rice Chemical Engineering History Capsule

1912: Rice Institute opens the doors to its first class of students.

1916: The first three chemical engineering degrees are awarded.

1921: A. J. Hartsook is hired as instructor of industrial chemistry.

1927: Hartsook is promoted to Assistant Professor of Chemical Engineering and assumes the leadership of chemical engineering, a post he will hold until 1956.

1928: Anna Rebecca Lay becomes Rice's first woman graduate in Chemical Engineering.

1938: Chemical engineering ceases to be a part of the department of chemistry and becomes one of the four Rice Engineering departments.

1941: Rice Chemical Engineering becomes the first chemical engineering department in Texas accredited by E.C.P.D. (the precursor of A.B.E.T.)

1941: The first M.S. degrees in Chemical Engineering are granted to Sam Bethea (Thesis title: "Studies on Decolorizing Clays") and Ervon Eggimann (Thesis title: "Performance of an Adiabatic Fractionating Column").

1947: The Chemical Engineering Department receives a mandate from Rice President Houston to start a full-scale graduate program.

1948: Construction of the Abercrombie laboratory is completed. The undergraduate chemical engineering program and Professor Hartsook remain in the Chemistry Building, while the graduate students and other faculty occupy the center wing of Abercrombie.

Bill Akers holds a le ventricular bypass device that was implanted in 10 patients in the late 60's.

1955: Orrin K. Crosser is awarded the first Ph.D. in chemical engineering (Thesis title: "Condensing Heat Transfer Within Horizontal Tubes")

1965: The Biomedical Engineering Laboratory is established with the help of a large federal grant. Under the leadership of Bill Akers, this laboratory develops the first successful left ventricular heart bypass in cooperation with the Department of Surgery at Baylor.

1967: Fritz Horn and other chemical engineering faculty are instrumental in the formation of the Mathematical Sciences (applied math) department. Horn becomes acting chair of the new department.

1968: The Department of Environmental Science & Engineering is created, with chemical engineering faculty at its core.

1997: The Department of Bioengineering is created. Four chemical engineering faculty transfer their primary appointments to the new department and Larry McIntire becomes its first chair.

1998: The University approves a strategic plan for Chemical Engineering. Its implementation begins with the help of an Advisory and Development Board.

Chemical Engineering Faculty and their Research Areas

Primary Appointments

Constantine D. Armeniades, Professor; Ph.D., Case Western Reserve, 1969; polymer science, biomaterials.

Walter G. Chapman, Professor; Ph.D. Cornell, 1988, Thermodynamics, statistical mechanics, polymer solutions, gas hydrates, surface-fluid interactions, molecular simulations.

George J. Hirasaki, A. J. Hartsook Professor, Ph.D., Rice, 1967; Foams and emulsions, aquifer remediation, NMR-measured transport properties of fluids and rocks, enhanced oil recovery.

Paul E. Laibinis, Associate Professor; Ph.D. Harvard, 1991, Surface engineering, self-assembly, chemical sensor design, DNA arrays, , nanotechnology.

Nikos V. Mantzaris, Assistant Professor in Chemical Engineering and Bioengineering; Ph.D. Minnesota, 2000; Biosystems engineering, cell population heterogeneity, gene regulatory networks, signal transduction.

Clarence A. Miller, Louis Calder Professor; Ph.D. Minnesota, 1969; Interfacial phenomena, surfactants, foam, emulsions, aquifer remediation.

Matteo Pasquali, Assistant Professor; Ph.D., Minnesota, 1999; Microstructured liquids, carbon nanotubes, free surface flows, computational modeling of processing flows.

Marc A. Robert, Professor; Ph.D. Swiss Federal Institute of Technology, Lausanne, 1980; Thermodynamics, interfacial phenomena, thin films, random media.

Michael S. Wong, Assistant Professor in Chemical Engineering and Chemistry; Ph.D. MIT, 2000; Catalysis, quantum dots, hollow microspheres, materials chemistry, green chemistry, nanotechnology.

Kyriacos Zygourakis, A.J. Hartsook Professor and Department Chair, Professor of Bioengineering; Ph.D. Minnesota, 1981; Cellular and tissue engineering, chemical reaction engineering, nanomanufacturing.

Teaching Faculty

Kenneth R. Cox, Lecturer in Chemical Engineering, Ph.D. University of Illinois, 1979; Colloidal dynamics and stability, phase equilibria of complex systems

Sam H. Davis Jr., Emeritus Professor, Sc.D. MIT, 1957.

Joe W. Hightower, Emeritus Professor, Ph.D. Johns Hopkins, 1963.

Joint Appointments

Vicki Colvin, Associate Professor and Executive Director of the CBEN (joint with Chemistry); Ph.D. University of California, Berkeley, 1994; Photonic band gap materials, nano-crystalline ceramics, mesoporous and macroporous solids.

Antonios G. Mikos, J.W. Cox Professor (joint with Bioengineering); Ph.D. Purdue, 1988; Biomaterials, targeted drug delivery, tissue engineering.

Ka-Yiu San, Professor (joint with Bioengineering); Ph.D., California Institute of Technology, 1984; Metabolic engineering, systems biotechnology.

Jennifer L. West, Associate Professor (joint with Bioengineering); Ph.D. University of Texas at Austin, 1996; Biomaterials, tissue engineering.

Mark R. Wiesner, Professor (joint with Civil & Environmental Engineering); Ph.D. Johns Hopkins, 1985; Membrane processes, nanotechnology, environmental transport.

Emeritus Faculty

W. W. Akers, Professor, Ph.D. Michigan, 1950.

D. C. Dyson, Professor, Ph.D. Univ. of London, 1966.

J. D. Hellums, E.D. Butcher Professor, Ph.D. Michigan, 1961.

R. Kobayashi, L. Calder Professor, Ph.D. Michigan, 1951.

Members of the National Academy of Engineering

George J. Hirasaki (1991)

Riki Kobayashi (1995)

J. David Hellums (1998)