ChE department

Washington University in St. Louis

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The best-known symbol of St. Louis is the Gateway Arch, situated on the west bank of the Mississippi River in the city's downtown, and designated as the Jefferson Memorial National Monument. Another well-known St. Louis landmark, Washington University, was founded in 1853 and recently celebrated its sesquicentennial. The university, always an integral part of the St. Louis community, has grown from a nonsectarian "streetcar" school attended primarily by commuters to an international, research-based university.

Washington University in St. Louis (WUSTL) has about 3,000 instructional faculty and 11,000 full-time students. The students are almost equally divided between its undergraduate divisions and graduate and professional schools. The university currently is tied for 11th place in the 2005 *U.S. News & World Report* rankings for undergraduate programs. Led by Chancellor Mark S. Wrighton, a chemistry professor, WUSTL has seven divisions: the College of Arts and Sciences, the Olin School of Business, the Sam Fox School of Design and Visual Arts, the School of Engineering and Applied Science, the School of Law, the School of Medicine, and the George Warren Brown School of Social Work.

The St. Louis Gateway Arch at dusk.

WUSTL received more than $533 million in research support in fiscal year 2005. A fund-raising campaign that ended on June 30, 2004, netted $1.55 billion.

The university's School of Engineering and Applied Science (SEAS) is a small, highly competitive but friendly place promoting high-quality education and research. The school's dean is Christopher I. Byrnes, a professor of applied mathematics and systems science who is well known for his contributions to nonlinear control theory. SEAS has six departments: biomedical engineering, chemical engineering, civil engineering, computer science and engineering, electrical and systems engineering, and mechani-

** Rarely are four department chairmen still active within a relatively small department. The Department of Chemical Engineering at Washington University in St. Louis, however, is in such a fortunate situation.*

Brookings Hall, a Washington University in St. Louis landmark.

Lawrence E. Stout, WUSTL's first ChE chairman, pictured in 1940.

cal and aerospace engineering. It counts 1,200 undergraduates, 750 graduate students, and 88 tenured/tenure-track faculty. SEAS also has 35 endowed professors, six national academy members, five foreign national academy members, 17 national young investigators, and 59 fellows of professional societies. Fiscal year 2004 research expenditures were $42 million.

EARLY HISTORY

The name "Chemical Engineering" first appeared in Washington University catalogs in 1910 as a Bachelor of Science degree within the engineering school. Students were required to master concepts in general chemistry, analytical chemistry, organic chemistry, physical chemistry, stoichiometry, and industrial chemistry. They were also expected to familiarize themselves with technologies for producing clean water, food, milk, and milk products. Extensive laboratory work was required.

Between 1910 and 1930, few changes occurred in the curriculum. In this predepartmental era, chemical engineering courses were the responsibility of the Department of Chemistry in the College of Liberal Arts. It is noteworthy that **Lawrence E. Stout**, an associate professor of chemistry, was responsible for teaching the chemical engineering principles course as well as the chemical engineering laboratory and the engineering metallurgy course—all requirements for the ChE program at the time.

In 1940, the Department of Chemical Engineering was founded as an autonomous unit within the School of Engineering, and Dr. Stout was named its first chairman. The university's first master of science degree in chemical engineering was granted in 1941. The first doctorate was awarded in 1945. And the first woman with a B.S. in chemical engineering graduated in 1948.

POST-WAR ERA

The post-World War II era saw a sharp rise in ChE degrees at the university, cresting at 66 diplomas in 1949. In the 1950s, there was a modest increase in graduate work, and in 1959 the department's current home, Urbauer Hall, was built. By 1960, there were six full-time faculty members.

The addition of **James M. McKelvey** and **G.I. Esterson** to the ChE faculty brought about a notable change. The former focused on developing new approaches to quantifying polymer processing, and the latter embraced modern process-control techniques. *Polymer Processing*, the pioneering book written by Jim McKelvey and published in 1962, was the first of its kind and enhanced the department's reputation in teaching and research.

THE SIXTIES AND SEVENTIES

With Jim McKelvey (1962-1964) and **Eric Weger** (1964-1977) as department chairmen, the next two decades witnessed tremendous changes. During this era, the university gained international status. Moreover, the importance of graduate work and research grew, thanks in large part to increased federal funding. Biomedical engineering at WUSTL had an early start—and thrived—due to the prominence of the School of Medicine. Environmental concerns, new petrochemical and chemical processes, and the issues of energy and synthetic fuels all contributed to help make chemical engineering a popular major.

The undergraduate curriculum underwent a thorough transformation in these decades. Introduced in this period were mathematical analysis and modeling of chemical systems, transport phenomena as a basis for unit operations, quantitative treatment of chemical reaction engineering, process control, process synthesis, and design. New laboratory courses illustrated the key concepts of transport, unit operations, and chemical reaction engineering.

In summation, a curriculum that was firmly based on chemical engineering sciences emerged in the 1960s and—capitalizing on emerging advances in information technology—was augmented by process synthesis and model-based control in the 1970s. With modest changes, this successful curriculum remained in effect until 2000. Currently, a revised curriculum is being phased in.

Faculty additions and accomplishments

More remarkable than curriculum evolution in these two pivotal decades were changes that took place in research and

graduate-level coursework. These changes were brought about by new faculty members and the synergism the department developed with the Corporate Engineering Division at Monsanto in St. Louis.

Professor John L. Kardos joined the ChE department in 1965, and in that year, the university and Monsanto were awarded a $1 million federal grant to develop the technology of composite materials. This government-sponsored university-industry program, the first of its kind, was part of a larger experiment by the federal government to learn how to couple universities and companies in joint research efforts.

The Washington University/Monsanto research effort was judged the most successful among seven such partnerships nationwide. From it emerged the engineering school's Materials Science and Engineering Program and an internationally recognized research group in composite materials. Today, this interdisciplinary program spans several engineering departments as well as other divisions of the university. On June 30 of this year, the professor so instrumental in its success, John Kardos, retired after 40 years of exemplary research and teaching at Washington University. He continues to provide advice and guidance as a professor emeritus.

Others made their mark on the school's success as well. **Professor Buford Smith**, who joined the department in 1965, established a world-renowned thermodynamics laboratory for determination of vapor-liquid-equilibria in binary systems and for development of estimation methods for equilibria in multicomponent systems. In addition, Smith—with the help of **Dr. James Fair** and other Monsanto-affiliate faculty—developed a series of process-design case studies still used in classrooms worldwide. Upon Smith's retirement in the late '80s, his laboratory was purchased by DuPont.

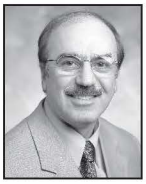
Professor Robert Hochmuth (on the faculty from 1967 to 1978), pursued early biomedical research. An expert in the red blood cell membrane and its viscoelasticity, he developed unique experimental methods to test the effects of diseases such as sickle cell anemia on the membrane.

Professor Bob Sparks and **Professor Curt Thies** arrived at ChE in the early 1970s, and proceeded to put the department on the map

Chemical Engineering Faculty

at Washington University in St. Louis

Milorad P. Dudukovic, Department Chair
The Laura and William Jens Professor
Ph.D., Illinois Institute of Chicago, 1972
chemical reaction engineering, multiphase reactors, visualization of multiphase flows, environmental engineering, tracer methods



Muthanna Al-Dahhan
Associate Professor
D.Sc., Washington University, 1993
reaction engineering, multiphase reactors, bioprocessing engineering

Largus T. Angenent
Assistant Professor
Ph.D., Iowa State University, 1998
molecular tools for microbial ecology, anaerobic treatment of water and waste, bioreactor design and operation

Pratim Biswas
The Stifel and Quinette Jens Professor
Ph.D., California Inst. of Tech., 1985
aerosol science and engineering, air quality and pollution control, nanotechnology, environmentally benign processing

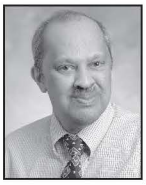
John T. Gleaves
Associate Professor
Ph.D., University of Illinois
industrial catalysis, microstructured materials

John L. Kardos
Professor Emeritus
Ph.D., Case Western Reserve Univ., 1965
structure-property relations in polymers and reinforced plastics, interface chemistry and physics of composites, processing science of composites

Bamin Khomami
The Frances F. Ahmann Professor
Ph.D., University of Illinois, 1987
transport properties of complex fluids, polymer physics, biomolecular physics

James M. McKelvey
Senior Professor
Ph.D., Washington University, 1952
thermodynamics, polymer processing, rheology, polymer technology

Rodolphe L. Motard
Senior Professor
D.Sc., Carnegie Mellon University, 1952
reaction engineering, multiphase reactors, bioprocessing engineering



P.A. Ramachandran
Professor
Ph.D., University of Bombay, 1971
chemical reaction engineering, applied mathematics, process modeling

Radakrishna Sureshkumar
Associate Professor
Ph.D., University of Delaware, 1996
complex fluid dynamics, interfacial nanostructures, multiscale modeling and simulations

Jay R. Turner
Associate Professor
D.Sc., Washington University, 1993
environmental engineering, air quality policy and technology, aerosol science and engineering

A bird's-eye view of Urbauer Hall, which is connected to other buildings in the WUSTL engineering campus.

in the area of controlled drug release and microencapsulation research. Sparks' research eventually culminated in the licensing of several patents and his retirement from SEAS in 1990 to found his own company. Thies became a professor emeritus in 2002 and continues to run his microencapsulation business from Nevada.

In 1974, **Professor Milorad P. (Mike) Dudukovic** arrived to start building the Chemical Reaction Engineering Laboratory (CREL), which now enjoys a world-class reputation. Funded by industry (18 companies from five continents) and government, CREL continues to be the most productive research unit in the department. Its focus is on the development of improved models and scale-up procedures for various multiphase reactors that are predominant in petroleum, chemical, and pharmaceutical applications.

Washington University was founded in 1853 and recently celebrated its sesquicentennial.

Dudukovic and his team have implemented novel noninvasive methods—gamma ray computer tomography and computer-assisted radioactive particle tracking—for monitoring phase distributions, flow, and mixing within multiphase contactors. The research team utilizes these techniques to validate computational fluid dynamics codes and to establish fundamentally based reactor models.

Dudukovic has also been long known as one of the most effective teachers at the university, and has been honored nationally and internationally for his pioneering research. Under his guidance, CREL has recently become a core partner with the University of Kansas, the University of Iowa, and Prairie View A&M University in the National Science Foundation Engineering Research Center for Environmentally Beneficial Catalysis (CEBC). CREL efforts for the center are focused on identifying the best reactor types for novel catalytic processes that lead to minimal impact on the environment.

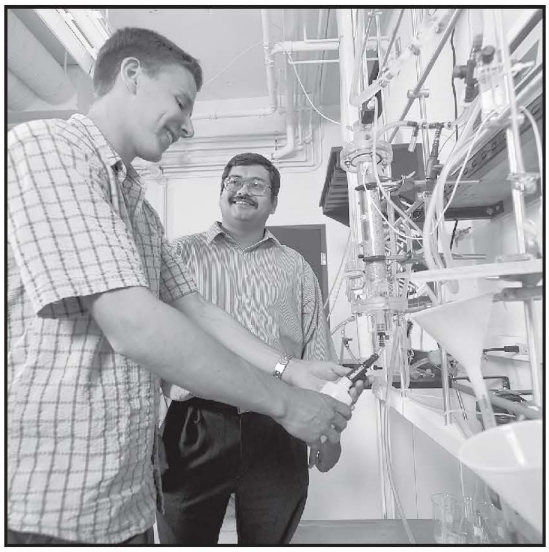
Professor Rodolphe L. (Rudy) Motard became the department's sixth chairman in 1978. Motard's research interests included flowsheeting, process synthesis, and data and information modeling—all of which have had a significant impact on industrial practice. He was one of the charter founders of the CACHE Corporation in 1968 and served as a consultant to the ASPEN development group at MIT. He also was instrumental in the formation of AIChE's Process Data Exchange Institute (pdXi). Motard became a senior professor in 1996 and continues to do research in process synthesis and database mining with the help of Yoshio Yamashita (D.Sc. '80).

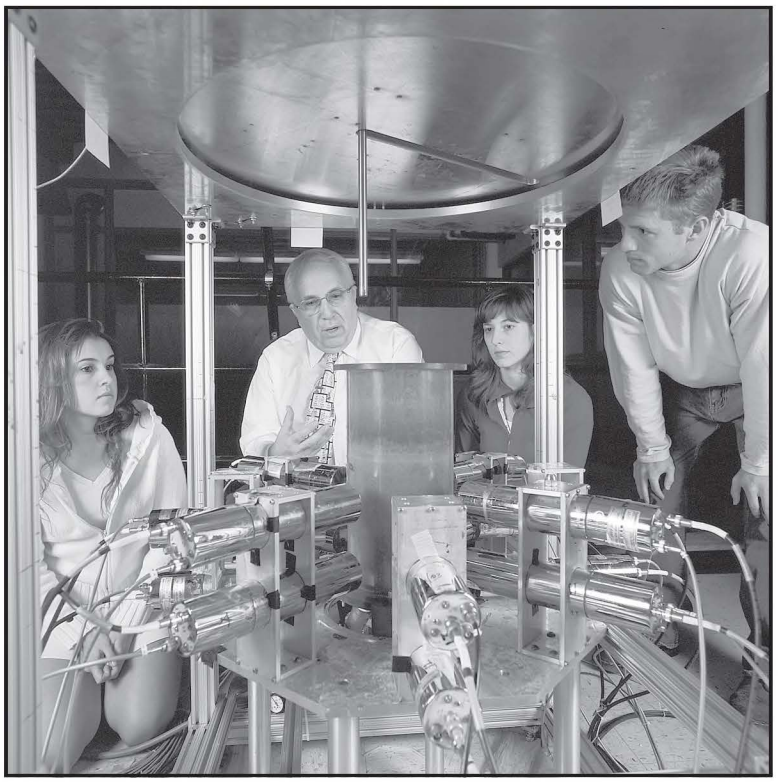
Professor Babu Joseph (1978-2002) worked with Motard to develop a cooperative effort in process synthesis design and control and sensor development based on wavelet transforms for early corrosion detection. Joseph also pioneered Web-based control experiments and the effective introduction of information technology in classroom teaching. He left the department in 2002 to become chairman of the ChE department at the University of South Florida in Tampa.

THE EIGHTIES TO THE PRESENT

The period of 1980 to the present has seen gradual change in the evolution of the undergraduate program—now firmly entrenched in chemical engineering science principles. Dur-

Right, ChE Chair and Professor Milorad P. (Mike) Dudukovic guides student researchers in the Chemical Reaction Engineering Laboratory. Below, Professor Pratim Biswas works with a student in the Air Quality Research Lab.





ing these years, the program embraced process synthesis and model-based control driven by information technology.

Professor P.A. Ramachandran joined the department in 1984. He has added a wealth of expertise in the area of applied mathematics and multiphase reaction engineering, and has strengthened CREL's chemical reaction engineering modeling activities. Ramachandran's research interests are in the modeling of heterogeneous reactions and the study of transport and reaction effects in design of chemical reactors.

His book, *Three-phase Catalytic Reactors*, published in 1983, is widely used even today by industrial practitioners as a first-reference source. Recent interests include pollution prevention strategies in chemical reactions, and design of green processes and reactors.

Non-Newtonian flows, polymer rheology, and processing were the main research interests of **Professor Bamin Khomami** when he joined the department in 1987. His current research focus is on the study of nonequilibrium transport and pattern formation in micro- or nano-structured media. Khomami's research involves studies of hydrodynamic instabilities and pattern formation in complex fluids, microdynamics of complex fluids, and synthesis of nano-structured particles and thin films via aerosol routes.

Professor John Gleaves came to the department in 1988 from Monsanto. He brought his Temporal Analysis of Products (TAP) system for probing of reaction mechanisms on real catalytic surfaces. Gleaves rapidly achieved worldwide acclaim for his technique, which has now been adopted at catalytic laboratories on four continents.

During the 1990s and beyond, the department added faculty to further support its research excellence in materials and reaction engineering, and to provide leadership in environmental engineering—an area targeted for growth by SEAS. John Kardos provided stable leadership from 1991 to 1998. Mike Dudukovic then became chairman and remains so at the present. During this period, more impressive faculty additions occurred.

Professor Jay Turner joined the department in 1993. Turner spearheaded the effort to reestablish environmental engineering as an interdisciplinary graduate-degree-granting program at SEAS. He established himself as a leading authority in the transport and monitoring of atmospheric aerosols, and has been in charge of a multiyear, multiuniversity project funded by the Environmental Protection Agency (EPA) and National Science Federation (NSF). He also has won multiple teaching awards at WUSTL.

In 1997, **Professor R. Sureshkumar** joined the department, bringing additional strengths in applied mathematics and physics of complex fluids. His research interests are nonlinear dynamics of complex fluids, interfacial nanostructures, and multiscale modeling and simulation. His work elucidating the physics of turbulent drag reduction by polymeric additives has been noted by theoreticians in the field and has had practical applications in saving pumping energy for farmers. Sureshkumar is the cofounder of the Chemical Engineering Learning Laboratory (CELL).

In 1998, Professor **Muthanna Al-Dahhan** was converted from part-time to full-time status to further CREL's chemical reaction engineering activities. Al-Dahhan has worked hard to expand CREL's industrial and governmental support. He also spearheaded CREL diversification into the biochemical area, where he has led projects in anaerobic digestor design and in photosynthetic reactions by algae.

Professor **Pratim Biswas** became director of the interdisciplinary Environmental Engineering Science Program in 2000. Biswas brought with him world-class expertise and recognition in aerosol generation, monitoring, transport, and applications. His Aerosol Research Laboratory team has established new applications of aerosol technology in generating catalysts for conversion of solar energy to hydrogen, for mercury abatement in power plants, and for water purification.

In 2002, Professor **Lars Angenent** joined the department, adding breadth to the Environmental Engineering Science Program and novel research initiatives. Angenent's traditional environmental engineering background led to his patent for an improved anaerobic digestor. He also has extensive experience in molecular-biological techniques. He is currently studying biological means for converting waste to electricity.

All members of our tenure-track faculty are very active in research, yet still teach one and often two courses a semester, senior professors included. In addition, we have a team of superb professionals—many of whom are ex-research fellows at Monsanto, Solutia, or Boeing— that contributes significantly to teaching and research as adjunct faculty. **Chuck Carpenter**, with over 30 years experience in process design at Monsanto, is in charge of our capstone design and economic evaluation courses. (Thanks in part to his contributions, our students have won AIChE national design contests several times.) **Marti Evans**, who worked in research and technical service in refining and petrochemicals for Shell, teaches as needed; currently, she is teaching a laboratory course that gives undergraduate students hands-on experience with advanced analytical instruments.

Greg McMillan is a principal consultant for TAC Worldwide Companies and is working on the next generation of advanced control in DeltaV for Emerson Process Management; he advises students on internships in control. **Terry Tolliver**, an ex-senior fellow at Monsanto/Solutia, teaches our control course. **Bob Heider** brings outstanding practical experience in designing, running, and controlling various chemical processes to our control laboratory course. Washington University ChE graduate **Nick Nissing**—who earned 11 U.S. patents while working for Procter & Gamble—currently is president of a consulting firm and teaches two senior-level classes on new-product development.

Robin Shepard teaches safety courses in the department. Starting in 2002 the AIChE design project began awarding a separate prize for the best applications of the principles of chemical engineering safety design, and Washington University students took home that prize three years in a row.

We also have a number of affiliate and research faculty (particularly, in this latter category, **Gregory S. Yablonsky**), who use their expertise to broaden the horizons of, and the availability of, diverse research projects for our graduate students.

STUDENTS AND ALUMNI

A generous, need-based scholarship program ensures that the best students can apply to SEAS, while a merit scholarship program enables the engineering school to attract students whose quality is second to none. It is our awesome responsibility to motivate this extremely talented group of young people. We accomplish this by taking our teaching duties very seriously, by having a strong advising and mentoring program, by offering abundant research opportunities, co-ops, and internships, and by allowing students to work on product development and capstone design projects with industry. Moreover, through exit interviews and correspondence, we monitor their careers and receive comments on the effectiveness of our programs.

Of all our graduates of distinction, perhaps the most unusual was Charlie Johnson, who, on his graduate-school application listed as his occupation: "Quarterback—St. Louis Football Cardinals." During the 1960s, Johnson tossed footballs during the fall semesters and took courses during the spring terms. He earned his M.S. ChE in 1963 and a D.Sc. in 1966.

On the graduate level, a strong chemical engineering core consisting of applied mathematics, transport phenomena, reaction engineering, and computational techniques is required of all students.

The diversity of the accomplishments of our alumni is astonishing. A few examples: **Julian Hill** (B.S. ChE '24) performed research and patented processes that made the manufacture of nylon possible. **Jim McKelvey** (M.S. ChE '47, Ph.D. ChE '50) was recognized *twice* with SEAS Alumni Achievement Awards, for his pioneering contributions to polymer processing and for his accomplishments as SEAS dean for 27 years. **Raymond W. Fahien** (B.S. ChE '47) taught at Iowa State University and the University of Florida and authored a textbook on fundamentals of transport phenomena. He was also former editor of *Chemical Engineering Education*.

The list goes on. **Bill Patient** (B.S. ChE '57) was CEO of Geon, one of the industry's major corporations. **Joe Boston** (B.S. ChE '59) was a cofounder of ASPENTECH. **Andrew Bursky** (B.S. ChE '78, M.S. ChE '78) is a successful businessman in the industry. **Mark Barteau** (B.S. ChE '75) is a leading figure in heterogeneous catalysis and chairman and distinguished professor at the University of Delaware. **Todd Przybycien** (B.S. ChE '84) is chairman of biomedical engineering at Carnegie Mellon University.

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THE DEPARTMENT TODAY

The mission of our ChE department has always been to provide a first-rate chemical engineering education, to conduct exciting, world-class research and engage students at all levels in research activities, and to be of service to the community.

The department continues to provide a first-rate undergraduate education leading to the accredited B.S. ChE degree as well as the optional B.S. in Applied Science degree with emphasis in chemical engineering. The five-year B.S./M.S. program is increasingly popular, as is the control option leading to a combined ChE and Electrical and Systems Engineering degree. On the graduate level, a strong chemical engineering core consisting of applied mathematics, transport phenomena, reaction engineering, and computational techniques is required of all students.

The department currently ranks first at SEAS in research dollars from external research funding sources obtained per-year, per-faculty, and in overhead recovery generated per-faculty, per-year. The ChE department currently has about 40 full-time doctoral students and several postdoctoral research associates and research professors.

ChE AT WASHINGTON IN THE FUTURE

The ChE department's 1970 undergraduate curriculum was highly reflective of the "state of the science" at the time, and changed little until the year 2000. Now, however, with an overall objective to reflect chemical engineering's multiscale and multidisciplinary nature, our department is phasing in a revised curriculum. As can be seen in Table 1, basic science requirements now include biology (emphasizing cell structure and function). Other highlights of curriculum changes include: emphasizing multiscale concepts, including molecular level; stressing product design and development; and providing greater flexibility in customizing the curriculum. To this end, the core curriculum has been reduced to accommodate up to six additional elective courses in the desired area of concentration (*e.g.*, bioprocessing, environmental, materials, product development, or others as approved).

In addition, a strategic plan developed with the help of the Departmental Advisory Board calls for establishing a strong biomolecular presence in bioprocessing. This should allow us to capitalize more on the unique strengths of the university in biological sciences by appropriate expansion of our faculty.

Our ongoing goal of forming a natural link with both biomedical and environmental engineering begins with establishing modern, molecularly based chemical engineering principles. Using those as a basis for scaling up the pace of discoveries in life sciences, we aim to pursue products and processes that are environmentally desirable as well as being a foundation for comprehensive studies of the environment. The result should be an exciting environment for research and education.

Associate Professor John Gleaves explains his TAP (Temporal Analysis Products) system to visitors.

Our challenge for the future is to incorporate biomolecular engineering into our curriculum and research, thus strengthening our existing areas of excellence in environmental engineering, clean processing, aerosols, transport, reaction engineering, and materials. This biomolecular engineering initiative should also fill a major need in the St. Louis metropolitan area, which is strong in generating discoveries in life sciences but still lacks a focused center for either transferring these discoveries to useful products, energy, and processes, or for examining their environmental effects in a holistic manner.

TABLE 1
Revised ChE Core Curriculum

Basic Sciences	
(Biology, Chemistry, Mathematics, Physics)	**39**
Engineering Sciences	**12**
Chemical Engineering Core Courses	
Modern Technological Challenges (ChE 146A)	2
Analysis of Chem. Eng. Systems (ChE 351)	3
Thermodynamics (ChE 320)	3
Materials Science (ChE 325)	3
Molecular Transport Processes (ChE 359)	3
Transport I & II (ChE 367 or 366, 368)	6
Mass Transfer Operations (ChE 462)	3
Process Dynamics & Control (ChE 462)	3
Reaction Engineering (ChE 471)	3
Chemical Engineering Laboratory (ChE 373A)	4
New Product & Process Development (ChE 450)	3
Process and Product Design (ChE 478A)	3
Subtotal	**39**
Humanities & Social Science & Communications	18
Total ChE Core	**108**
Engineering Electives	
(6 courses from area of concentration)	18
Total	**126**

In his speech of Feb. 22, 1854, **William Greenleaf Eliot**, president of Eliot Seminary (which was later renamed Washington University) said:

> *"There is one view of the Washington Institute which I desire to keep particularly prominent—its practical character and tendencies. I hope to see the time when what we call the practical and scientific departments will stand in the foreground, to give character to all the rest. In some way or another, a practical and scientific direction must be given to all educational schemes of the present day . . . ."*

We in chemical engineering at Washington University are still striving to make Eliot's dream come true. Our theoretical advances are scientifically founded and motivated by the need to improve the quality of life through environmentally beneficial technology.

ACKNOWLEDGMENT

The authors thank **Barbara Carrow** for her technical assistance. ❐