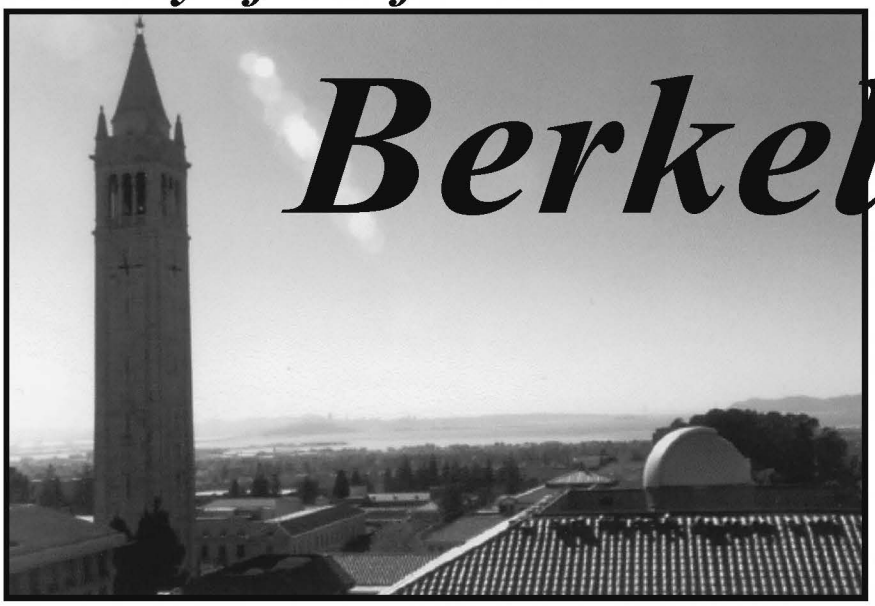
University of California

Berkeley



The Campanile overlooking San Francisco Bay.

ARUP K. CHAKRABORTY, P.B. PLOUFFE, STACEY SHULMAN
University of California • Berkeley, CA 94720-1462

The academic year 2003-2004 marks the 56th anniversary of the Department of Chemical Engineering at the University of California, Berkeley. Developed as an academic discipline in the United States near the turn of the century, chemical engineering moved toward engineering science in the late 1940s and 1950s. During those years, Berkeley's young department rose to prominence. It took the lead in developing new areas of research such as electrochemical engineering, molecular thermodynamics, semiconductor processing, and biochemical engineering. The department has consistently ranked among the top three research and teaching programs in the country. It continues to be at the forefront in developing programs in emerging areas of chemical, materials, and biological technology.

The success of the department has been facilitated by being part of a world-famous university with leading departments in all fields of engineering, the natural sciences, social sciences, and the humanities. Strong synergies with research programs at the Lawrence Berkeley National Laboratory have also added to the richness of the intellectual culture of the department.

The Chemical Engineering Department at Berkeley is part of the College of Chemistry, which also houses the nation's top-ranked chemistry department. Nineteen members of the faculty work together congenially with 115 graduate students, 333 undergraduates, and 31 postdoctoral fellows in the pursuit of excellence in teaching and scholarship.

The current faculty has received many awards and honors recognizing their accomplishments in teaching and research. These awards include four members of the National Academy of Engineering, one member of the National Academy of Science, two Allan P. Colburn Awards (AIChE), two Professional Progress Awards (AIChE), three Food, Pharmaceutical and Bioengineering Awards (AIChE), the Award in Heterogeneous and Homogeneous Catalysis (ACS), the Marvin Johnson Award in Biochemical Technology (ACS), The Colloid and Surfaces Chemistry Award (ACS), the EV Murphree Award (ACS), two Emmett Awards in Heterogeneous Catalysis (North American Catalysis Society), two Amgen Awards in Biochemical Engineering (Engineering Foundation), one Dillon Medal (APS), one AVS Award in Plasma Physics, three Camille Dreyfus Teacher Scholar Awards, and numerous Presidential Young Investigator, National Young Investigator, and CAREER Awards (NSF).

Research groups in the department are housed primarily in

Gilman Hall, a National Historic Chemical Landmark where plutonium was discovered, and Tan Kah Kee Hall (dedicated in 1997). These buildings provide state-of-the-art facilities and infrastructure for research.

HISTORY OF THE DEPARTMENT

The appointment of the first Professor of Chemical Engineering in July of 1946 marked the administrative decision that ultimately led to the present chemical engineering program at Berkeley. As the university began to more fully recognize the importance of chemical engineering—especially through its contributions to the war effort in the development of the atomic bomb and in the petroleum and chemical industries—the need for a full-fledged program became appar-

TABLE 1
Chronology of Events in Chemical Engineering at Berkeley

1912 ► **G.N. Lewis** institutes a chemical technology major.

1942 ► An interdepartmental graduate group offers the MS degree in chemical engineering.

1945 ► Provost **Monroe Deutsch** authorizes establishment of a Chemical Engineering program in the College of Chemistry.

1946 ► Initial faculty members are appointed to teach chemical engineering: **Philip Schutz** (deceased, 1947); **LeRoy Bromley** (retired, 1972); **Charles Wilke** (chair 1953-63; retired, 1987).
► Undergraduate instruction begins.

1947 ► **Theodore Vermeulen** (chair 1947-53; deceased, 1984), **Donald Hanson** (chair 1963-66; retired 1989), **Charles Tobias** (chair 1966-71; retired, 1991; deceased, 1996), join the faculty.
► PhD program is approved.

1948 ► BS degree program in Chemical Engineering is approved.
► **F. Campbell Williams** joins the faculty (left for Petrobas and University of Brazil, 1952).

1949 ► The Chemistry Department is renamed the Department of Chemistry and Chemical Engineering.
► BS program is accredited by the AIChE.

1952 ► A Division of Chemical Engineering is created within the Department of Chemistry and Chemical Engineering.
► **Kenneth Gordon** joins the faculty (left for University of Michigan, 1954).

1953 ► **Eugene Petersen** (retired, 1991) joins the faculty.

1954 ► **Andreas Acrivos** joins the faculty (left for Stanford, 1963).

1955 ► **John Prausnitz** joins the faculty.

1956 ► **Donald Olander** joins the faculty (left for UCB Nuclear Engineering Department, 1961).

1957 ► Chemical Engineering is established as a separate department.

1958 ► **David Lyon** (retired, 1982) joins the faculty.

1961 ► **Alan Foss** (retired, 1994) and **Michel Boudart** (left for Stanford, 1965; appointed Adjunct Professor, 1994-97) join the faculty. **Simon Goren** (chair, 1994-97; retired, 2001) and **Richard Wallace** (resigned, 1965) join the faculty.

1963 ► **Edward Grens** (retired, 1987), **C. Judson King** (chair, 1972-81), **John Newman, Richard Ayen** (left for Stauffer Chemical Co., 1968), join the faculty.

1964 ► **Robert Merrill** joins the faculty (left for Cornell, 1977).

1965 ► **Michael Williams** (retired, 1989) joins the faculty.

1966 ► **Robert Pigford** joins the faculty (returned to University of Delaware, 1975).
► Room 307 Gilman Hall is designated a registered National Historic Landmark by the U.S. Department of the Interior as the location for the discovery of plutonium.

1967 ► **Scott Lynn** (retired, 1994) and **Alexis Bell** (chair, 1981-91) join the faculty.

1969 ► **Mitchell Shen** joins the faculty (deceased, 1979).

1970 ► **Lee Donaghey** (left for Chevron, 1977) and **Thomas Sherwood** (deceased, 1976) join the faculty.

1975 ► **Clayton Radke** joins the faculty.

1977 ► **Dennis Hess** (left for Lehigh University, 1991) joins the faculty.

1978 ► **Elton Cairns** and **Harvey Blanch** (Chair, 1997-2001) join the faculty.

1979 ► **David Soane** (Soong)(left for Soane Technologies 1994; appointed Adjunct Professor, 1994) and **Edward Reiff** (left for DuPont, 1982) join the faculty.

1981 ► **Morton Denn** (Chair, 1991-94; left for CCNY, 1999) joins the faculty.

1982 ► **Jeffrey Reimer and James Michaels** (left for Mobil, 1989) join the faculty.

1986 ► **Douglas Clark, David Graves,** and **Doros Theodorou** (left for University of Patras, 1994) join the faculty.

1988 ► **Arup Chakraborty** (Chair, 2001-) joins the faculty.

1991 ► **Susan Muller** joins the faculty.
► Room 307 Gilman Hall is designated a Nuclear Historic Landmark by the American Nuclear Society as the site of the first chemical identification of plutonium on February 23-24, 1941).

1992 ► **Jay Keasling** joins the faculty.

1993 ► **Enrique Iglesia and Roya Maboudian** join the faculty.
► Construction of Tan Hall begins.

1997 ► Gilman Hall designated as an ACS National Historic Chemical Landmark.
► Dedication of Tan Kah Kee Hall (April 12, 1997).

1999 ► **David Schaffer** joins the faculty.

2000 ► **Alexander Katz** joins the faculty.

2004 ► **Rachel Segalman** will join the faculty.

. . . the [Berkeley] chemical engineering faculty has contributed to the emergence of a number of different areas that are now considered quintessential chemical engineering.

ent. Initially, considerable controversy developed as to whether the program should be in the College of Engineering or the College of Chemistry. For a while, this led to the amusing situation where Berkeley had two chemical engineering departments—one housed in the College of Engineering and the other in the College of Chemistry. The stronger program in the College of Chemistry ultimately prevailed.

Professor John Prausnitz and students in the unit operations laboratory.

Philip Schutz, a professor of chemical engineering at Columbia University, was selected to head the fledging chemical engineering program. To assist him, Dean Wendell Latimer appointed Charles Wilke (PhD, University of Wisconsin) and LeRoy Bromley (MS, Illinois Institute of Technology). Sadly, shortly after the first class enrolled in September 1946, Philip Schutz passed away. Theodore Vermeulen (PhD, UCLA) joined the program in February 1947 and became its head. Don Hanson (PhD, University of Wisconsin) and Charles Tobias (a Hungarian émigré, PhD, Budapest) joined the faculty in the fall of 1947, and they were followed by F. Campbell Williams in 1948.

This initial faculty group remained in place without further additions until 1952 when Ken Jordan from MIT joined the faculty. During this period, a PhD program was formally approved (1948) and the BS program was fully accredited (1949). Charles Wilke succeeded Theodore Vermeulen as Chairman in 1953, and between 1953 and 1955, he recruited three more remarkable intellects: Eugene Petersen from Penn State (1953), Andreas Acrivos from Minnesota (1954), and John Prausnitz from Princeton (1955).

With these pioneers establishing standards of excellence that have consistently marked the department, new areas of research were established in the period between 1953 and 1985. The sub-field of electrochemical engineering (under the leadership of Charles Tobias) is a notable example. During those same years, John Prausnitz developed a systematic approach for obtaining activity coefficients and equations of state for substances central to the petrochemical industry. The major award in this field, now called molecular thermodynamics, is named after Dr. Prausnitz, who continues to be active in teaching, research, and administration.

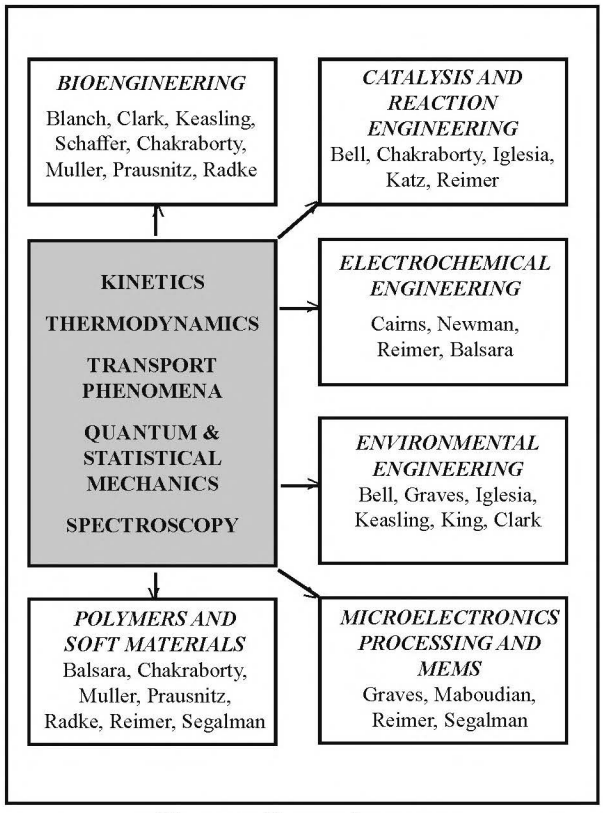


Figure 1. *Research areas.*

In the 1970s, Dennis Hess headed up the first program in micro-

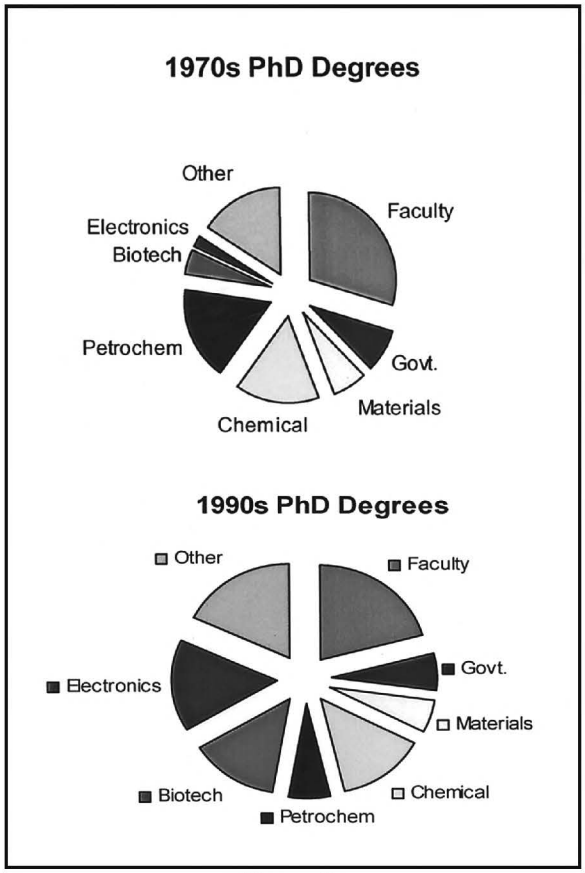
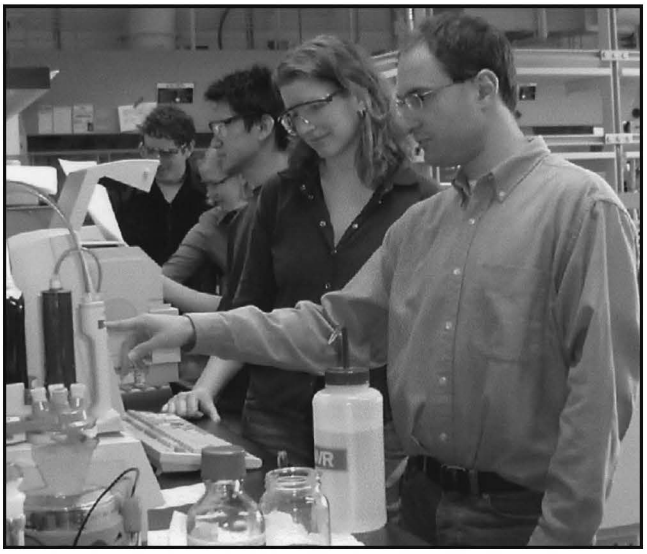


Figure 2.

TABLE 2
Textbooks Published by Berkeley Faculty

Blanch & Clark	• *Biochemical Engineering*
Denn	• *Process Fluid Mechanics* • *Process Modeling* • *Introduction to Chemical Engineering Analysis* (with T.W.F. Russell) • *Stability of Reaction and Transport Processes* • *Optimization by Variational Methods*
King	• *Separation Processes* • *Freeze Drying of Foods*
Hanson	• *Computation of Multistage Separation Processes*
Newman	• *Electrochemical Systems*
Petersen	• *Chemical Reaction Analysis*
Prausnitz	• *Molecular Thermodynamics of Fluid Phase Equilibria* (with Lichtenthaler and de Azevedo) • *Properties of Gases and Liquids* (with B. Poling and R. Reid) • *Regular and Related Solutions* (with J.H. Hildebrand and R.L. Scott)
Reimer	• *Chemical Engineering Design & Analysis* (with T.M. Duncan)
Sherwood, Pigford & Wilke	• *Mass Transfer*



Professor Alex Katz and students.

electronics processing within a chemical engineering department. In that same decade, Charles Wilke and Harvey Blanch initiated a pioneering program in biochemical engineering. Under the leadership of Gene Petersen, Michel Boudart, and Alex Bell, an innovative program in catalysis and reaction engineering was established. When Mort Denn joined the faculty in 1981, he set up a world-class program in polymer processing on the Berkeley campus and at the Lawrence Berkeley National Laboratory. (The research programs that have evolved since 1985 are described in the "Graduate Program" section of this article.)

THE UNDERGRADUATE PROGRAM

The BS degree in chemical engineering at UC Berkeley, accredited by ABET, is acknowledged as one of the most demanding majors on campus. The curriculum provides a strong background in mathematics and the basic sciences of physics, chemistry, and biology. The core principles of thermodynamics, reaction engineering, and transport phenomena are often illustrated by examples drawn from the petroleum, petrochemical, pharmaceutical, biomedical, and microelectronics industries. The program includes extensive laboratory experience, with mandatory laboratory courses in unit operations, transport phenomena, and control systems. In addition, elective courses in biochemical engineering, polymers, and microelectronics processing include large laboratory components. Under the supervision of a faculty member, the students work in teams to design a process in the capstone course.

In the final two years, students choose an option that allows them to more deeply study a sub-field of chemical engineering. In particular, option programs are available in biochemical engineering, materials science and engineering, chemical processing, and microelectronics. The options program, in place for 16 years now, constantly evolves to meet student and industry needs.

A special feature of the undergraduate program at Berkeley is the high premium placed on teaching students how to communicate technical information effectively, both orally and in writing. Each laboratory course and the design course include oral presentations and written reports. In addition, a required course in technical communication and ethics is taught by a lecturer in the department. Alumni and employers report back to us the great advantage and value of these experiences.

The undergraduate program in chemical engineering is constantly reviewed by the faculty. This has allowed it to continuously evolve, and perhaps it is the reason why we do not perceive an urgent need to make revolutionary changes to the curriculum. Constant fine tuning has allowed us to make necessary modifications to meet the needs of students who find employment in a wide range of corporate sectors.

The department values excellence in teaching and over the years several landmark textbooks have been written by the faculty (see Table 2). They include *Molecular Thermodynamics* and *Properties of Liquids and Gases* by Prausnitz, *Separation Processes* by King, *Process Fluid Mechanics* by Denn, *Biochemical Engineering* by Blanch and Clark, and *Introduction to Chemical Engineering* by Reimer. The faculty's excellence in teaching has been recognized by numerous campus awards, including four Distinguished Teaching Awards. Faculty from all departments on the Berkeley campus are eligible for this award, and only three distinguished teachers are chosen each year.

Our commitment to teaching has continued to inspire the next generation of teachers. Fifteen percent of the current fac-

The Emergence of High-Technology Industries

Berkeley has developed research areas on the frontiers of chemical engineering. A Berkeley PhD, Andy Grove (1963), together with Gordon Moore (BS Chemistry, 1950) and Robert Noyce, founded the Intel Corporation. The growing importance of the semiconductor manufacturing industry led to Dennis Hess joining the department in 1977, and he initiated collaborations that were critical in the expanding role that chemical engineers have continued to play in many areas of electronic materials processing.

The proximity of Silicon Valley was a distinct advantage for the development of the program at Berkeley, and opportunities for undergraduate and graduate student employment increased. Today, nearly one-third of the students at all degree levels find employment in electronics materials processing. This area has been strengthened at Berkeley by the addition of David Graves (in 1986), with his interests in plasma processing and Roya Maboudian (in 1993), who studies surface processes occurring during electronic-materials processing (especially MEMS technologies). Jeff Reimer's research has complemented the research program in electronic materials. At the undergraduate level, Lee Donaghey first developed an elective course in electronic materials processing in 1970. Subsequently, Hess and then Graves expanded the course, which has become a key component of the options program in chemical engineering.

The second area to benefit from Berkeley's location was biochemical engineering. Charlie Wilke turned his research effort from diffusion and mass transfer to this new field in the 1960s. His early studies on the kinetics of microbial growth and gas-liquid mass transfer provided the engineering underpinnings for the revolution in molecular biology that was to come. The advent of recombinant DNA and cell fusion (hybridoma) technology in the mid-1970s led to tremendous opportunities for the production of new, high-value therapeutic proteins and specialty chemicals. The Bay Area soon became home to start-up companies such as Cetus, Chiron, and Genentech. The department's research in this area expanded with the addition of Harvey Blanch in 1978, Douglas Clark in 1986, Jay Keasling in 1992, and David Schaffer in 1999.

The biochemical engineering program is now one of the largest in the United States. Jay Keasling introduced environmental biotechnology to the undergraduate curriculum, highlighting the increasing role of biological routes to environmental remediation.

Environmental engineering has also become a leading career option for BS graduates. Jay Keasling has developed a major program in synthetic biology. David Schaffer has brought cutting-edge biomedical research to the department, developing vectors for gene delivery. Arup Chakraborty's work on how cells in the immune system communicate and Clay Radke's interest in contact lenses are two other examples of biomedical research in Berkeley's Chemical Engineering Department.

In recent years, many new technologies have emerged that require advance materials with specific functionality. Precise control of these properties requires a detailed knowledge of the molecular constitution and mesoscopic structure of the material. Berkeley's Chemical Engineering Department has been able to capitalize on the strengths of the Chemistry Department and develop collaborations that elucidate the relationship between materials structure and their function. Synthesis, quantum and statistical mechanical theory, and characterization are being employed by several groups to develop novel catalytic and polymeric materials (*e.g.,* Balsara, Bell, Chakraborty, Katz, Iglesia, Muller, Reimer, Segalman).

ulty at MIT and 18% of the faculty at Cal Tech received their PhDs from Berkeley's Department of Chemical Engineering.

THE GRADUATE PROGRAM

Both the MS and PhD degrees in chemical engineering are granted, but a preponderance of graduate students pursue the PhD. The central focus of graduate education is research conducted under the supervision of a faculty advisor. The faculty-advisee relationship is truly collaborative and is one of the most enriching aspects of graduate (and, indeed, faculty) life at Berkeley. As noted earlier, the chemical engineering faculty has contributed to the emergence of a number of different areas that are now considered quintessential chemical engineering. Research areas represented in the department today can be broadly classified as shown in Figure 1.

Professor David Schaffer and graduate student Karen Lai working on an I-cycler, a quantative PCR machine.

A special feature of a chemical engineering education at Berkeley is that a deep knowledge of phenomenological concepts pertinent to transport phenomena, reaction kinetics, and thermodynamics is buttressed by a strong foundation in the underlying molecular phenomena. Thus, experimental methods such as scattering and spectroscopy, and the conceptual frameworks of statistical and quantum mechanics, are as much a part of the basic tools in the arsenal of a PhD chemical engineer as are continuum models, macroscopic reaction studies, and measurements of macroscopic mechanical properties of materials. As shown in Figure 2, graduate research at Berkeley can be viewed as bringing to bear the chemical engineer's rare ability to think across molecular, mesoscopic, and macroscopic scales to develop knowledge that can aid the development of new technologies and discover new phenomena in the related sciences.

Research in areas pertinent to biotechnology and microelectronics processing are facilitated by our geographical location. The San Francisco Bay area is a hotbed for biomedical research and companies focused on developing new biochemical and microelectronic products, and there are many collaborations between research groups in the department and these companies.

Another facilitator of research in biological engineering has been the establishment of an institute called QB3, a multidisciplinary institute that involves the Berkeley campus and the U.C. San Francisco Medical School. QB3 aims to bring leading scientists and engineers on the Berkeley campus together with medical researchers at UCSF Medical School to help solve important problems in biomedicine. Three faculty in the Chemical Engineering Department have appointments in QB3.

Several faculty in the department are working to develop materials that can function with precision. Such materials, particularly those that can carry out functions in response to changes in external stimuli, are important components of many emerging technologies. The way to make such materials is to learn how to manipulate molecular components such that the desired function is obtained. Strong and collaborative research programs exist in the department wherein synthesis, characterization, and theory are brought together to design new catalytic and polymeric materials as well as those pertinent to microelectronics and MEMS technologies. In this regard, graduate students in the department benefit from strong synergies with the Department of Chemistry as well as the Molecular Foundry at LBNL. The Molecular Foundry is a new national facility with the aim of developing "designer" materials by manipulating molecular-scale phenomena. Two centers of excellence—the Center for Catalysis and the Center for Biochemical Engineering—further foster collaborative research.

Chemical engineering draws from various areas and is perhaps the broadest of all engineering disciplines. Preparing students to meet today's challenges for energy-efficient processes, pollution abatement, and rapid translation of chemical and biological discoveries into products and processes requires faculty dedication to research and teaching. This kind of dedication assures that Berkeley graduates will continue to contribute to the solution of important societal problems.

Future chemical engineering students will need skills not even contemplated when the department was founded. The Berkeley Chemical Engineering Department has been traditionally at the forefront in new fields and will remain so through research that challenges the boundaries of contemporary science and engineering.

Acknowledgments: *We thank all faculty colleagues in the department and Yvette Subramanian for helping us write this article.* ❐