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A History of Berkeley Chemical Engineering: Pairing Engineering and Science

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A HISTORY OF BERKELEY CHEMICAL ENGINEERING:

PAIRING ENGINEERING AND SCIENCE

C. JUDSON KING

A HISTORY OF BERKELEY CHEMICAL ENGINEERING:

PAIRING ENGINEERING AND SCIENCE

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PREFACE

Chemical Engineering at the University of California, Berkeley has an unusual history among chemical engineering programs in the United States and also has become one of the most respected departments in that area. The effort toward creating a history of the department was started in 2006 at the impetus of Chair Jeffrey Reimer of the Department of Chemical Engineering working with Professor Cathryn Carson of the History Department, with research and collection of materials being carried out during the period from 2006 to 2014 by a succession of graduate students – Elizabeth Popp Berman, Elif Kale-Lostuvali, James Anderson, James Skee, and Michael Hahn. The material thereby gathered and analyzed was immensely valuable to me as I picked the project up in 2018 and brought their material together with oral histories, my own experiences and resources, and other sources.

This work is intended to be a history of the department as an organization and institution, and not biographies of individuals *per se*. Hence emphasis is on ways in which circumstances, policies, and contributions of individuals and groups of individuals built the department and its reputation. Although there is an appendix listing some of the broader faculty recognitions, there is no effort to give a comprehensive list of faculty awards and involvement in various activities, which are indeed myriad. Attention is somewhat greater to the years up to 1981 than for subsequent years both because of a goal to analyze what was formative and because my own career went into higher administration as I became Dean of the College of Chemistry in 1981. My absence from the department during my years of higher administration may well have led to some errors of omission or confusion, for which I take full responsibility.

There are numerous supporting citations and references. Since many of those are internet-based and it is important that they be continually accessible to readers, I have used Perma.cc to place these references in permanent form.

The Perma.cc references also refer to original web pages, which reader can pursue for purposes such as links to other web pages. Since several of the reference sources are repeated often, there is also in Appendix G a list of General References, to which some of the footnotes refer. A footnote giving just the author's name and publication year refers to a reference in Appendix G. A particularly valuable source with regard to the early years when the organizational location of chemical engineering within the campus was being resolved is a set of documents and copies of correspondence collected by Kenneth Pitzer, denoted in the references as the Pitzer file. It, other supporting materials, and general historical information on the Department of Chemical and Biomolecular Engineering are maintained in the office of the Chief Administrative Officer of the CBE department, currently Kim Eastman.

I want to express gratitude to Jeffrey Reimer, John Prausnitz, and Marge D'Wylde for encouraging me to undertake the project and being helpful throughout.   The two editors of the *Gilman Hall Newsletter*, Michael Williams and the late Alan Foss, sustained a tally of vital information from 1976 to 1991 that would otherwise have been lost. Alan Foss In addition to them, I thank Steven Sciamanna , Paul Bryan, Alex Bell, Clayton Radke, Susan Muller, and Nitash Balsara for recollections and valuable review comments. Geralyn Unterberg provided excellent copy-editing services, which I much appreciate. Finally, I want to express my gratitude to the entire Department of Chemical (and now Biomolecular) Engineering as a very supportive environment for my University of California professorial career, which has now extended over fifty-seven years. As for everything during all aspects of my career and our now sixty-three years of marriage, my wife Jeanne has been a vital partner.

C. Judson King

Kensington, CA
August 2020

ORIGINS OF CHEMICAL ENGINEERING

The field of chemical engineering had its origins in the latter parts of the nineteenth century and gained coherence and definition in the first two decades of the twentieth century. The early history of the discipline is described by Scriven[1] with additional perspectives by Reynolds[2] and Van Antwerpen.[3] In essence, more sophisticated and complex methods for production of commodity chemicals created a need for chemistry-oriented engineers and industrially-minded chemists. Two of the early chemical processes bringing about these needs were the contact process for manufacture of sulfuric acid that was developed during the 19th century and the Solvay Process developed in the 1860s for producing sodium carbonate. The engineers were initially for the most part mechanical engineers, but then interests grew in professionals who were hybrids of chemists and engineers. The development of the automobile in the late 1800s and early 1900s and the consequent growing needs for petroleum products intensified these needs.

The new field became codified and recognized through professional societies, instructional curricula, books, and research. In 1881, leaders of the British chemical industry formed the Society of Chemical Industry and in 1886 defined its mission as being to support the "conversion of laboratory processes into industrial ones."[4] In 1888, Lewis Norton at MIT initiated the first recognized academic program in chemical engineering, consisting of a mechanical engineering curriculum modified to include some courses in industrial chemistry. This program and ones that followed it in the ensuing decade at institutions such as the University of Pennsylvania, Tulane, the University of Michigan, and Tufts were based largely on descriptive discussions of individual

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[1] Scriven, 1991. (See Appendix G, General References when reference is denoted in this way without author initials.)
[2] T. S. Reynolds, "Defining Professional Boundaries: Chemical Engineering in the Early 20th Century," *Technology and Culture* 27 (1986),pp. 699-701.
[3] F. J. Van Antwerpen, "The Origins of Chemical Engineering," pp. 1-14 in *History of Chemical Engineering*, W. F. Furter, ed., *Advances in Chemistry*, American Chemical Society, Washington, DC, 1980.
[4] Scriven, 1991.

chemical processes and methods for scaling them up.[5] An early handbook was that of George E. Davis,[6] based upon lectures that he had given in Manchester in the mid-1880s. It was also the first prominent use of the name "chemical engineering." The American Institute of Chemical Engineers started in 1908.

Academic research was begun, most notably at MIT through the Research Laboratory of Applied Chemistry, which was launched in 1908 as a part of the pre-existing (1903) and well-respected Research Laboratory of Physical Chemistry. The Research Laboratory of Applied Chemistry was headed by William H. Walker, an early leader of the chemical engineering profession, while the Research Laboratory of Physical Chemistry was led by Alfred A. Noyes, a prominent chemist. As an aside important to both California and Berkeley chemistry and chemical engineering, strong animosity developed between Walker and Noyes, with Walker demanding that MIT President Richard Maclaurin remove Noyes from his position, or else Walker would resign. Since Maclaurin sought to build the institutional finances of MIT through relations with industry, he chose to remove Noyes and also made Walker head of a Division of Industrial Cooperation and Research.[7,8,9,10] Noyes consequently chose to relocate to what was then the Throop Institute of Technology in Pasadena, CA, and along with George Ellery Hale and Robert K. Millikan turned it into the California Institute of Technology (Caltech) that we know today. A

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[5] J. W. Westwater, "The Beginnings of Chemical Engineering Education in the USA," pp. 141-152 in *History of Chemical Engineering*, William F. Furter, ed., *Advances in Chemistry*, No. 190, American Chemical Society, Washington, DC, 1980.

[6] G. E. Davis, "A Handbook of Chemical Engineering," 2 vols., Davis Brothers, Manchester, England, 1901-02. Held by Othmer Library of Chemical History, Science History Institute, Philadelphia, PA. https://othmerlib.sciencehistory.org/record=b1006196~S6

[7] J. W. Servos, "The Industrial Relations of Science: Chemical Engineering at MIT, 1900-1939," *Isis*, *71*, No. 4, pp. 530-549 (1980).

[8] R. L. Geiger, *To Advance Knowledge: The Growth of American Research Universities, 1900-1940,* pp. 87-88, Oxford (1986).

[9] H. C. Weber, "The Improbable Achievement: Chemical Engineering at MIT," pp. 77-96 in W. F. Furter, ed., *History of Chemical Engineering*, in *Advances in Chemistry*, No. 190, American Chemical Society, Washington DC, 1980.

[10] King, 2018, pp. 257-258.

second departure from the Research Laboratory of Physical Chemistry was the noted young physical chemist Gilbert Newton Lewis, who, being put off by the disagreements and the removal of Noyes, accepted an offer from President Benjamin Ide Wheeler of the University of California to become Dean of the College of Chemistry at Berkeley, a position which he held for thirty years from 1912 to 1941 as he led it intellectually to world-wide distinction.[11]

In its early years the discipline of chemical engineering did not have many cohesive or powerful organizing concepts. In 1916, Arthur D. Little, a prominent consulting industrialist, member of the MIT Corporation, and Chair of its Visiting Committee[12] for Chemical Engineering, built upon ideas from Davis's *Handbook* and put forward the concept of "unit operations" in a Visiting Committee report to MIT, defining them as follows.

> "Chemical engineering is based on a series of chemical or physical operations (e.g., distillation, fluid flow, heat transfer, extraction) that, in their sequence and coordination, constitute a chemical process as conducted on the industrial scale. Operations such as grinding, extracting, roasting, crystallizing, drying, adsorbing, and so on, are not ordinarily the subject matter of chemistry or mechanical engineering. These operations are called unit operations because some, often most of them, are constituents of a typical industrial chemical process."[13]

Seeking to define the difference between this concept and what had become generally known as industrial chemistry, Little made a distinction between chemical processes and their component unit operations.

> "There should always be kept in mind the definite line of demarcation between industrial chemistry, which is concerned with individual processes as entities in themselves, and chemical engineering, which focuses attention upon those unit operations common to many

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[11] Jolly, 1987, pp. 47-76.
[12] MIT has a Visiting Committee for each academic discipline, composed of prominent practitioners and academicians from the field, reporting directly to the President as part of the governance structure.
[13] A. D. Little, quoted by Reynolds (Ref. 2), p. 709, 1986.

> processes and the proper grouping of these unit operations for the production of the desired product as efficiently and cheaply as the ruling conditions permit."[14]

The unit operations became the subject for standard textbooks and a primary organizing concept for chemical engineering for fifty years into the 1960s and beyond. The name "unit processes" was sometimes applied to the industrial chemistry end of the curriculum but did not become as strong an organizing concept as the unit operations.

One of the most prominent outgrowths of chemical engineering research in the 1930s was fluid-bed catalytic cracking, which came into industrial use early in World War II and was vitally important to the U. S. war effort. It was developed at the Standard Oil Development Company[15] through the consulting input of Warren K. Lewis and Edwin R. Gilliland of MIT.[16] With that, the tie between academic research in chemical engineering and the industrial economy became well recognized.

During World War II it had become apparent that more knowledge of basic science and applied mathematics and more ability to draw on them creatively would be useful for engineers in order to improve their abilities as innovators. For chemical engineering, primary drivers of this recognition were the needs for isotope separation and recovery and processing of radioactive materials encountered in the Manhattan Project. As we shall see, this issue was crucial for the determination of the organizational location for chemical engineering at Berkeley. Courses dealing with applied mathematics and science increased in chemical engineering programs at all levels at most institutions after the war. Within chemical engineering a leader in this regard was Neal Amundsen,[17] who

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[14] A. D. Little as quoted in M. M..
0 Denn, "The Identity of Our Profession," in *Perspectives in Chemical Engineering Research and Education*, C. K. Colton, ed., Academic Press, San Diego, CA, 1991.
[15] predecessor to today's Exxon.
[16] A. M. Squires, "The Story of Fluid Catalytic Cracking: The First 'Circulating Fluid Bed'", in Prabir Basu, ed., *Circulating Fluidized Bed Technolo*gy, pp. 1-19, Pergannon, 1985.
[17] Andreas Acrivos & Dan Luss, "Neal Russell Amundsen," Biographical Memoirs, National Academy of Sciences, https://perma.cc/S5JC-8D5A. Dan Luss & Arvind Varma,

developed the more fundamental approach as a hallmark of chemical engineering at the University of Minnesota in the 1950s and subsequently. Perhaps the single most important product of this approach was the book *Transport Phenomena*, published in 1960 by Robert Bird, Warren Stewart and Edwin Lightfoot of the University of Wisconsin. It served to place fluid dynamics, heat transfer, and mass transfer on a common intellectual basis as related to transports of momentum, heat, and matter.

DEVELOPING USES OF CHEMICAL ENGINEERING

The origins of chemical engineering related to the heavy-chemical[18] and petroleum industries. That fact was reflected in both the identification of the individual unit operations themselves and the employment opportunities for graduates. The concentration of chemical-engineering jobs into those two industrial categories also meant that the availability of employment for chemical engineering graduates was tied closely to the economic cycles of those industries. Economic "ups" meant more job openings than could be filled, and economic "downs" resulted in lay-offs and few jobs being open.

The arrival of more scientific bases for chemical engineering education and subjects of instruction such as transport phenomena, molecular thermodynamics, catalysis, and a more general approach to means of separating solutions and mixtures meant that the principles of chemical engineering became important for many more applications. Recognizing that spreading the use of chemical engineers to these broader areas would widen and stabilize employment and benefit the economy, the American Institute of Chemical Engineers chartered a study, "The Expanding Domain of Chemical Engineering," in the mid-1970s in an effort to stimulate this trend.[19] The use of

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"Neal R. Amundsen," *Memorial Tributes*, National Academy of Engineering, National Academies Press, *15*, 2011. https://www.nap.edu/read/13160/chapter/5

[18] i. e., chemicals with large production volumes.

[19] The author co-chaired this study with Sumner West of Rohm & Haas Corp. See C. J. King & A, S. West, "The Expanding Domain of Chemical Engineering," *Chem. Eng. Progr.*, 72, No. 3, 34 (1976). See also King, 2013, pp. 188-193.

chemical engineers in the wider scope of applications did not happen spontaneously for reasons of inertia, self-interests of the heavy-chemical and petroleum industries, and slow starts toward there becoming a critical mass of researchers and others interested.[20] Much of the story of chemical engineering at Berkeley has to do with its roles in spurring this movement.

On its web site, the American Institute of Chemical Engineers now observes,

> "It would take too long to list all the products that are impacted by chemical engineers, but knowing what industries employ them may help you comprehend the scope of their work. Chemical engineers work in manufacturing, pharmaceuticals, healthcare, design and construction, pulp and paper, petrochemicals, food processing, specialty chemicals, microelectronics, electronic and advanced materials, polymers, business services, biotechnology, and environmental health and safety industries, among others."[21]

THE INITIATION OF CHEMICAL ENGINEERING AT BERKELEY

There are several key and unique features of the development of chemical engineering at Berkeley.

- It was comparatively quite late in its start, with the eventual sustained chemical engineering program not being launched until after World War II.
- Chemical engineering became one of the two departments within a College of Chemistry, the other being Chemistry itself. By contrast, at nearly all other universities it is a department within a College or School

[20] Berkeley's Charles Tobias observed reflectively that "chemical engineering is, unfortunately, not a missionary field, and … not sufficiently concerned with the vast spectrum of chemical technology, which is way, way beyond petroleum processing and beyond the major products of the chemical process industries." (Tobias, 1995, pp. 16-17).

[21] American Institute of Chemical Engineers, "What Chemical Engineers Do." https://perma.cc/K6PJ-8NWQ

of Engineering. No other major U. S. university has a free-standing *College* of Chemistry.

- Before that structure became final at Berkeley, there was a decade-long struggle with a competing Process Engineering program within the College of Engineering.
- Berkeley chemical engineering has throughout its history had close ties with an adjacent national laboratory of the U. S. Department of Energy, a connection that does not exist to the same degree for any other similar department in the United States.
- The department achieved stature remarkably rapidly. Several faculty members received major awards during the early years of the program.
- Berkeley chemical engineering was an early entrant into several newer applications of chemical engineering, most notably microelectronics and biotechnology, both of which grew up to greater extents in the San Francisco Bay Area than elsewhere.

There were several antecedents to the eventual chemical engineering program at Berkeley. First, Frederick Cottrell[22] (Figure 1), a faculty member in chemistry from 1902 to 1911, was interested in industrial processes and achieved lasting fame as the inventor of the electrostatic precipitator, which is still the most widely used method for removing particulate matter from industrial exhaust gas streams. His original design of the electrostatic precipitator was to control mist emissions at the DuPont contact-process sulfuric acid plant in nearby Pinole, CA.[23] Cottrell went on to direct the U. S. Bureau of Mines and also formed the Research Corporation, to which he donated his patents on the electrostatic precipitator. The Research Corporation was a significant sponsor of university research for many years and managed other university patents as well.[24]

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[22] Vannevar Bush, "Frederick Gardner Cottrell, 1877-1948," Biographical Memoir, National Academy of Sciences, 1952. https://perma.cc/PRB5-J699

[23] Jolly, 1987, pp. 32-33.

[24] T. D. Cornell, *Establishing Research Corporation: A Case Study of Patents, Philanthropy, and Organized Research in Early Twentieth-Century America*, Research Corporation, Tucson, AZ, 2004.

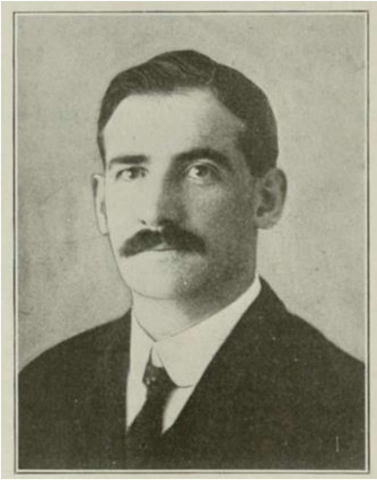

FIGURE 1. Frederick G. Cottrell, Berkeley Chemistry Faculty, 1903-11, Inventor of the Electrostatic Precipitator, founder of the Research Corporation, and Director, Bureau of Mines (Wikimedia Commons).

Second, in 1912, Gilbert N. Lewis upon becoming dean of the College of Chemistry instituted a chemical technology major, of which Merle Randall, who had come with Lewis from MIT to Berkeley, became director. This program took an industrial-chemistry approach, and remained small and relatively unorganized and unsupported, reflecting the low priority given by Lewis to applications of chemistry and industrial uses, perhaps as a consequence of the Walker-Noyes controversies that Lewis had experienced at MIT before coming to Berkeley. Randall retired in 1944, and the chemical engineering program started in 1946 was *de novo* rather than being an extension, enlargement, or reorientation of Randall's program.

Third, in 1942,[25] Donald McLaughlin and Llewellyn M. K. Boelter of the College of Engineering, Wendell Latimer and Merle Randall of the College of Chemistry, and others formed a Graduate Group[26] to offer the M.S. degree in chemical

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[25] It is significant that this occurred soon after (rather than before) Lewis left the deanship in 1941.

[26] Graduate Groups are a mechanism used by the University of California to enable degrees in newer or multidisciplinary fields, usually staffed by existing faculty without additional resources.

engineering.[27] This program was hampered by lack of dedicated resources, contentions between the two colleges reinforced by the involvement of the deans of both colleges (McLaughlin and Latimer), and the 1944 departure of Boelter to become Dean of the new College of Engineering at UCLA.

The Budget Committee Weighs In. With Boelter's departure, the university undertook to devise a more substantial, functional, and permanent structure for chemical engineering. Both the College of Chemistry and the College of Engineering expressed desires to create the program. President Robert Gordon Sproul delegated resolution of the matter to Provost Monroe Deutsch.[28] Following established UC protocols of shared governance, Deutsch obtained the analysis and advice of the Academic Senate Committee on Budget and Interdepartmental Relations (CBIR), known familiarly as the Budget Committee. The advice[29] of that committee was to establish the new program within the College of Chemistry. The rationale was that the College of Chemistry could provide students with greater insights into underlying scientific phenomena and thereby give them broader and more capable approaches toward meeting engineering needs creatively; they could go where conventional engineers of the time would fear or not be able to tread.

This argument was a manifestation of the particular times. Since it was immediately after World War II the successes of the major, rush technological projects of wartime such as the Manhattan Project (atomic bomb) and the Radiation Laboratory[30] at MIT (the development of radar) were fresh in peoples' minds. One striking feature of those projects was that they were carried out almost totally by stellar young scientists, not by engineers, even though the developments in the projects heavily involved engineering. One reason for this

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[27] Vermeulen, 1967.

[28] I. M. Linforth, B. H. Lehman & E. C. Tolman, "Monroe Emanuel Deutsch, Classics: Los Angeles and Systemwide," *In Memoriam*, University of California, 1958. https://perma.cc/933F-E8VR

[29] Minutes of Budget Committee Meeting of November 28, 1945, University of California Berkeley. Contained in materials given by Kenneth Pitzer to the College of Chemistry, hereafter designated "Pitzer file."

[30] So named by Ernest Lawrence after his laboratory at Berkeley. The seemingly unrelated name was chosen to provide a cover of secrecy.

seemingly odd fact was that the education of engineers, at the time, had only limited breadth and depth of coverage of underlying science and hence did not have much tradition of either methodology or research based upon fundamental science. The Budget Committee advisory memo specifically cited passages from an editorial, "Longhairs vs. Hairy Ears,"[31] from the then-current issue of *Fortune* that contended that it was the breadth and depth of knowledge of scientists, along with their creativity and their ability and willingness to think far afield, that enabled the successes of these projects in so short a time. It contended that engineering education was not providing those capabilities to engineers. The passages from that editorial cited by the Budget Committee are given in their entirety in Appendix A along with my own commentary and an analysis of the implications for engineering education.[32]

A companion article[33] in the same issue of *Fortune* explored these issues for the specific case of the development of microwave radar at the MIT Radiation Laboratory. The contention was that engineers would not have had the knowledge to enable them to come up with the outside-the-box solutions that were needed, and that they would as well have been limited by inherent conservatism. The implications of both the article and the editorial were that

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[31] "Longhairs vs. Hairy Ears," *Fortune*, v. 32, no. 5, p. 115, November 1945. The term "hairy ears" derives from an old-time ditty pertaining to the U. S. Army Engineers beginning "The engineers have hairy ears and live in caves and ditches," and proceeding on through other, often unprintable lyrics.

[32] Professor Joel Hildebrand of Chemistry was then a current, but also long-time and respected, member of CBIR and was also a close and trusted associate of UC President Robert Sproul [King, 2018, pp. 174, 261-262, 422-423]. He was a principal in the so-called Berkeley Revolution of 1919 that established the roles of the Academic Senate, and he was influential in defining the criteria for academic advancement of the faculty through intense periodic reviews of their work. The CBIR minute states, "Mr. Hildebrand absented himself from the conference with the Provost and from the final consideration of this memorandum." However, Hildebrand had transmitted the same excerpt from the *Fortune* editorial to President Sproul with a cover memo on November 7, 1945, three weeks before the CBIR minute (memo in Pitzer file). Thus, he had a substantial influence on both the Budget Committee and the administration.

[33] "Longhairs and Short Waves," *Fortune*, v. 32, no. 5, pp. 162-169, 206, 208, November 1945.

these factors would apply to other situations in the future where rapid development of technology would be desirable, and that industrial progress would be well served by efforts to increase the science and mathematics contents of engineering education considerably. Views such as these formed much of the impetus for the introduction of more mathematics and science into engineering education after World War II.

This issue, although attuned to the times immediately following World War II, has in various ways pervaded the entire history of chemical engineering at Berkeley, in matters such as the selection of faculty, the design of the curriculum, identification of desirable fields of research, and interactions with other disciplines.

Dueling Programs. In December 1945, Provost Deutsch informed the two deans of his decision to place chemical engineering in the College of Chemistry, stating that he recognized that the decision to place Chemical Engineering administratively with Chemistry was an unusual one.[34,35] Deutsch's decision was quickly challenged by Morrough (Mike) O'Brien, who had become Dean of Engineering in 1943.[36] A letter from Deutsch to President Sproul describes O'Brien coming to him "in considerable of a state."[37] O'Brien made a counterproposal to Sproul in which the discipline of chemical engineering would be divided by subfield, with the College of Engineering taking responsibility for

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[34] See M. E. Deutsch to R. G. Sproul, 22 August 1945, 12 November 1945, and 11 December 1945 [Pitzer file].

[35] The only other major universities in the U. S. where chemistry and chemical engineering are together organizationally are the University of Illinois at Urbana-Champaign where the two departments compose the School of Chemical Sciences and Caltech where there is a Division of Chemistry and Chemical Engineering. Two universities in Sweden, Uppsala and Lund, have had similar College organizations in the past, but both of those appear now to have been reorganized.

[36] In addition to the territorial aspect, O'Brien may have been driven by perceptions of the slight of engineering implied in the arguments used by the Budget Committee.

[37] See M. E. Deutsch to R. G. Sproul, 19 December 1945, from Pitzer file. O'Brien's own oral history gives a good sense of his personality ["Morrough P. O'Brien: Dean of the College of Engineering, Pioneer in Coastal Engineering, and Consultant to General Electric," Regional Oral History Office, University of California, Berkeley, 1986. https://perma.cc/4JS3-F5ZT]

"the unit operations of process engineering" and the College of Chemistry taking responsibility for "the unit processes of industrial chemistry."[38] This would have put the principal disciplinary aspects at the time (unit operations) within Engineering. In an effort to resolve the matter, Deutsch then authorized a degree-granting program in Process Engineering within the College of Engineering, while sustaining the placement of the Chemical Engineering Program itself, with that name, within the College of Chemistry.[39] The two programs coexisted uncomfortably for a decade. The Process Engineering faculty within the Department of Mechanical Engineering consisted of several members and was led by Professor Richard G. Folsom,[40] who later became President of Rensselaer Polytechnic Institute. The Process Engineering program was positioned by O'Brien as being a discipline in between Chemical Engineering and Mechanical Engineering, but such a distinction appears artificial and both was and is not consistent with any program designations elsewhere.

The university requested engineering accreditation for both programs. The initial visits in 1949 resulted in a careful analysis of the situation along with an indication that no actions would be taken until the university itself sorted things out.[41] A subsequent request in 1952 resulted in accreditation of both programs for two years only, with comments by the accrediting agency on Chemical Engineering that were more positive than those on Process Engineering, and again with the expectation that the university would resolve the matter of conflicting programs.

Clark Kerr and Earl Parker. When Clark Kerr (Figure 2) became the first Chancellor of the Berkeley campus in 1952, he entered a newly formed office as administrative head of the Berkeley campus, but for which university-wide President Sproul had created no job description and made hardly any

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[38] See M. P. O'Brien to R. G. Sproul, 22 February 1946, from Pitzer file.

[39] See April 17, 1946 Deutsch to O'Brien and CBIR memo in response to President Sproul's request of November 8, 1949, both from Pitzer file.

[40] "Rensselaer President Richard Gilman Folsom," Institute Archives and Special Collections, Rensselaer Polytechnic Institute. https://perma.cc/G9BZ-23ZC

[41] See CBIR memo in response to Sproul request of Nov. 8, 1949, from Pitzer file. Also E. B. Christiansen, faculty member at the University of Utah and member of 1949 accrediting team, personal communication to the author, Spring 1978.

delegations. Kerr was left to define his job himself and did so by emphasizing issues of planning.[42] Kerr thereby reopened the matter of overlapping programs in chemical/process engineering to gain an ultimate resolution. He began with a memo[43] to Deans Pitzer (College of Chemistry) and O'Brien (College of Engineering) in January 1953 seeking answers from both to two questions, "To what extent and in what ways is Process Engineering a distinct discipline from Chemical Engineering?" and "To what extent do the Chemical Engineering curriculum and the Process Engineering curriculum parallel one another on the undergraduate level?". The responses were shared with the Academic Senate Committee on Budget and Interdepartmental Relations for advice. This time the CBIR response[44] was to retain the two separate programs in the separate colleges. The matter was then taken up by the Engineering Advisory Council[45] of the University of California, which in April 1954 urged consolidation into a single Chemical Engineering program within the College of Engineering.[46]

FIGURE 2. The author and his spouse Jeanne on either side of Clark Kerr, who guided and made the ultimate decision for the placement of Chemical Engineering in the College of Chemistry. Photograph taken in Taiwan, 1983.

[42] Kerr, 2001, pp. 40-47, 56-128.
[43] Clark Kerr to K. S. Pitzer and M. P. O'Brien, January 16, 1953, from Pitzer file.
[44] CBIR Minutes, May 29, 1953, from Pitzer file. Hildebrand was no longer on the committee.
[45] A body of prominent California engineers, reporting at the university-wide level. This Council no longer exists.
[46] G. C. Tenney memo to Chancellor Clark Kerr, April 29, 1954. From Pitzer file.

Chancellor Kerr then in December 1954 chose to put the matter to an *ad-hoc* multidisciplinary faculty Joint Committee on Chemical and Process Engineering,[47] which was chaired by Professor Francis Jenkins of Physics. During the deliberations of that committee, Earl Parker, Chairman of the Division of Mineral Technology within the College of Engineering, proposed that Process Engineering be placed in the Division of Mineral Technology to form two programs denoted Process Engineering (Petroleum Processing) and Process Engineering (Process Metallurgy), subjects which already had strength within that department.[48] Parker was added to the Joint Committee and deliberations went in the direction that he had proposed. Jolly[49] cites Charles Wilke as concluding that the solution was "due to the good will and cooperative attitude of Earl Parker." Kerr accepted the advice from the Joint Committee. As of January 1957 Chemical Engineering became a department in the College of Chemistry, on an organizational parallel with the Department of Chemistry.

Yet another factor was that, perhaps because of the actual name "chemical engineering" being on the College of Chemistry program, student enrollments were much greater there than for Process Engineering, by a factor as great as ten.[50] John Prausnitz, a new faculty member at the time, cites Kerr as having said that "the students voted with their feet."[51]

While Parker had much to do with the resolution of the matter, it was Kerr who made the ultimate decision and who steered the process to recover from the contrary advice of CBIR and the Engineering Advisory Council. Kerr notes that O'Brien "was, however, very unhappy that I decided to leave chemical engineering in the College of Chemistry where it had an outstanding record and where its faculty members were very satisfied. A hot dispute, but Mike reluctantly accepted my decision."[52] Kerr further noted his academic respect for the College of Chemistry as follows.

[47] Kerr to O'Brien and Pitzer, December 14, 1954, from Pitzer file.
[48] E. R. Parker to M. P. O'Brien, December 12, 1955, from Pitzer file.
[49] W. L. Jolly, 1987, p. 201.
[50] Jolly, 1987, pp. 200-201.
[51] Prausnitz, 2020, p. 38.
[52] Kerr, 2001, p. 66.

> "Chemistry was a "college," not a department, as it remains to this day (with two departments in it – chemistry and chemical engineering). It has been, and still is, in my judgment, the outstanding unit within the University of California – superb in research, superb in the teaching of both undergraduate and graduate students, and superb in the contributions of its faculty to university governance."[53]

Those chemistry faculty members who most visibly sought and enabled the inclusion of chemical engineering in the College of Chemistry are shown in Figure 3.

THE INITIAL YEARS: A RAPID RISE TO DISTINCTION

The First Faculty. Dean Wendell Latimer hired Philip Schutz as Associate Professor to lead the new Division of Chemical Engineering within the College of Chemistry. Schutz had been a research assistant with G. N. Lewis, had obtained his PhD in Chemistry at Berkeley under the tutelage of Latimer, and had then been a chemical engineering faculty member at Columbia University. LeRoy Bromley and Charles Wilke were hired as Instructors to join him, and formal instruction in chemical engineering began in the College in the fall of 1946. During his PhD program at the University of Wisconsin Wilke had switched from his original field of chemistry to chemical engineering. He had originally applied to the College of Engineering at Berkeley for a faculty position and been offered an assistant professorship there before receiving a telegram "stating that 'interdepartmental relations negate the possibility of appointment.'" He then wrote to Latimer, who invited him for an interview and hired him on the spot in the College of Chemistry.[54]

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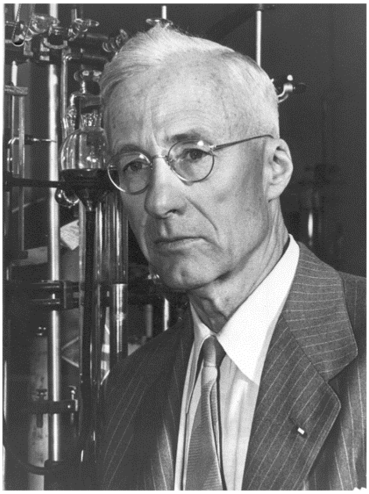
[53] Kerr, 2001, p. 61.
[54] Jolly, 1987, p. 179. Charles R. Wilke, autobiographical sketch in *Gilman Hall Newsletter*, June 1978.



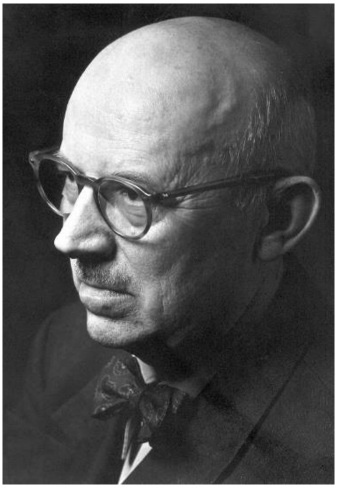
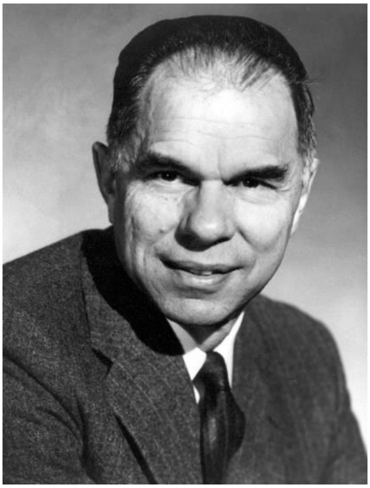


FIGURE 3. Berkeley Chemistry Faculty Members with Important Roles in Placing Chemical Engineering in the College of Chemistry

(from College of Chemistry Photo Archive)

Joel Hildebrand (upper left)
Wendell Latimer (upper right)
Kenneth Pitzer (lower left)
Glenn Seaborg (lower right)



Bromley came to Berkeley in 1943 to work as a research assistant with Chemistry Professors Leo Brewer and Wendell Latimer on aspects of the Manhattan Project. He became an instructor in chemical engineering while still working on his dissertation, and an assistant professor upon receiving his PhD in physical chemistry. His research focused on heat transfer in condensation and boiling. Thus, two of the three initial faculty members were proteges of Lewis or Latimer, and all three had backgrounds in chemistry. These facts may again reflect aspects of the argument cited by the Budget Committee in its 1945 recommendation that chemical engineering be placed in the College of chemistry, and/or it may reflect the desire of the College of Chemistry principals to hire persons whose work was well known to them.

Schutz, however, developed kidney cancer late that year and tragically died in February 1947.[55] Theodore Vermeulen was brought in from Shell Development Company that same month to replace him as director of the program, having been recruited by Dean Wendell Latimer with the support of Joel Hildebrand and Kenneth Pitzer. Vermeulen, too, had a background in chemistry, having been the recipient of the first Chemistry PhD given by the University of California at Los Angeles (UCLA).[56] He was recruited by Latimer to replace Schutz on the basis of recommendations from Kenneth Pitzer, who had known of Vermeulen from Chemistry Professor Charles Coryell at UCLA, a prominent Manhattan Project chemistry figure, and through Caltech chemical engineering faculty member William Lacey, who in turn had been an early G. N. Lewis PhD graduate from Berkeley (see also Appendix A).[57,58] Charles Tobias (see below)

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[55] Jolly, 1987, p. 200.

[56] C. R. Wilke, D. N. Hanson, K. S. Pitzer, C. W. Tobias, "Theodore Vermeulen, Chemical Engineering: Berkeley," In Memoriam, University of California, 1985. https://perma.cc/R8VR-SDTZ

[57] Jolly 1987, p. 180. See also "Records of the College of Chemistry," Box 7, "Robert Sproul" folder, 21 January 1947 letter from Joel Hildebrand to Robert Sproul: "I am greatly pleased just now, also, that we have been able to meet the serious emergency caused by the prospective loss of Schutz by persuading Vermeulen to join our staff. We have had our eyes on him for over a year, for he has a fine background, an alert mind and a twinkle in his eye."

[58] Note that Pitzer, Lacey, and Coryell were all noted chemists.

and Donald Hanson,[59] who also came from Shell Development Company, joined the department in the fall of 1947.[60] The program was approved to grant the PhD and B.S. degrees in 1947 and 1948, respectively, and in 1949 the Department of Chemistry was renamed the Department of Chemistry and Chemical Engineering.[61] Vermeulen, Wilke, Bromley, Hanson and Tobias (Figures 4 and 5) became recognized as the Founding Five for Berkeley chemical engineering.

FIGURE 4. William Corcoran (long-time Caltech faculty member) together with Don Hanson and Ted Vermeulen at State College Airport, in connection with the American Society for Engineering Education Annual Conference at Penn State, June 1955.

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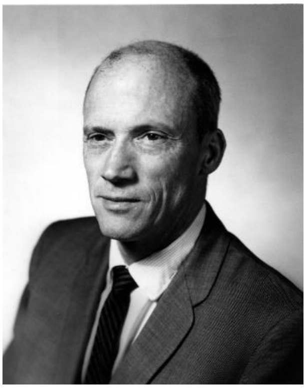
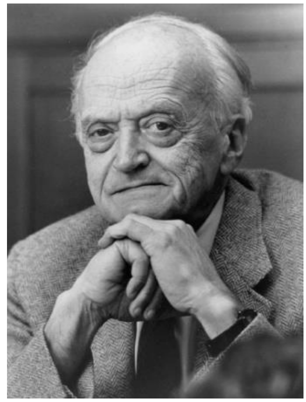
[59] A. T. Bell, C. J. King, J. S. Newman, "In Memoriam, Donald N. Hanson, 1918-2007," University of California, Berkeley. https://perma.cc/RJ5P-PR4U

[60] Vermeulen, 1967, p. 82. Two other early faculty members who stayed only a few years each were F. Campbell Williams (see Jolly, *loc. cit*., pp. 186-188) and Kenneth F. Gordon.

[61] Vermeulen, 1967, p. 82.





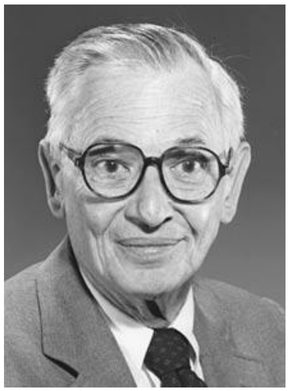


FIGURE 5. The Founding Five Faculty Members – LeRoy Bromley (upper left), Charles Tobias (upper right), Donald Hanson (center), Theodore Vermeulen (lower left), and Charles Wilke (lower right).

Some of the quaint working conditions for the early faculty members, which became folklore as the years went on, are described in the following passage from Jolly.[62]

> "At first, working conditions were fairly primitive. Wilke and Bromley shared an office on the second floor of Gilman Hall. They had no telephone. Calls would come into Miss Kittredge[63] on the first floor, and she would sound a buzzer in their office so that they could dash down to answer the call. However, as the administrative head, Vermeulen enjoyed his private phone. There were no secretaries, and he hated to miss a call. So, he always left his office door open and got so that he could detect his phone ringing from almost anywhere on the floor in time to run and answer it."

The department gained stature within the world of chemical engineering at a strikingly rapid pace. In the 1964 Cartter survey of the American Council on Education, seventeen years after its founding, the department was already ranked fourth in the United States for Effectiveness of Graduate Program and fifth for Quality of Graduate Faculty.[64] That ranking would become yet higher in subsequent surveys. Perhaps even more striking, two of the initial faculty members, Wilke (1951) and Bromley (1953), won the Allan P. Colburn Award of the American Institute of Chemical Engineers for excellence in publications by a member of the Institute under 35 years of age.[65] They were followed soon in the same award by John Prausnitz (1962). The William H. Walker Award of AIChE for excellence in contributions to chemical engineering literature was won in the earlier years by Wilke (1965), Prausnitz (1967), Vermeulen (1971), and King (1976). The awards performance of the faculty over the years has remained very strong.

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[62] Jolly, 1987, p. 200.

[63] Mabel Kittredge, later Mabel Kittredge Wilson, the long-time decanal assistant of the college, viewed during the days when Lewis was dean as having large administrative power.

[64] A. M. Cartter, *An Assessment of Quality in Graduate Education*, pp. 70-71, American Council on Education, Washington DC, 1966. (The actual survey was conducted in 1964.)

[65] Now changed to no more than twelve years beyond the highest academic degree.

Institutional and Environmental Factors. While the recognitions described in the previous paragraph relate to personal accomplishments, it is also important to recognize institutional factors that were influential and supportive for the rapid development of the stature of the department. Some of them are the following.

- **The post-World War II confluence of favorable factors for the University of California.** These include the state of California coming out of World War II with budgetary surplus equal to roughly a year's budget, a major post-war population surge through immigration to California from other states, a University of California enrollment surge of returning veterans bringing with them large financial support from the GI Bill, two foresighted and highly supportive long-time Governors – Earl Warren (1943-53) and Pat Brown(1959-67) – who established public higher education as a top priority for the state, a University of California president (Clark Kerr) who was an excellent long-term planner, and ultimately the 1960 California Master Plan for Higher Education which matched the primary research mission for the state with the University of California. Thus, the time at which chemical engineering was fully launched was a prime period for resources and support of the university.
- **The academic quality-control practices of the University of California.** In a separate book I have analyzed the institutional factors that brought about such a high academic stature for the Berkeley campus and the University of California as a whole.[66] One of these is a very structured and successful form of shared governance between the administration and the faculty Academic Senate. Working heavily through the Senate, there are intensive, career-long advancement reviews of individual faculty members, providing clear incentive for academic accomplishments and excellence. There are similar, periodic reviews of academic programs. The Academic Senate provides a continual outlook of academic quality control and enhancement thereby sustaining a culture of excellence that pervades all university academic activities.

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[66] King, 2018.

- **The stature, services, and practices of the College of Chemistry.** The College of Chemistry had developed world-wide eminence through its scientific accomplishments during the thirty-year deanship of Gilbert Lewis, 1912-1942. It had developed many internal practices that furthered the research mission. It had also honed approaches for locating and hiring faculty members who were outstanding in research. Many of those hired were Berkeley graduates, who had been observed and evaluated thoroughly. Schutz and Bromley were in that category among the original faculty members for chemical engineering. Another major benefit of the location in the College of Chemistry was the existence of very strong shops and services in support of research. These include the glass shop, machine shop, wood shop, electronics shop, micro-analytical laboratory (from the days of the Manhattan Project), NMR (Nuclear Magnetic Resonance) laboratory, mass spectrometry laboratory, X-ray crystallography laboratory, and now molecular graphics and computation. These facilities outshone what was available to most other chemical engineering departments.
- **Close ties with the neighboring national laboratory.** Glenn Seaborg headed the Nuclear Chemistry Division of the Lawrence Berkeley Laboratory,[67] which adjoins the campus atop the "Hill" to the east. Through that division he and co-workers carried out their well-recognized research creating and identifying new, man-made chemical elements. A strong supporter of the new chemical engineering program, Seaborg made available a small percentage of his budget from the Atomic Energy Commission (AEC) to support research by members

[67] The laboratory has had various names over the years. Starting with its founding in 1931, it was originally the Radiation Laboratory ("Radlab"), or more formally the University of California Radiation Laboratory (UCRL). Upon the death of Ernest Lawrence in 1959 it was renamed the Lawrence Radiation Laboratory (LRL). With the separation of the Lawrence Livermore Laboratory from the laboratory administratively in 1971, the Berkeley laboratory became the Lawrence Berkeley Laboratory (LBL), and then in 1995 the Lawrence Berkeley National Laboratory (LBNL), in use contracted to Berkeley National Laboratory. Rather than matching the names to the dates under consideration, the name is cited as Lawrence Berkeley Laboratory, or LBL, throughout, so as to minimize confusion.

of the chemical engineering faculty, provided that the research pertained sufficiently to the interests of the AEC. This practice was begun as Seaborg became Associate Laboratory Director for Nuclear Chemistry in 1953 and continued through the subsequent Nuclear Chemistry Division directorship of Berkeley Chemistry professor Isadore Perlman beginning in 1958 and extending to the mid-1960s.

The Lawrence Berkeley Laboratory was initially devoted to the interests of Ernest Lawrence surrounding the cyclotron, which he had invented, and then to closely related subjects, such as the work of Seaborg and associates on the creation and identification of new heavy chemical elements, for which the cyclotron was key. In 1960-61 a new Inorganic Materials Research Division was formed to address materials needs for nuclear reactors and space vehicles. This activity grew and diversified to become important for support of the Tobias and Newman programs in electrochemical engineering and then the work of Bell and others in catalysis. In the early 1970s, with the Arab Oil Embargo and the rise of environmental concerns, an Energy and Environment Division of the laboratory was formed. That move was further reinforced by the conversion of the research portion of the Atomic Energy Commission into the Energy Research and Development Administration (ERDA) in 1975 and then the Department of Energy in 1977. The Energy and Environment Division (subsequently the Applied Sciences Division, and now distributed among divisions within Earth and Environmental Sciences, Energy Sciences, and Energy Technology) and subsequent programs in areas such as biotechnology and earth sciences have provided research opportunities for members of the faculty in many sub-fields of chemical engineering who can receive joint appointments with LBL.

- **The San Francisco Bay Area as the foremost high-tech incubator of the world.** After the Department of Chemical Engineering was established, the San Francisco Bay Area became the prime home for technological ventures in electronics and computing hardware and software (Silicon Valley) and the new biotechnology industry that arose as of the 1980s. Although department faculty members were not prominent in the originations of these two areas, graduates of the department were, and faculty members have developed very strong ties and made important contributions in subsequent years.

- **Shell Development Company.** Shell Development Company[68] was formed in nearby Emeryville, CA in 1928[69] and lasted there until it was moved to Houston TX in 1972 as the wave of consolidation and reduction of the large industrial research laboratories began. It was one of the premier industrial research laboratories in the golden age of such laboratories. Shell Development was well known and highly respected within chemical engineering circles and had significant roles as a source of early faculty members of the department (Vermeulen, Hanson), in bringing faculty members-to-be for recruiting visits to Shell Development and the Bay Area (Prausnitz), and as a source of both distinguished figures[70] and research accomplishments[71] in the field.

Faculty Research Directions. The research of the four of the original five Founding Faculty members was remarkably conventional chemical engineering despite the unusual affiliation of the program with the College of Chemistry and the chemistry backgrounds of three of them. Bromley continued research on heat transfer in boiling and condensation, eventually focusing upon evaporative desalination of sea water, including thermodynamic properties of electrolyte solutions. He spent the middle years of his faculty career working at field stations in La Jolla and at Bodega Bay on development of a multi-effect

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[68] Shell Development Emeryville, CA. *Wikipedia*, https://perma.cc/64NJ-LAYB.

[69] The proximity of the Berkeley College of Chemistry must have been a factor in the Emeryville site selection, since there is little other apparent rationale for what was, at the time, the rather remote west-coast U. S. location, other than the presence of Shell refineries in Martinez and Puget Sound and a distribution facility in Carson, CA.

[70] See, e. g., National Academy of Engineering Memorial Tributes to Mott Souders (https://perma.cc/RL68-NNCQ) and Thomas Baron (https://perma.cc/AP3E-KMVB).

[71] As but one example, one of the most influential early papers on the Marangoni Effect in chemical engineering came from Shell Development: C. V. Sternling & L. E. Scriven, "Interfacial Turbulence: Hydrodynamic Instability and the Marangoni Effect," *AIChE Jour*., v. 5, pp. 514-523, 1959.

centrifugal evaporator for conversion of sea water to fresh water.[72] His last research project before his 1976 retirement concerned the use of seawater to remove sulfur dioxide from stack gases. Wilke[73] undertook research over a broad range, mostly centered upon mass transfer and diffusion (core chemical engineering fields) but also including examinations of thermal diffusion[74] and the relatively new refining process of zone melting. In his later career he moved to what was then the very new field of biochemical engineering (see below). Hanson[75] developed methods for using digital computers, then in an early stage, for calculations of performance of multicomponent distillation and other multistage processes. He and his coworkers produced one of the first books on the subject.[76] But Hanson was primarily known as teacher and mentor *extraordinaire*, with his office door open at all times, usually with one or more students in the office. Vermuelen[77] worked in ion exchange and analyses of fixed-bed processes, where his research on that subject with the department's first PhD student, Nevin K. Hiester, was classic. He developed and made effective research use of an optical probe for determining interfacial areas of dispersions, such as occur in many phase-contacting operations. He was also active with the Academic Senate working toward resolution of matters stemming from the 1964 Free Speech Movement on the Berkeley campus.[78] He

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[72] "Sea Water Distillation," *University Bulletin*, University of California, v. 6, no. 32, p. 144, March 24, 1958.

[73] Jolly, 1987, loc. cit., pp. 178-179. J. M. Prausnitz, "Charles R. Wilke, 1917-2003," *Memorial Tributes*, National Academy of Engineering, v. 16, National Academies Press, Washington DC, 2012. https://www.nap.edu/read/13338/chapter/66. J. Prausnitz & H. Blanch, Charles R. Wilke, In Memoriam," University of California. https://perma.cc/9F23-JNML

[74] which had gained attention during the Manhattan Project.

[75] A. T. Bell, C. J. King & J. S. Newman, "Donald N. Hanson, In Memoriam, University of California." https://perma.cc/RJ5P-PR4U.

[76] D. N. Hanson, J. H. Duffin & G. F. Somerville, *Computation of Multistage Separation Processes*, Reinhold, New York, 1962.

[77] Jolly, 1987, *loc. cit*., pp. 180-181. C. R. Wilke, D. N. Hanson, K. S. Pitzer & C. W. Tobias, "Theodore Vermeulen, Chemical Engineering: Berkeley," *In Memoriam*, University of California, 1985. https://perma.cc/T5GP-JEJB

[78] Wilke, et al., 1985, *loc. cit.*, https://perma.cc/R8VR-SDTZ

was extremely approachable and well-liked by students, as well as dedicated to nurturing the careers of newer faculty members. He passed away from leukemia in 1983, at the relatively early age of 67.

Electrochemical Engineering. The exception among the founding five faculty members with regard to attention to conventional areas of chemical engineering was Charles Tobias,[79] an émigré[80] from Hungary who came to Berkeley in 1947 to join his brother, Cornelius, who was already in John Lawrence's[81] Donner Laboratory, which was the part of the Lawrence Berkeley Laboratory using particle acceleration for medical purposes. Although Charles was fully educated through a PhD in chemistry from the University of Technical Sciences of Budapest, his only means of getting to the United States was a student visa, which limited him to half-time employment. John Lawrence supplied him with a fellowship and the necessary Affidavit of Support.[82]

Following John Lawrence's suggestion, soon after his arrival in Berkeley, Tobias met with Chemistry Dean Wendell Latimer, expressing his rather vague interests in working with Glenn Seaborg in nuclear chemistry. Latimer had a long-standing interest in areas relating to electrochemistry and had authored a well-regarded book[83] on oxidation potentials. Seizing upon the facts that Tobias had worked as a chemical engineer in United Incandescent Lamp and Electrochemical Company in Hungary before undertaking his PhD and had done

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[79] D. N. Hanson, H. C. Mel, R. H. Muller, and J. S. Newman, "Charles W. Tobias, Chemical Engineering: Berkeley," In Memoriam, University of California, 1996. https://perma.cc/9KJ4-724K. C. J. King, "Charles W. Tobias, 1920–1996," Memorial Tributes, National Academy of Engineering, v. 127, National Academies Press, 2013. https://www.nap.edu/read/18477/chapter/53

[80] The story of Tobias's early career in Hungary and his emigration to the U. S. is told by Tobias himself in an oral history, Tobias, 1995 and in much shorter form by Jolly, 1987, pp. 182-185.

[81] Brother of Ernest O. Lawrence, the inventor of the cyclotron and founder of the Lawrence Berkeley Laboratory, of which the Donner Laboratory (medical physics) was a part.

[82] Tobias, 1994.

[83] W. M. Latimer, *The Oxidation States of the Elements and Their Potentials in Aqueous Solutions*, Prentice-Hall, 1938.

some work with electrochemical processes, he urged Tobias to start *de novo* a program on electrochemical processes, for which he would hire Tobias as an Instructor in the new chemical engineering program.

Starting essentially from scratch, Tobias did exactly this, creating the pioneer and pre-eminent analytically based program of research and teaching for electrochemical engineering in the United States. His initial course was a seminar, attended regularly by Latimer and occasionally by Pitzer, Brewer, and Giauque.[84] Tobias and Wilke received the department's first government-agency research grant in 1950 to study mass-transfer effects in electrolysis. Much of Tobias's research dealt with mass transport at electrodes. Similar to the situation for unit operations and transport phenomena, analyses and research on electrochemical phenomena and processes were heavily descriptive when Tobias started his program of research, and so his principal broad accomplishment was to establish more scientific and quantitative understanding.[85] Over the years Tobias's PhD graduates then launched electrochemical engineering programs throughout the United States.[86] It proved to be a very fertile field which Berkeley has continued to lead through the work of subsequent faculty members (see below).

THE SECOND GENERATION OF FACULTY

Several additional faculty members arrived between 1953 and 1965. The first was Eugene Petersen, who was appointed in 1953 after receiving his doctorate at Pennsylvania State University. Petersen focused has research on the principles of chemical reactor analysis and design and established himself as a major figure in that field. He developed a theoretical model for predicting catalyst performance and used Monte-Carlo simulations of transport and chemical reaction within porous catalysts. By studying chemical kinetics and heat and mass transfer principles, Petersen successfully developed tools useful for scaling from laboratory experiments up to large industrial reactors. He

[84] Tobias, 1994.
[85] Tobias, 1995, p. 22
[86] Tobias, 1994.

developed the single -pellet catalytic reactor as a useful research device, wrote a well-regarded graduate-level text[87] on the subject, and spent his entire career with the department.[88]

Andreas Acrivos,[89] who arrived in 1954, came from and well represented the aforementioned Amundsen school of fundamental and mathematical approaches to chemical engineering. Perhaps sensing an opportunity to put his own stamp on things at a major university, he switched to Stanford University in 1962 and had much to do with the development of chemical engineering there. He has had an outstanding career focusing largely upon fluid dynamics, in which he is considered to be one of the foremost leaders of the past 60 years.

A successor to Acrivos in interests was Simon Goren, who came to Berkeley as an Assistant Professor in 1962, following a PhD at Johns Hopkins University and a year with Esso Research and Engineering Company. His activities were in applied mathematics, particulate systems, aerosol filtration, fluid mechanics of suspended particles, oscillatory or unstable flows, and liquid-jet break-up. Goren spent his full career with the department, including serving as department chair from 1994 to 1997, and retired in 2002.

Molecular Thermodynamics. John Prausnitz[90,91,92] arrived in Berkeley in 1955 following doctoral work with Richard Wilhelm at Princeton. Although his dissertation had dealt with turbulent concentration fluctuations in packed-bed reactors, he had broad interests and had been encouraged in pursuing those wider interests by Princeton's requirement that PhD candidates develop and defend ten(!) original research propositions. For one of those propositions, he

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[87] E. E. Petersen, *Chemical Reaction Analysis*, Prentice-Hall, 1965.
[88] Enrique Iglesia & J. M. Prausnitz, "In Memoriam: Eugene E. Petersen," University of California. https://perma.cc/G6DP-G48J
[89] Acrivos & Shaqfeh, 2013.
[90] Annual Reviews Conversations Presents An Interview with John M. Prausnitz, Annual Reviews Conversations, 2011. https://perma.cc/6J5R-YUPR
[91] Editorial: John M. Prausnitz at Berkeley, 1955-2004, *Fluid Phase Equilibria*, v. 241, pp. 1-3, 2006.
[92] J. P. O'Connell, "Preface to the John Prausnitz Festschrift," *J. Chem. Eng. Data*, v. 56, pp 691-693, 2011.

had read the writings by Joel Hildebrand on solubility[93] and developed interests in that area. Thus, the presence of Hildebrand on the College of Chemistry faculty was strong among the attractions of Berkeley for Prausnitz.[94] Following these interests upon his arrival, Prausnitz was in touch with not only Hildebrand but also Kenneth Pitzer and Leo Brewer, two other prominent chemistry faculty members with interests in thermodynamic phenomena and properties, as well as Berni Alder at the nearby Lawrence Livermore Laboratory, managed by the University of California. He developed an entire new field within chemical engineering which has become known as molecular thermodynamics, involving the analysis and prediction of thermodynamic properties, notably phase equilibria, on the basis of fundamental molecular properties. A primary tool has been statistical mechanics. Previous work on the correlation and prediction of phase-equilibrium properties had been empirical or semi-empirical at best. The use of the more molecular approach enabled a framework of understanding that greatly reduces the amount of experimental work that has to be done to establish the vapor-liquid equilibria of a particular solution mixture.[95] Some specific accomplishments were the UNIQUAC (UNIversal QUAsiChemical)) model,[96] which serves to provide fittable parameters which can serve to predict activity coefficients over a range of conditions from a limited amount of experimental methods, and the UNIFAC (UNIquac Functional-group Activity Coefficients) model,[97] which builds a group-contribution method (chemical effects of different functional groups of atoms within molecules) onto the

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[93] Prausnitz, 2020, p. 39, specifically credits J. H. Hildebrand and R. L. Scott, *Solubility of Non-electrolytes*, 3rd ed., Reinhold, 1950.

[94] Interview: John Prausnitz on Molecular Thermodynamics and Careers, ChEnected, American Institute of Chemical Engineers, November 30, 2016. https://www.youtube.com/watch?v=aAZ6CXBT1JQ

[95] Prausnitz, 2020, p. 43.

[96] D. S. Abrams, & J. M. Prausnitz, "Statistical thermodynamics of liquid mixtures: A new expression for the excess Gibbs energy of partly or completely miscible systems," *AIChE Journal*, v. 21, no. 1, pp. 116–128, 1975; G. Maurer & J. M. Prausnitz, "On the derivation and extension of the uniquac equation," *Fluid Phase Equilibria*, v. 2, no. 2, pp. 91–99, 1978.

[97] Aage Fredenslund, R. L. Jones & J. M. Prausnitz, "Group-Contribution Estimation of Activity Coefficients in Nonideal Liquid Mixtures," *AIChE Journal*, v. 21, p. 1086, 1975.

UNIQUAC approach.[98] Further along in time, Prausnitz worked with Harvey Blanch on thermodynamic properties and functional-group interactions in biological systems.

The intellectual relationship of Prausnitz with Hildebrand was reflected as the two of them and Robert L. Scott of UCLA coauthored the third edition of the book that had originally drawn Prausnitz to his field of research, to Hildebrand, and to Berkeley. That third edition was published in 1970, fifteen years after Prausnitz arrived in Berkeley.[99] Even more significant was Prausnitz's own textbook (Figure 6) laying out the new field of molecular thermodynamics, ten years in the writing and published in 1969.[100] This book, now in its third edition,[101] is still widely used.

FIGURE 6. John Prausnitz receives congratulations from Joel Hildebrand upon publication of his book, "Molecular Thermodynamics of Fluid-Phase Equilibria," 1969.

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[98] Interestingly, the co-author of this paper, Russell Jones, was doing a side project with Prausnitz during his PhD work, the research for which was on an entirely different subject (freeze-drying) with the author.
[99] J. H. Hildebrand, J. M. Prausnitz & R. L. Scott, *Regular and Related Solutions: The Solubility of Gases, Liquids, and Solids*, Reingold/Van Nostrand, 1970.
[100] J. M. Prausnitz, *Molecular Thermodynamics of Fluid-Phase Equilibria*, Prentice-Hall, 1969.
[101] J. M. Prausnitz, R. N. Lichtenthaler & E. G. de Azevedo, *Molecular Thermodynamics of Fluid-Phase Equiilibria*, 3rd ed., Prentice-Hall, 1998.

The development of the field of molecular thermodynamics by Prausnitz and his co-workers was in line with the trend of the period toward more use of fundamental science in chemical engineering, but toward an end that was different from other such efforts in that it dealt with equilibrium or static properties rather than dynamic properties as is the case for transport phenomena and chemical kinetics. Calculations stemming from statistical mechanics and other properties of molecules themselves are complex, and the enormous growth in digital-computing capabilities over the years has been highly enabling to such computations.

Prausnitz became one of the rare members of two National Academies – Science and Engineering – and has received many other recognitions including the National Medal of Science (2003).

Others who started as faculty members later in the pre-1960s period were Donald Olander and David Lyon. Olander arrived in 1958, directly from his doctorate at MIT with Thomas Sherwood. He had interests and background in nuclear engineering and switched to that department in 1961, shortly after it was formed in the College of Engineering in 1958. David Lyon,[102] trained in chemistry, had arrived in Berkeley in 1942, pursued PhD research with Nobelist William Giauque in the Low Temperature Laboratory, and received that degree in chemistry in 1948. He stayed on with Giauque as a principal in the Low Temperature Laboratory, overseeing design and upgrading of the complex magnets and cryogenic systems there. A very capable person who was already on hand, David became Lecturer in the Department of Chemistry in 1954, Lecturer in Chemical Engineering in 1958, and Professor of Chemical Engineering in 1965. He continually distinguished himself as a teacher and received the Distinguished Teaching Award of the campus. He undertook important service as Assistant Dean of the College from 1969 through 1972 at a time of considerable need and with short notice, overseeing and reorganizing facilities and business operations. His research evolved over the years to nucleate boiling in cryogenic systems.

[102] C. J. King, H. Chiladakis & N. E. Phillips, "In Memoriam: David N. Lyon," University of California. https://perma.cc/X4TN-5M28

Separation Processes. King[103] arrived midyear in 1962-63, with a 1960 Sc. D. from MIT and having also been a Director of the MIT School of Chemical Engineering Practice at the (then) Esso Bayway Refinery in New Jersey, 1959-61. His initial research dealt with fundamental aspects of mass transfer, similar to that of Wilke. He was invited, early on, by Donald Hanson to co-author a textbook with him in the area of distillation or separation processes more generally, but then Hanson withdrew as he took on the added responsibility of being department chair. Although still only an Assistant Professor, King continued onward and produced a text, *Separation Processes*,[104] that served to consolidate into a single field the concepts of separating mixtures.[105] Previously, subjects such as distillation, absorption, drying, and ion exchange had been taught separately, which was the unit-operations tradition. The history and pedagogical developments surrounding the book are described elsewhere.[106] It continues life in print form as a Dover reprint[107] and an online, open-access publication.[108]

In addition to research on food dehydration processes (see below), another field of research undertaken by King and his group later on was separation by reversible chemical complexation with extractants, adsorbents, or bulk solid sorbents. One emphasis was recovery of carboxylic acids by reversible complexation with amines, such as for recovery of acids from fermentation broths.

King moved more and more into an administrative career,[109] and ended chemical engineering research in 1999, partway through his nine years as

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[103] John M. Prausnitz, "C. Judson King of UC Berkeley," from Chemical Engineering Education, v. 39, No. 3, Summer 2005, reprinted by Lawrence Berkeley National Laboratory, Report No. LBNL-59685, June 1, 2005. https://perma.cc/E7T9-D93B
[104] C. J. King, *Separation Processes*, McGraw-Hill, 1971, 2nd ed., 1980.
[105] King, 2013, pp. 153-165.
[106] C. J. King, "From Unit Operations to Separation Processes," *Separ. & Purif. Methods*, 29, No. 2, pp. 233-245 (2000).
[107] C. J. King, *Separation Processes*, Dover, New York, 2013.
[108] C. J. King, *Separation Processes*, 2nd ed. https://escholarship.org/uc/item/6rj182v7
[109] Dean, College of Chemistry, 1981-87; Provost – Professional Schools and Colleges, 1987-94; Vice Provost for Research (university-wide), 1994-95; Provost and Sr. Vice

Provost and Senior Vice President – Academic Affairs for the University of California as a whole.

In the following decades the department appropriately moved its interests relating to separations to the development of separating agents with particular and useful properties of selectivity, capacity, and/or regenerability, as well as to important new world issues such as carbon capture. In the 21st century Berend Smit (see below) joined forces with Jeffrey Reimer (see also below) in a multinational collaboration aimed at developing solid adsorbent materials that capture carbon dioxide from the air or the exhaust streams of industrial processes. They are two of the co-authors of a 2013 book on carbon capture and sequestration.[110] This team includes Chemistry professor Jeffrey Long, who is now a joint faculty member in CBE. These researchers have addressed equilibrium as well as rate phenomena in a number of materials relevant for industrial gas separations.[111]

Chemical Processes. Several faculty additions were made in the 1960s with the aim of strengthening the faculty in areas relating to chemical processing and design. The first of these was Alan Foss,[112] who arrived in 1961 following a 1957 PhD from the University of Delaware and four years of employment at the DuPont Experiment Station in Wilmington, DE. Alan created an instructional laboratory and a course in process dynamics and control. His research concerned the same areas, with the primary application being catalytic reactors. Concomitant with the growth in computing capabilities during his career, he and his group were early users of computer-based process control.

Edward Grens joined the faculty in 1963, following a PhD that year with Tobias and three years with Union Oil Company before that. He was interested in the

President, Academic Affairs (university-wide), 1995-2004; Director, Center for Studies in Higher Education, 2004-2014.

110 Berend Smit, J. A. Reimer, C. M. Oldenburg, and I. C. Bourg, *Carbon Capture and Sequestration*, World Scientific Press, Singapore, 2013.

111 The Reimer Group, College of Chemistry, University of California, Berkeley, consulted June 12, 2019. https://perma.cc/5RUB-CZL9

112 C. J. King, S. L. Goren, P. H. Wallman. "In Memoriam: Alan S. Foss," University of California. https://perma.cc/5Y3J-LMBN

use of digital computers for process simulation and other purposes within chemical engineering and launched the department's first graduate course in that area. It was becoming apparent at that time that rapid advances in computer hardware and software would bring important capabilities for simulation of process components and for complex calculations. His research concerned those areas, electrochemical energy storage and conversion, and processes for coal liquefaction (joint with Vermeulen). Grens left the faculty in 1987 and died in 2019.

In addition to his studies of separation processes in general (above) and dehydration of foods and beverages (below), Judson King undertook early studies on systematic process synthesis, i.e., logical methods for putting chemical processes together.

In 1967 Scott Lynn joined the faculty after a PhD from Caltech (1954), a postgraduate year at the Technical University, Delft, and 12 years with the Dow Chemical Company in Pittsburg, CA. His activities concerned process innovation and environmental protection. Removal of sulfur and nitrogen oxides from exhaust gases became particular interests of his, along with recovery of sulfur, fluid-bed combustion, and stripping sparingly soluble gases from aqueous streams. Lynn retired in 1994. King and Lynn together created undergraduate and graduate elective courses on process selection, synthesis, and evaluation, which Tobias joined as an instructor later on.

FACULTY PLANNING AND SELECTION

Faculty Hiring in the First Decades. From the start of the chemical engineering program through 1967, faculty hiring was very much of the "target of opportunity" variety developed through personal knowledge and contacts, rather than through systematic and comparative searches. To a degree it was typical of the times, but the approach was particularly developed in the Berkeley College of Chemistry, where faculty hiring judgements were placed with relatively few people starting with Gilbert Lewis when he became dean in 1912 and continuing through Deans Latimer, Pitzer, and Connick and through

Wilke for Chemical Engineering.[113] The approach was very successful for bringing in top-notch faculty, but it did not spread a wide net. It reflected skilled judgement of promise for a faculty position, but not a widespread search.

Schutz, Bromley, and Lyon all had Berkeley Chemistry PhDs – Schutz and Bromley with Latimer and Lyon with Giauque. Wilke and Hanson were hired following their own direct inquiries from Union Oil and Shell Development, respectively, where they had had initial employment following PhDs from the University of Wisconsin. Vermeulen was recruited from Shell Development to head the program upon the early death of Schutz. As was already noted, the recommendations of three prominent chemists were determinative. Acrivos was personally recommended by Amundsen to Wilke, was taken on as a temporary Instructor for a year, and was then made a regular faculty member during that year.[114] Michel Boudart, who joined the faculty in 1961 (see below), had taken a sabbatical leave from Princeton at Berkeley just two years before. Prausnitz[115] elected to make a side trip to Berkeley upon making a recruiting visit to Shell Development Company, made a positive impression, and was hired in a non-competitive fashion.

In a manner similar to that for Prausnitz, Bell[116] made a side visit on a pleasure trip to the San Francisco area and was then invited back, coupling the trip with a recruitment visit to Chevron. He was made an offer on the spot, after a day and a half of interviews. During a sabbatical leave that Wilke took at MIT in Spring, 1961, Thomas Sherwood recommended King to him, and Wilke then paid a visit to visit King at MIT's Bayway (Linden, New Jersey) Station of Chemical Engineering Practice, ostensibly to see the station and learn the nature of the program. An offer came to King a year later, without anyone else having interviewed him or his having been to Berkeley at all.[117] Goren wrote a letter of inquiry and application in 1961, listing several references at Johns Hopkins. He heard nothing for a year, and then received a telephone call from Wilke,

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[113] King, 2018, pp. 263, 265.
[114] Acrivos & Shaqfeh, 2013.
[115] Prausnitz, 2020, pp. 34-37.
[116] Bell, 2020, pp. 60-66.
[117] King, 2013, pp. 101-102.

followed by an offer. He had never been west of Pittsburgh, PA and had met no one else from Berkeley.[118] Grens was kept on after completing his PhD with Tobias. While completing his Master's thesis with Tobias, Newman was made an Acting Instructor with the expectation of gaining a chemical-engineering faculty position upon completing his PhD, which was carried out with Frederick S. Sherman of Mechanical Engineering at Berkeley.[119] Scott Lynn was hired directly from the Dow Chemical research operation in Pittsburg, CA where department chair (at the time) Charles Tobias had been a frequent consultant, becoming impressed with Lynn. At Dow, Lynn worked under Charles Oldershaw who was supervisor of chemical engineering research and also Lecturer with the department (see below).

Similarly, two major additions of senior scholars already having very high academic standing were made opportunistically. Robert L. Pigford[120] was a distinguished long-time faculty member and department chair from the University of Delaware who had had much to do with building that highly ranked department. He spent a sabbatical leave with the department at Berkeley in Spring 1954, became Professor at Berkeley in 1966 and stayed until he returned to Delaware in 1975. While at Berkeley he edited a major journal (*Industrial & Engineering Chemistry Fundamentals*), was elected to both the National Academy of Engineering (1971) and the National Academy of Sciences (1972), and started new lines of research in several important areas including crystallization, absorption of sulfur dioxide, and development and theoretical analysis of a new technique to enhance adsorption, dubbed cycling zone adsorption. Thomas K. Sherwood,[121] a Founding Member of the National

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[118] Simon L. Goren, personal communication to the author, October 2019.
[119] "ECS Masters – John S. Newman," video, Electrochemical Society. https://www.youtube.com/watch?v=QaVgRz7kIBI
[120] R. E. Emmert, H. S. Kemp, A. B. Metzner & C. R. Wilke, "Robert L. Pigford: A Prince Among Men," Biographical Memoirs, National Academy of Sciences, v. 65, pp. 274-289, 1994. https://www.nap.edu/read/4548/chapter/15
April 16, 1917-August 4, 1988.
[121] H. C. Hottel, "Thomas Kilgore Sherwood, July 25, 1903–January 14, 1976," Biographical Memoirs, National Academy of Sciences, v. 63, pp. 505-521, 1994. https://www.nap.edu/read/4560/chapter/23#521.

Academy of Engineering, prominent researcher, author of several textbooks, and former Dean of Engineering at MIT, had also taken a sabbatical leave at Berkeley in 1958. Upon retirement from MIT in 1969 he came to Berkeley as Visiting Professor until his death in 1976. While the three of them were together on the faculty at Berkeley, Sherwood, Pigford, and Wilke prepared and published the classic book, *Mass Transfer*.[122] Sherwood too was also a member of the National Academy of Sciences (1958). These two senior and experienced figures were valued advisors to the department during the latter portion of their times at Berkeley.

During these years up to 1967 the one major faculty-hiring issue within the department was whether to seek faculty coverage of a variety of different areas within chemical engineering or to concentrate and go deep in only a few areas.[123] The former position was held by Wilke and prevailed, whereas the latter position was promoted by Acrivos and may have contributed to his receptiveness to the offer from the relatively new department at Stanford in 1962.

More Structured Procedures. In the late 1960s, at the time of the initiation of the affirmative-action policies of the U. S. government and greater awareness of such matters, the University of California and the Berkeley campus paid more attention to policies and procedures for recruiting and selecting faculty. In particular, steps were taken to encourage and then assure outreach to many quarters as well as engagement of broad and diverse pools of candidates, so that opportunities were accessible to everyone as opposed to what had become popularly known as “the old boys’ network.” These procedures, developed for the Berkeley campus in the late 1960s and early 1970s, require first an annual departmental faculty planning document that presents the need, field(s) of interest, and rationale for one or more proposed faculty recruitments. These proposals are reviewed and acted upon by the Provost with advice from the Academic Senate Committee on Budget and Interdepartmental Relations. Recruitments thereby authorized are announced widely through mailings to departments at other universities and advertisements in publications and

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[122] T. K. Sherwood, R. L. Pigford & C. R. Wilke, *Mass Transfer*, McGraw-Hill, 1975.
[123] Prausnitz, 2020, p. 66.

online, including media specifically emphasizing affirmative action and diversity. There is then usually a departmental faculty search committee, the members of which review applications and nominations and also actively seek applicants. Perhaps six to eight people are then brought to campus for visits of typically two days, during which they give a seminar and have interviews widely among the existing faculty. The person to whom an offer is made is then chosen in a faculty meeting with a vote of the department faculty. A department's request for campus approval of the hire must include a description of the procedures used, identification and analyses of finalists including reasons for deselection of those not chosen, and the rationale in support of the candidate chosen. This material is reviewed within the Chancellor's Office and can result in requests to add to or redo the search. Alternatively, the department may choose to make no offer, in which case the recruitment authorization automatically carries over to the following year. Subsequent faculty recruitments for Berkeley chemical engineering have been carried out in this way.

Lecturers, a Vital Supplement. A basic faculty-planning decision made early in the history of the department was to use Lecturers for instruction in certain aspects of the curriculum where an industrial perspective is of particular value and/or the expertise of current tenure-track faculty may be small to non-existent. Lecturer positions involve only teaching and can be part-time, as they were for those who simultaneously held essentially full-time positions in industry. This practice was unusual at the time that it was started but became more common throughout the United States as the years went on. A cynic could say that the practice lets the tenure-track faculty off the hook from teaching some practical portions of the curriculum, but it does bring valuable perspectives to the department continually from highly respected practicing engineers and more direct exposure for students to industry.

The first two persons to hold these positions were distinguished chemical engineers from local industry who taught the department's senior-year process design courses for many years. The first, starting in 1956, was Charles F. ("Chuck") Oldershaw,[124] Berkeley chemistry graduate, self-made chemical

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[124] *Gilman Hall Newsletter*, v. 8, no. 1, June 1983.

engineer, accomplished pilot, the originator of the Oldershaw column[125] for laboratory distillations while he was working with Shell Development Company, and then after that supervisor of chemical engineering research at Dow Chemical Company in Pittsburg, CA. Chuck taught senior-year process design with the department for twenty years through 1976.

The second person was E. Morse ("Bud") Blue,[126] also a Berkeley chemistry graduate with a Master's degree in chemical engineering from MIT, and long-time employee of Chevron (and Standard Oil Company of California before the name change), who became Manager of Invention Development for that company. Bud started alternating with Oldershaw in teaching process design in 1959 and continued through 1990, a remarkable stretch of 31 years. David Quady, another Chevron employee took over Oldershaw's role in 1977 and continued through 15 more years through 1992. The practice of the process design course being taught by such people from industry has continued through the years to this day. During the sixteen years of the quarter system (1966-1983), Scott Lynn, a regular, tenure-track faculty member with extensive experience at Dow Chemical, would often teach the third quarter of the senior-year process design course.

As a result of an early recommendation from the Advisory Board (see below) of the department**,** J. Frank Valle-Riestra of Dow Chemical in Pittsburg, CA was hired in 1975 as a Lecturer to give what became a graduate-level course in Process Economics and Project Evaluation, which he did until 1986. An outcome of that teaching and his Dow experience was his 1983 book on project evaluation.[127] He was succeeded in that role in 1986 by Arnold Grossberg, former Vice President of Chevron Research, who evolved the subject matter over time to Chemical Engineering Management and continued through 2009, another remarkable run of 23 years, until he was age 86.

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[125] C. F. Oldershaw, "Perforated Plate Columns for Analytical Batch Distillations," *Ind. Eng. Chem*., v. 13, No 4, pp. 265-268, 1941.
[126] *Gilman Hall Newsletter*, v. 7, np. 1, June 1982.
[127] J. F. Valle-Riestra, *Project Evaluation in the Chemical Process Industries*, Mc-Graw-Hill, 1983.

In the professional vein as well, as the field of energy became even more important for chemical engineers, the department engaged Hubert Davis, ex- of Union Carbide, to teach a graduate course in Energy Resources and Production in the early 1980s. Similarly, given the increasing importance of the food industry as a job market for chemical engineers and the existence of one of the regional research centers of the U. S. Department of Agriculture in adjacent Albany, CA, the department brought in the Director of that laboratory**,** Arthur I. Morgan, Jr**.**, to teach a graduate course in Food Production and Processing, which lasted for 14 years, 1969-1983.

It has also proven useful and effective to have a coordinator for the undergraduate chemical engineering laboratory course (ChE/CBE 154) so as to provide continual oversight to equipment needs, design of new experiments, and other matters. This practice was started in 1980, with the addition as Lecturer of William Benjamin, who had a long career with Shell Development in process design and development, including authoring corporate manuals.[128] He was succeeded in 1983 by Fred Vorhis, who had been with Chevron. Continuing oversight and coordination of the core undergraduate course continues today through Lecturer Negar Beheshti Pour, a 2019 PhD chemical engineer from Washington State University.

Other Lecturers have been distinguished scholars and teachers brought in for specific teaching purposes as well as to gain use of their wide experience and counsel. The first of these was Otto Redlich,[129] a distinguished thermodynamicist, who had emigrated from Vienna in 1938 through the Emergency Committee in Aid of Displaced Foreign Scholars.[130] By way of Berkeley and Washington State University, he moved on to a distinguished career with Shell Development Company in Emeryville, CA, including creation of the noted Redlich-Kwong Equation of State. Upon retirement from Shell in 1962 he came to Berkeley Chemical Engineering as a Lecturer, teaching

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[128] *Gilman Hall Newsletter*, v. 5, no. 1, 1980.
[129] Simón Reif-Acherman, "Otto Redlich: Chemist and Gentlemen from the 'Old School'," *Química Nova*, v. 31, no. 7, São Paulo, 2008. https://perma.cc/4VZ7-BL5G
[130] Isabella Löhr, "Emergency Committee in Aid of Displaced Foreign Scholars," *Transatlantic Perspectives*, January 25, 2014. https://perma.cc/2FC6-K924

thermodynamics until his final retirement in 1976. Another such Lecturer appointee (1975-80) was Alan S. Michaels,[131] who had had a distinguished faculty career in colloid and surface chemistry at MIT and then had founded two successful companies – Amicon Corporation (now part of Millipore) and Pharmetrics, Inc. in Palo Alto, CA, which ultimately became part of ALZA Corporation, now absorbed into Johnson & Johnson. He taught Applied Surface and Colloid Chemistry as well as Polymer Synthesis. A third was Heinz Heinemann,[132] who came to the Lawrence Berkeley Laboratory upon his retirement in 1978 from Mobil Oil, where he had overseen research in catalysis. He served simultaneously as Lecturer in chemical engineering. Alex Bell describes several of the valuable ways in which Heinemann interacted with catalysis research and teaching.[133]

Two other early, long-time Lecturers were Rolf Muller, an LBL scientist, who taught a graduate-level course on Optical Methods in Chemical Engineering Research for 23 years from 1967 to 1991, and Gerhard Klein, who worked with Theodore Vermeulen in the Seawater Conversion Laboratory and then the Water Thermal and Chemical Technology Center, and co-taught with Vermeulen courses in adsorption separations in fixed beds for 19 years, 1966-86.

Yet another use of Lecturers occurred later on, when they were hired to give coordinative oversight to the undergraduate curriculum and give more extensive attention to certain other undergraduate courses. Shannon Ciston, on the faculty from 2011 to 2020, carried out the coordinative-oversight function and also gave continual attention to ABET accreditation matters. Ciston taught, and Marjorie Went hired in 2013, and Negar Beheshti Pour hired in 2019 teach, in undergraduate courses, including the laboratory and the introductory CBE 40 course (see below). The use of full-time lecturers to co-teach the undergraduate curriculum is not without controversy as the policies of the University of California provide that research, teaching, and service are all duties

[131] Andeas Acrivos, "Alan S. Michaels, 1922-2000," *Memorial Tributes*, National Academy of Engineering, v. 123, 2008. https://www.nap.edu/read/12473/chapter/36
[132] G. A. Somorjai & A. T. Bell, "In Memoriam: Heinz Heinemann," University of California, Berkeley. https://perma.cc/VJG2-CKPZ
[133] Bell, 2020, pp. 170-175.

of the tenure-track faculty. However, burgeoning enrollments and the desirability of offering core undergraduate courses each semester have meant that full teaching loads for the tenure-track faculty do not provide sufficient instructional person power. The department does maintain a requirement that all ladder-rank faculty teach a core undergraduate course each year.

Teaching Assistantships. The use of Teaching Assistants (TAs) to support instruction is common throughout the University of California and American universities in general. Within the sciences and engineering the use of TAs is limited to grading of exams and homework, consulting with students, and sometimes preparing and giving a few lectures. In the humanities and some social sciences the responsibilities of Teaching Assistants can often be greater. The CBE department, early on, recognized TA service as being valuable educational experience for the TA himself or herself, and was a pioneer in the use of "instruction in instruction" and an enrolled-course experience required for the PhD degree to recognize that fact. This follows the oft-cited maxim that the best way to learn a subject is to teach it. Teaching brings a need to organize one's thoughts thoroughly and to confront one's full understanding or lack of understanding. Also, it is important to provide knowledge of teaching and teaching experience to those PhD graduates who go on to university careers.

The course ChE 300, "Professional Preparation: Supervised Teaching of Chemical Engineering," was instituted in 1969 as a PhD degree requirement to formalize the expectation that faculty would engage with their Teaching Assistants tutorially on the subject of how to be an effective instructor. That tutorial instruction was probably inconsistent at best. Subsequently, in 1995 ChE 300 became a formal course with a content relating to objectives, methods, styles, and content of teaching, as well as approaches to homework, exams, etc. It has been taught by Jeffrey Reimer and then Shannon Ciston. In 2004 this course (now CBE 375) became a campus-wide requirement for the PhD.

Teaching Assistants are both students and employees. In California, state law gives unionization rights widely among employees of public universities, and there is a history in California and many other states of efforts to promote unionization of graduate-student employees such as Teaching Assistants. The primary national union interested in organizing TAs has been the United Auto

Workers (UAW). For the University of California, interest in unionization for TAs started in 1983. Exam readers and tutors gained the right to unionize at UC in 1993, and in 1999 that right was extended to TAs, with the UAW being the organizing entity.[134] Thus the department, as part of the Berkeley campus and in turn as part of the entire University of California, now has a complex relationship with its Teaching Assistants who are both students and union-represented contract employees.

EXPANDING HORIZONS

Starting in the mid-1960s the department developed activities in several additional areas of chemical engineering through the evolution of faculty interests, development of programs by new faculty members, and targeted recruitments.

Biochemical Engineering, evolving to Biomolecular Engineering. About 1967, Charles Wilke made the decision that he would undertake to learn the areas of biotechnology and bioengineering and direct his future scholarly work toward that end. This was a striking and daring decision for a faculty member who currently stood at the top of his field of mass transfer, still a central core of chemical engineering. It showed considerable foresight, since it would take time to learn the field and required confidence that the field could and would advance markedly. Biochemical engineering was very much in its infancy, having been started in United States universities shortly after World War II by pioneers such as Elmer Gaden at Columbia and his PhD graduate Arthur Humphrey at Penn to try to establish understanding that could place the production of new antibiotics such as penicillin, streptomycin, and tetracycline from cultures on more knowledgeable and analytical bases.[135]

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[134] Graduate student employee unionization, *Wikipedia*, consulted June 12, 2020. https://perma.cc/45BU-8MHJ

[135] A. E. Humphrey, "Elmer L. Gaden, Jr., Father of Biochemical Engineering," *Biotechnol. & Bioeng*., v. 37, pp. 995-997, 1991.

To learn the field, Wilke arranged to be given the use of a period of about two years during which he brought in senior figures such as Humphrey, Robert Finn from Cornell University, Shuichi Aiba of the University of Tokyo, and Murray Moo-Young of the University of Waterloo to Berkeley as visitors. His early studies focused on understanding the role of mass transfer in bioreactors and determining the kinetics of enzymatic and microbial growth processes.[136] Initial research was directed toward the production of ethanol from newsprint, corn, and corn stover. This made sense in view of the growing interest in ethanol as a synthetic fuel during and after the energy crises of the early 1970s. He obtained research support from ERDA and then the Department of Energy through the Lawrence Berkeley Laboratory as the missions of those agencies and the laboratory grew to include fuel-related research. The presence of LBL was thereby a distinct asset.

As the capabilities of recombinant DNA and genetic engineering became known and rapid advances in molecular biology occurred during the 1970s[137] it became apparent that biotechnology was indeed a field of the future. Recognizing that promise and at the urging of Wilke, the department hired Harvey Blanch, an established young leader in biochemical engineering, from the University of Delaware in 1978. Blanch had received his undergraduate degree at the School of Chemical Engineering of the University of Sydney and his PhD at the School of Biological Technology at the University of New South Wales. In the early 1960s the University of New South Wales had a focus on yeast fermentations and biological applications in the mining industry such as microbial leaching of metals. After three years of post-doctoral study at the ETH in Zurich, Switzerland, focusing mostly on industrial microbiology, Blanch came to the United States to work for Squibb in New Brunswick, NJ on improving penicillin and tetracycline fermentations.[138] In 1974, Blanch joined the chemical-engineering faculty of the University of Delaware, where he worked on fermentations and gas-liquid mass transfer, particularly in relation to efforts to

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[136] J. M. Prausnitz and H. W. Blanch, "In Memoriam: Charles R. Wilke." 2003. https://perma.cc/9F23-JNML

[137] King, 2018, pp. 350 ff.

[138] Harvey Blanch, "Faculty Sketch," *Gilman Hall Newsletter,* v. 16 (June 1991).

turn hydrocarbons into single-cell proteins. In addition to joining Wilke in his ethanol-production efforts, Blanch undertook research relating to transport, catalytic mechanisms, and kinetics of enzymatic and microbial processes. He examined electrophoretic separations of DNA and other species and joined into an effective collaboration with Prausnitz on thermodynamic interactions within biochemical systems. In the 1980s Blanch turned his interests toward genetic engineering and focused on large-scale use of cell-fusion technology to increase production of monoclonal antibodies that deliver drugs directly to unhealthy cells. By 1997 Blanch began to investigate marine biotechnologies for antiviral and anti-cancer agents.

The third biochemical engineering faculty member was Douglas Clark, who arrived in 1986, following a 1983 PhD with James Bailey at Caltech and two years as Assistant Professor at Cornell. His research emphases have been enzyme technology, biomaterials, and bioenergy. He has had a longstanding interest in microorganisms from extreme environments ("extremophiles") and extremophilic enzymes. His projects have included structural characterization and activation of enzymes in non-aqueous reaction media, with the goal of overcoming process limitations imposed by aqueous conditions; the development of enzyme- and cell-based microscale systems for high-throughput biocatalysis and bioactivity screening; protein design and assembly for the formulation of advanced biomaterials with unique structural and functional properties; and enhanced conversion of lignocellulosic feedstocks to biofuels. He also works with the development of protein and cellular arrays for high-throughput biosynthesis and activity/toxicity screening of drug candidates.[139] A text[140] co-authored by Blanch and Clark is now a standard text for biochemical engineering.

Next to be hired, arriving in 1992, was Jay Keasling, who has successfully developed various means for controlling metabolic pathways within cells so as to produce new molecules and microbial hosts that enable the production of desired commodity and specialty chemicals and biofuels. He has gained

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[139] Research Interests, Douglas S. Clark, College of Chemistry, University of California, Berkeley, September 24, 2019. https://perma.cc/SQ3S-Q4EC

[140] H. W. Blanch & D. S. Clark, *Biochemical Engineering*, 2nd ed., CRC Press, 1997.

considerable national attention. One very noteworthy accomplishment of Keasling and his group has been the production of artemisinin, a prominent antimalarial drug, by synthetic means.[141] Commercial development of this accomplishment was funded by the Gates Foundation through an innovative partnership of the University of California, OneWorld Health, and Amyris Biotechnologies.[142] Keasling has also taken on several simultaneous research administrative functions, notably Associate Laboratory Director for Biosciences in the Lawrence Berkeley Laboratory, Chief Executive Officer of the Joint BioEnergy Institute (see below), and Director of Synthetic Biology Engineering Research Center (see also below). He has won many awards and recognitions. Strikingly, *all* of the first four faculty members in biochemical engineering (Wilke, Blanch, Clark, and Keasling) have become members of the National Academy of Engineering.

David Schaffer was the next addition in the biochemical/biomolecular area, arriving in 1999 after a PhD at MIT with Douglas Lauffenburger. His research is directed toward biomedical needs and opportunities using molecular and cellular engineering approaches, in particular the areas of gene therapy and stem cell biology with applications to therapies for diseases of the nervous system.[143] He has been an affiliate of the Helen Wills Neuroscience Institute at Berkeley since his arrival, has directed the Berkeley Stem Cell Center, and as of 2020 is Director of the Berkeley portion of the QB3 Institute (see below for all three).

Danielle Tullman-Ercek arrived in 2009 and carried out research on transport across biological membranes before moving to Northwestern in 2016. Newly hired in 2011 with a PhD from UCLA and a postdoc at Harvard Medical School, Wenjun Zhang carries out research relating to scientific understanding and

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[141] See, e. g., "Synthetic Biology Assures Global Access to a Vital Nobel Prize Winning Malaria Medication," *Twist Bioscience*, December 12, 2017. https://perma.cc/4UEJ-G6XL

[142] Robert Sanders, "$43 million grant from Gates Foundation brings together unique collaboration for antimalarial drug," University of California, Berkeley, December 13, 2004. https://perma.cc/N2LW-S4CQ

[143] Research Interests, David V. Schaffer, College of Chemistry, University of California, Berkeley, September 24, 2019. https://perma.cc/DQ7G-MF8W

engineering for biosynthesis of natural products, discovery and functional study of new bioactive molecules, and development of means for natural product tagging and applications.[144] Starting as an Assistant Professor in 2020, Karthik Shekhar is exploring molecular description of cellular diversity in complex tissues, its developmental and evolutionary origins, and its biological consequences for tissue function and degeneration.

The nature of the research undertaken by the biochemical and biomolecular engineering faculty within the department has evolved considerably over the years, having started with fermentation processing and applications of mass transfer and having progressed to more fundamental molecular-level opportunities and important applications in new fields such as stem cells and gene therapy. Research in the biological areas has also led the move by the faculty of the department to participate much more actively in multidisciplinary research settings (see below).

The importance of chemical engineering for bioprocessing and biomolecular engineering and the promise and blossoming of that area led the department to change its name in 2010 to Department of Chemical and Biomolecular Engineering. Changes to that name and others similar to it have now been made by many other chemical-engineering programs in U. S. universities.

Catalysis and Surface Science. Another area that has blossomed over the years has been catalysis. The field first arrived in the department through Michel Boudart,[145] who joined the faculty in 1961. Boudart, whose chemistry PhD was with Hugh Taylor at Princeton, had earlier been attracted by Acrivos to spend a spring 1959 sabbatical leave at Berkeley from his faculty post at Princeton, and he and Acrivos became friends. Acrivos relocated to Stanford in 1962, the year after Boudart's arrival. Boudart then followed Acrivos to Stanford in 1964, and the two became long-term stalwarts of the new Stanford chemical engineering

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[144] Research Interests, Wenjun Zhang, College of Chemistry, University of California, Berkeley, September 24, 2019. https://chemistry.berkeley.edu/faculty/cbe/zhang
[145] R. B. Levy, J. Dumesic, J. A. Cusumano & E. Iglesia, "Michel Boudart, 1924-2012," Biographical Memoirs, National Academy of Sciences. http://www.nasonline.org/publications/biographical-memoirs/memoir-pdfs/boudart-michel.pdf

program. Boudart was a principal figure in catalysis nationally and internationally.

The next addition relating to catalysis was Robert Merrill,[146] who came in 1964 and stayed until 1977 when he transferred to Cornell. Merrill's ScD research at MIT had been with Raymond Baddour on molecular-beam studies combining simultaneous measurement of surface properties and catalytic effects on chemical reactions. Merrill continued this line of research while at Berkeley.

Alexis Bell, who joined the faculty as Assistant Professor in 1967, had also carried out his doctoral research with Baddour at MIT, but on plasma processing. Bell's early Berkeley research was on plasma processing directed toward electronics materials,[147] but in the early 1970s he started research in catalysis, and that became his research career. The move to catalysis was made in an interesting way. Petersen offered Bell the use of about $15,000 remaining in a loosely defined Environmental Protection Agency grant if he would apply it to a project related to catalysis. It happened that Bell, a native Russian speaker, had during his graduate work at MIT translated papers from the Russian for William Koch,[148] a fellow Baddour graduate student. These related to the use of infrared spectroscopy to monitor species on the surface of the catalyst for the conversion of ethylene and oxygen to ethylene oxide. Given the head start of having done these translations, Bell chose the same subject for the research that he and his first catalysis graduate student, Edwin Force, did under those EPA funds.[149]

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[146] J. Ballantyne, P. Houston, W. Olbricht, T. Rhodin, "Robert P. Merrill," obituary, Cornell University. https://perma.cc/GL9E-5LSH
[147] Bell, 2020, pp. 80-89.
[148] William (Bill) is one of the three of the four Koch brothers who have been much in the public eye in recent years (see, e. g., Daniel, Schulman, *Sons of Wichita: How the Koch Brother Became America's Most Powerful and Private Dynasty*, Grand Central Publishing, 2014). An Interesting coincidence is that the twin Koch brothers, David and Bill, both did bachelor's theses with the author at MIT in the year between his Practice School directorship and his move from MIT to Berkeley. David (deceased 2019) and Charles, an older brother, have been the politically active Koch brothers. Bill, among other things, founded Oxbow Carbon and in 1992 won the America's Cup.
[149] Bell, 2020, pp. 89-93.

With regard to specific catalysis systems and needs, Bell's research work next proceeded to the reduction of nitrogen oxides, an important topic for catalytic converters and the reduction of pollution from automobile exhaust gases. That research was supported by the National Science Foundation and also involved collaboration with researchers in the Soviet Union.[150] In the mid-1970s, the Arab oil embargo had occurred and ERDA and then the Department of Energy had been formed. It thereby became attractive to investigate a series of important matters relating to catalysis having to do with energy sources and conversion. One of these was improvement of the Fischer-Tropsch class of processes for making fuels and related chemicals from synthesis gas (carbon monoxide and hydrogen). Another, sparked by Bell's aforementioned interactions with Heinz Heinemann, was the understanding of mechanisms of zeolite catalysis and synthesis of improved zeolites for catalysis. Another has been electrocatalysis research with the Joint Center for Artificial Photosynthesis of LBL directed toward the conversion of carbon dioxide to useful products, yet another has been joint research with Blanch on the use of ionic liquids to catalyze aspects of biomass conversion, and still another has been research on metal-oxide catalysts (e. g., vanadia) dispersed on silica gel, much of it joint with Enrique Iglesia (see below).

Bell's catalysis research has made good use of various levels of instrumentation for monitoring catalyst structures and surfaces. Instrumentation used for surface studies grew more advanced and sophisticated over time, going from the original infrared spectroscopy to Raman spectroscopy, ultraviolet/visible spectroscopy, X-ray photoelectron spectroscopy, Auger electron spectroscopy, electron microscopy, and X-ray absorption spectroscopy.[151] His research has also integrated well with theoretical studies, and Bell himself started carrying out related theoretical work and going back and forth between theory and experiment to reinforce one another.[152]

Bell's recently completed oral history focuses on his research, including his philosophies and methodology for approaching it, the choice of approaches on

[150] Bell, 2020, pp. 132-145.
[151] Bell, 2020, p. 183.
[152] Bell, 2020, pp. 192-195, 228-254.

the scientific and molecular levels, rationales for choice of topics, and the ways in which he has used collaborative research for the education of graduate students.[153] He was elected to the National Academy of Engineering in 1987, to the National Academy of Sciences in 2010, and to the Russian Academy of Sciences in 2019.

Enrique Iglesia joined the department in 1993. He had previously for eleven years been with Exxon Research and Engineering Company, and had headed their catalysis research program, thereby giving him a deep and valuable industrial perspective. Prior to that he had achieved his PhD at Stanford, working with Michel Boudart. His early life was both unusual and formative. He was born in Cuba five years before the Castro government took power. When he was fourteen, his family moved from Cuba via Mexico to Miami in the U. S.[154] Iglesia's Berkeley research has dealt with the synthesis of novel catalytic solids, *in-situ* structural and mechanistic characterization of catalytic materials, and modeling of kinetic and transport processes in catalysis. Applications have included the conversion of methane to higher hydrocarbons, uses of light alkanes in desulfurization and de-NO_x reactions, dehydrogenation of light alkanes to alkenes and aromatics, catalytic reforming and cracking processes, low-temperature isomerization, alkylation, and combustion reactions. He has also investigated catalytic membranes that can combine reaction and separation functions in alkane dehydrogenation and conversion processes.[155] He is a member of the National Academies of both Engineering and Sciences and has won many awards relating to catalysis and industrial chemistry.

Alexander Katz joined the faculty in 2000 after a Caltech PhD and a postdoctoral appointment at Institut Le Bel in Strasbourg, France. His research seeks to understand how catalysts function given a certain molecular active-site structure, including transferring the most essential features of functional group organization found in biological systems to synthetic heterogeneous platforms for catalysis and adsorption. This approach enables rational design of catalysts

[153] Bell, 2020.
[154] Iglesia, 2014.
[155] Research Interests, Enrique Iglesia, College of Chemistry, University of California, Berkeley, September 24, 2019. https://perma.cc/FKY7-YCLQ

for emerging applications. These applications require catalysts with both high activity and selectivity, whereas conventional approaches often optimize one at the expense of the other.[156]

The Berkeley faculty members working with catalysis have been involved in several large industrially supported projects. One of these, including Bell, Iglesia, and Katz, has received long-term support from Chevron Energy Technology, starting in 2007 and as of 2020 still continuing.[157] A second project was joint with Caltech and funded by BP (formerly British Petroleum) in support of research in homogeneous catalysis at Caltech and heterogeneous catalysis at Berkeley, both relating to conversion of methane to useful chemicals.[158] Bell participated in a third project, the Energy Biosciences Institute (see below) from, 2007 to 2017, in which he and Harvey Blanch carried out their research on ionic liquids as catalysts for aspects of biomass conversion.

Processing of Electronics Materials. The department was not directly involved in the start of Silicon Valley, but it was indirectly and has had many interactions subsequently. Andrew Grove[159] (PhD, 1963) was the first employee hired by Robert Noyce[160] and Gordon Moore (BS, Chemistry, 1950) when they left Fairchild Semiconductor to form Intel Corporation in 1968[161] (Figure 7). Grove was subsequently President (1979-1997), CEO (1987-1998) and Chairman (1987-2004) of Intel, a highly-admired guru of Silicon Valley management, and *Time* magazine's "Man of the Year" in 1997 for being "the person most responsible for the amazing growth in the power and the innovative potential of

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[156] Research Interests, Alexander Katz, College of Chemistry, University of California, Berkeley, September 24, 2019. https://perma.cc/W4LC-K32Q
[157] Bell, 2020, p. 186-87.
[158] Bell, 2020, p. 189-191.
[159] Jonathan Kandell, "Andrew S. Grove Dies at 79; Intel Chief Spurred Semiconductor Revolution," *New York Times*, March 21, 2016. https://perma.cc/992Y-MSKP. Andrew S. Grove, *Swimming Across*, Plunkett Lake Press, 2018.
[160] Younger brother of UCB Chemistry professor and Associate Dean Donald S. Noyce, whose oral history is hosted by the Science History Institute. https://oh.sciencehistory.org/oral-histories/noyce-donald-s)
[161] Leslie Berlin, *Troublemakers: Silicon Valley's Coming of Age*, Simon & Schuster, 2017.

microchips." He had carried out his PhD research with Petersen.[162] As well, a number of Tobias graduates in electrochemical engineering went to companies such as IBM, Bell Labs, Intel, and National Semiconductor, as well as start-ups.

FIGURE 7. Andrew Grove (PhD, Petersen, 1963), Robert Noyce, and Gordon Moore at Intel, 1978. By Intel Free Press. https://commons.wikimedia.org/w/index.php?curid=38385134)

Tobias constantly encouraged the department to bring aboard faculty with expertise and research relating to the budding microelectronics industry. His having been such a crusader is recalled by Alex Bell,[163] the author,[164] and Dennis Hess, who said,

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162 Grove's seminar at the conclusion of his PhD work was, in fact, the first such seminar heard by the author upon his arrival in Berkeley as an Assistant Professor in January 1963.

163 Bell, 2020, p. 88.

164 King, 2013, pp. 249-251.

> "I can still remember him telling me: If chemists and chemical engineers would have had to develop the semiconductor industry, it would have never happened. Any self-respecting chemist or chemical engineer would have looked at the problems that had to be solved and concluded that those problems cannot be solved. But the EEs and physicists did not know it couldn't be done, so they did it.[165] Now it is up to the ChEs to figure out how to better improve existing and develop new processes and maximize the yield in high volume production. This view turned out to be exactly correct. Chemical engineers had the background to deal with, for instance, reactor design and operation (for film deposition and etching), kinetics, transport processes, and chemical process modeling so that processes could be made more reproducible and controllable. They had the insight and background to undertake work that was needed on the numerous chemical process steps in place that required the development of new and creative approaches." [166]

The first graduates of the department to be hired by the microelectronics industry were put to work on the complex waste streams that the industry generated, but it was then recognized that they could contribute importantly to the processing methodology itself. As "Moore's Law"[167] took hold, new processing needs became continual and increasingly complex, leading to growth in the employment of chemical engineering graduates for those purposes, thereby bearing out the Tobias prediction.

Following the early efforts of Bell and a short period on the faculty by Lee Donaghey (1969-77), the next hire of a faculty member in these areas was Dennis Hess in 1977. His 1973 PhD was in chemistry with Frederick Fowkes at Lehigh University, and after that he had spent four years with Fairchild Semiconductor. His initial research was in the plasma (glow discharge) arena for plasma etching, deposition, and polymerization, chosen in view of projects that he had carried out at Fairchild that involved plasma-based photoresist stripping

[165] Shades of the Longhairs vs. Hairy Ears argument!
[166] Dennis W. Hess, personal communication to Judson King, September 7, 2019.
[167] David Laws, "Moore's Law @50: The Most Important Graph in Human History," Computer History Museum. https://perma.cc/YLS2-WS4H

and plasma enhanced deposition of silicon nitride for integrated-circuit packaging purposes. At that time little was known about the fundamentals of these processes. In that the program was the first, or one of the first, of its kind in a major U. S. research university, contacts and collaborations outside chemical engineering were important. Hess made fruitful connections with researchers at IBM and Bell Labs who were investigating similar matters, and with faculty researchers elsewhere on the Berkeley campus, notably electrical engineering, when it led to the use of existing experimental facilities as needed. Hess transferred back to Lehigh in 1991 and moved from there to Georgia Tech[168] in 1996.

Jeffrey Reimer joined the department in 1982 after a PhD in Chemistry at Caltech with John Baldeschwieler,[169] followed by postdoctoral work at IBM in Yorktown Heights in New York. He began his career at Berkeley working on amorphous silicon solar cells, and his early PhD students went on to faculty positions at Northwestern, MIT, UC Davis, and Case-Western Reserve. Further students continued work in electronics materials, including semiconducting materials for quantum information processing. His multi-faceted Berkeley career has spread into many other areas, as described at several points below.

The next faculty member with research centered on processing of electronics materials was David Graves, who arrived in 1986 following his PhD in chemical engineering from the University of Minnesota with Klavs Jensen. His research concerned the fundamentals and applications of weakly to partially ionized gases, or plasmas, to technological problems, primarily in the microelectronics industry. These plasmas operate at near-ambient temperatures and thereby are quite different from the hot, usually strongly magnetized plasmas in stars or that are used in thermonuclear fusion and weapons applications. His primary applications of interest related to interactions between the plasma and its

[168] Dennis W. Hess, School of Chemical and Biomolecular Engineering, Georgia Institute of Technology. https://perma.cc/WRQ5-3K8L

[169] "Caltech Thesis – Reimer," Caltech Library Services. http://thesis.library.caltech.edu

bounding surfaces.[170] He retired in 2020 to become Associate Laboratory Director for the Princeton Plasma Physics Laboratory.

Roya Maboudian came as a new faculty member to Berkeley in 1994 with a very different background. Her PhD in applied physics from Caltech in 1989 with David Goodstein and Thomas Tombrello dealt with surface modifications using scattering of ballistic phonons.[171] She had then been a postdoctoral research fellow in the Department of Chemistry at Pennsylvania State University and a research associate in the Department of Chemical Engineering and Center for Quantized Electronic Structures at UC Santa Barbara. Her research program centers around physical and chemical issues related to the development of new applications of micro- and nanotechnology. She combines interest and expertise in materials, interfacial phenomena, electrochemistry, nanostructures, and self-assembly to seek fundamental and practical advances in a variety of applications, including micro/nanosystems technology, sensing, energy, and biomimetics. An interesting example of the latter has been her work with gecko-inspired synthetic adhesives.[172]

Further Development of Batteries and Other Aspects of Electrochemical Engineering. The next addition in electrochemical engineering after Tobias was John Newman in 1963. Throughout his UCB career, Newman's interests focused upon the investigation of efficient and economical methods for electrochemical energy conversion and storage, development of mathematical models to predict the behavior of electrochemical systems and to identify important process parameters, and experimental verification of the completeness and accuracy of the models. Within the department he has been a stalwart on the use of applied mathematics and instruction in that subject. He too has been involved with the Lawrence Berkeley Laboratory for much of his career, in charge of the battery program in later years and concentrating on better understanding of

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[170] Research Interests, David B. Graves, College of Chemistry, University of California, Berkeley. https://perma.cc/2H73-SXKW

[171] "Caltech Thesis - Maboudian," Caltech Library Services, 1989. http://thesis.library.caltech.edu/611/

[172] Research Interests and Research Group, Roya Maboudian, College of Chemistry, University of California, Berkeley. https://perma.cc/3MZ8-EQVH

lithium batteries, industrial electrochemical processes, and methanol fuel cells.[173] Newman has been an intellectual leader of the electrochemical field during his career, having won many awards in recognition of his work. His book, *Electrochemical Systems*, first written in 1972,[174] has been a standard work for the field and is going into its fourth edition, now coauthored with Berkeley CBE colleague Nitash Balsara. He retired in 2011.

A few years after the formation of the Energy and Environment Division of the Lawrence Berkeley Laboratory in 1973,[175] a national search[176] was carried out to identify an Associate Laboratory Director to head that division and lead the development of the laboratory's activities in those areas. The person selected was Elton Cairns, who was at the time assistant head of the Electrochemistry Department of the General Motors Research Laboratories. Before then, he had been the first PhD graduate (1959) of John Prausnitz at Berkeley, carrying out research on chemical kinetics and transport processes in packed and fluidized beds before Prausnitz's interests shifted toward molecular thermodynamics. His initial employment had been with General Electric Research Laboratory conducting research in a number of electrochemical areas, toward which his interests had been stimulated by Charles Tobias. He had then joined Argonne National Laboratory in 1966 as Group Leader for Liquid Metals and Molten Salts, before switching to the General Motors position in 1973.[177] The LBL position brought a joint professorial appointment in the UC Berkeley Department of Chemical Engineering which would be continuing beyond his service in the laboratory position. Cairns started in 1978 and served 18 years in the LBL position until 1996.

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[173] Research Interests, John S. Newman; the Newman Research Group, consulted September 29, 2019. https://perma.cc/2LTP-WG42

[174] J. S. Newman, *Electrochemical Systems*, Prentice-Hall, 1972.

[175] Dan Krotz, "An Historical Perspective on the Lab's Legacy: A Year-Long Series in *The View,"* Berkeley National Laboratory, consulted September 30, 2019. https://www2.lbl.gov/Publications/75th/files/04-lab-history-pt-5.html

[176] The author was on this search committee.

[177] "Elton J. Cairns, ECS President 1989-90, The Electrochemical Society, consulted September 30, 2019. https://perma.cc/L3E2-HLNJ

Cairns carried out electrochemical research through his LBL administrative years, relating to electrochemistry and electrocatalysis with particular attention to the fundamental properties and behavior of electrodes employed in high-performance rechargeable batteries and fuel cells. His group has synthesized and characterized new electrode materials in order to gain a fundamental understanding of the relationships among atomic and electronic structure, electrochemical performance, and long-term stability. They investigate fundamental means of enhancing material utilization and stability through modifications in the composition and structure of the electrodes, thereby increasing cell specific energy and lifetime. The performance of electrodes employed in fuel cells that directly oxidize fuels such as methanol and ethanol is typically limited by slow electrochemical kinetics. Therefore, Cairns and his group have sought new, highly active electrocatalysts and have characterized their kinetic and mechanistic behavior. They have utilized tools such as X-ray absorption spectroscopies (XAS) using synchrotron radiation, nuclear magnetic resonance (NMR), and photothermal deflection spectroscopy to characterize electrode materials.[178]

Nitash Balsara came to the department in 2000 as a senior hire at the Professor level, having previously been at Polytechnic University in Brooklyn, New York. His interests are in self-assembly and transport properties of nanostructured polymer materials. A primary application is to the improvement of all-solid, rechargeable lithium batteries, for which he and his group work on solid block copolymers and glass-polymer composites that selectively transport lithium ions. They use techniques such as AC impedance, NMR, electron microscopy, X-ray absorption and scattering, and hard X-ray microtomography to understand the morphology, ion-transport properties, and failure mechanisms of the electrolyte.[179]

Bryan McCloskey came to Berkeley's Chemical Engineering Department and the Berkeley National Laboratory in 2014 as an Assistant Professor. Following a

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[178] Research Interests, Elton J. Cairns, College of Chemistry, University of California, Berkeley, consulted September 30, 2019. https://perma.cc/2M2K-MMWV

[179] Balsara Lab, Research Overview, College of Chemistry, University of California, Berkeley, consulted September 30, 2019. https://perma.cc/K7SX-26KV

2009 PhD in chemical engineering from University of Texas at Austin, he was a postdoc and then an employee of the IBM Almaden Research Center in San Jose, CA. At Berkeley his research concerns electrochemical energy storage, electrocatalysis, and molecular and ionic transport through polymers. Many potential battery chemistries possess high theoretical specific energies (e.g., lithium/oxygen and lithium/sulfur), and, as a result, are being explored by McCloskey and his group in hope that their development may lead to an increase in practical battery energy density compared to currently available batteries. However, for these batteries to become a commercial reality, material challenges that cause rechargeability and rate capability limitations need to be addressed. Accordingly, the objective of the McCloskey group is to characterize fundamental electrochemistry occurring at multi-phase interfaces to provide design insight for energy storage, electrocatalysis, and corrosion-resistant materials.[180]

When the 2019 Nobel Prize in Chemistry was awarded for the lithium-ion battery, the report on scientific background for the prize[181] noted that the essential features of the non-aqueous propylene carbonate electrolyte enabling these batteries were in the PhD dissertation of William Sydney Harris,[182] carried out under Tobias in 1958, sixty-one years earlier and long before the advent of interest in these batteries. As well it acknowledged John Newman's 1967 theory[183] for ion transfer in electrochemical cells.[184]

Food Processing. In 1964 Arthur Morgan, a graduate of the department who was then directing the Engineering Division of the U. S. Department of Agriculture Western Regional Research Center in Albany, CA, came to the

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[180] Research Interests, Bryan D. McCloskey, College of Chemistry, University of California, Berkeley, consulted September 30, 2019. https://perma.cc/VMV4-5RC5
[181] Royal Swedish Academy of Sciences, "Scientific Background on the Nobel Prize in Chemistry 2019," October 2019. https://perma.cc/P4YQ-FGAD
[182] W. S. Harris, "Electrochemical Studies in Cyclic Esters," University of California Radiation Laboratory Report No. UCRL-8381, July 1958. https://escholarship.org/uc/item/74t234gs
[183] J. S. Newman, "Transport in Electrolytic Solutions," *Adv. Electrochem. & Electrochem. Eng.,* v. 5, pp. 87-135, 1967.
[184] I am grateful to Nitash Balsara for pointing out these citations.

department suggesting several food-related topics that could be suitable for sponsored chemical-engineering research.[185] Judson King responded on the subject of freeze-drying,[186] and thus began 35 years of research relating to freeze-dying, freeze concentration, and spray drying. One of his emphases during that time was the retention of volatile flavor and aroma compounds during evaporative dewatering, where the flavor and aroma substances are more volatile than the water being removed. Another was the factors influencing the morphologies of spray-dried particles and the influences of the development of that morphology on the retention of volatile flavor and aroma substances. A third was the fundamental causes of product collapse in freeze drying and particle stickiness in spray drying.

As noted previously, King subsequently moved more and more into an administrative career, discontinuing research in 1999. These lines of research did not persist in the department's portfolio. Even though the food industry has for years been a significant employer of chemical engineers, usually at the bachelor's level, the amount of food-related research in academic chemical engineering departments has historically been small to non-existent. Reasons probably include faculty not seeing the potential of exploring fundamental issues within the food arena and the existence of food science and food technology as distinct fields outside of chemical engineering. Yet, as was also the case for electrochemical engineering and processing of materials within the electronics industry, research on foods, food production, and food processing is an area where chemical-engineering principles are important and where there has historically been little academic research involvement of chemical engineers. The involvement of academic chemical engineers in food-related research should increase as more and more start-up enterprises become based upon technologically-based synthetic and/or improved foods, and the tie of research to the product marketplace becomes clearer. There is already evidence of movement in this direction, four examples with Berkeley roots being the activities of Berkeley CBE alumnus Jason Ryder in co-founding

[185] King, 2013, pp. 128-132.
[186] after having had to find out what it was!

Miraculex which makes innovative sweeteners from plant-based materials,[187] CBE PhD alumnus Neil Renninger (PhD with Keasing, 2001) in co-founding Ripple Foods which makes plant-based dairy products,[188] the work of Jay Keasling and co-workers in engineering yeast for the production of hopped beer,[189] and some of the activities of David Soane (see below).

Polymers. The years after World War II brought large growth in the production and uses of synthetic polymers. These materials thereby became common subjects for chemical engineering research. Indeed, the first Nobel Prize in Chemistry awarded to a chemical engineer went to Giulio Natta, who together with Karl Ziegler was awarded the 1963 prize "for their discoveries in the field of the chemistry and technology of high polymers."[190] The first long-term faculty hire for the department in this area was Michael Williams, who came as an Assistant Professor in 1965. Williams had received his PhD in chemical engineering at the University of Wisconsin, working with Robert Bird, senior author of the path-breaking *Transport Phenomena* book, on modeling polymer flow. Williams became interested in the molecular underpinnings of polymer rheology. He spent a post-doctoral year studying polymer chemistry with Marshall Fixman at the University of Oregon's Institute for Theoretical Science. At Berkeley, he worked on both continuum and molecular models for polymer rheology, mechanisms of drag reduction by polymers, and enhancement of pool boiling with polymeric additives. In later years, he also did research on blood damage in shear flow at non-physiologic surfaces, as in extracorporeal assist devices. Williams moved in 1990 to a faculty position at the University of Alberta.

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187 Miraculex, http://www.miraculex.com/. Jason Ryder as of 2020 is Adjunct Professor with the department as Executive Director of the new Professional Master's Degree in Bioprocess Engineering (see below).

188 Meimei Fox, "The Cofounders of Ripple Share Why Plant-Based Foods Are Their Passion," *Forbes*, March 13, 2019. https://perma.cc/B3QA-DPR8

189 Charles Denby, et al., "Industrial brewing yeast engineered for the production of primary flavor determinants in hopped beer," *Nature Communications*, v. 9, no. 965, 2018.

190 The second, awarded in 2019, went to Frances Arnold (see below), UC Berkeley Chemical Engineering PhD (1985, with Blanch) "for the directed evolution of enzymes."

The next addition in the area of polymers was Mitchel Ming-Chi Shen, who arrived in 1969. Shen was a 1963 Chemistry PhD graduate from Princeton where he had carried out his PhD research with A. V. Tobolsky. Shen had then for six years been a member of the chemical physics staff at the North American Rockwell Science Center in Thousand Oaks CA. His research at Berkeley was on rubber elasticity, rheology of entangled liquids, membrane properties, polymer alloys, and plasma-generated polymers. Shen collaborated with Williams in polymer dynamics and, with Alex Bell in plasma polymerization.[191] He had strong intrapersonal skills and understanding and was Vice Chair of the department and Acting Chair during the Spring 1978 sabbatical of the author. Most regrettably, following a brief illness, Mitchel Shen passed away in 1979, at the early age of forty and at the peak of his career.[192]

The department then hired Shen's 1979 PhD graduate, David Soane, to maintain Shen's research group after his unexpected death and to develop research and teaching of his own. Soane himself became a leader in polymer science, investigating polymer rheology, polymerization reaction engineering, and the interplay of solution thermodynamics and phase-separation kinetics in membranes. His work then turned more into applications for microelectronics applications and advanced composites.[193] Soane also became strongly engaged with commercial utilization and founding companies, becoming successful in those areas. He left in 1994 to pursue those interests and become an entrepreneur for manufacturing specialty products. He is now Special Partner with Phoenix Venture Partners and founder of Soane Labs, a technology incubator which is part of Phoenix,[194] as well as being Founder, Director, and Chief Technology Officer of Crop Enhancement, a company engaged in

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[191] "In Memoriam: Mitchel Ming-Chi Shen," *Gilman Hall Newsletter* 4 (December 1979), p. 3.

[192] A. T. Bell, C. J. King & D. S. Soong "Mitchel Ming-Chi Shen, Chemical Engineering: Berkeley," *In Memoriam*, University of California, 1980. https://perma.cc/7E9A-7KKV

[193] *Gilman Hall Newsletter*, June 1989, pp. 7-8.

[194] David Soane PhD, Special Partner, Phoenix Venture Partners, consulted October 1, 2019. https://perma.cc/L9WT-AQ99

enhancing food production and fostering the development of sustainable agricultural practices. He is active with several other ventures as well.

The next major addition in the area of polymers, as well as with wider interests, was Morton Denn, who arrived as a senior faculty appointee in 1981 following a 16-year faculty career at the University of Delaware. Denn's PhD had been with Rutherford Aris at the University of Minnesota, and thereby in the Amundsen school of thought. His research relating to polymer rheology and non-Newtonian fluid dynamics achieved strong recognition. He was active in several other areas, as well, such as optimization of distributed-parameter systems. Beginning in the mid-1970s, he began to simulate polymer-processing operations, including melt spinning (a technique used to cool liquids quickly).[195] A summary of Denn's research to that date is given in a recognition written in connection with his 1986 receipt of the Bingham Award from the Society of Rheology.[196]

In 1981 Denn transferred to Berkeley chemical engineering as a senior faculty appointee. While at Berkeley Denn shifted his research more toward experimentation, notably the flow of fiber suspensions and viscoelastic jet break-up, as well as the fluid mechanics of liquid crystalline polymers and extrusion instabilities. Working within the Lawrence Berkeley Laboratory, he became Program Leader for Polymers and Composites in the Center for Advanced Materials and put together a strong and varied program with emphasis on anisotropic polymers and polymer-surface interactions.

In 2000 Denn became Albert Einstein Professor and Director of the Benjamin Levich Institute for Physico-Chemical Hydrodynamics at the City College of New York, following Andeas Acrivios in that position. He held those positions until his retirement in 2015.[197]

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[195] A. K. Chakraborty, A. B. Metzner & T. W. F. Russell, "ChE Educator: Morton M. Denn," Chemical Engineering Education, v. 30, No. 2, pp. 88-93, 1996.
[196] Morton M. Denn, University of California at Berkeley, Society of Rheology, consulted October 3, 2019. https://perma.cc/5Z9V-2AA3
[197] Morton Denn, Albert Einstein Professor of Science and Engineering, Emeritus, City College of New York, consulted October 3, 2019. https://perma.cc/DV69-52TG

Denn has been a prolific author of books, including a well-used fluid dynamics text and a book aimed at introductory chemical engineering courses.

In 1986 the department added Doros Theodorou as an Assistant Professor. A native of Greece, he had obtained the PhD in Chemical Engineering from MIT working with Ulrich Suter. Theodorou was among the first to use the power of molecular simulation to study diffusion, adsorption kinetics, and phase equilibria in polymeric systems. He and his group utilized concepts of statistical mechanics, thermodynamics, and transport phenomena for the elucidation of the relationships among structure, properties, and processing performance in polymeric materials, as well as for determining the separation and catalytic properties of zeolites. In 1995 the attraction of his homeland caused Theodorou to leave Berkeley for the University of Patras in Greece.[198] He then transferred to the National Technical University in Athens in 2002, where he continues research on computational methods for predicting the properties of materials from their molecular properties.

Susan Muller joined the Department in 1991 following the completion of her PhD in chemical engineering with Robert Armstrong and Robert Brown at MIT in 1986 followed by several years on the technical staff at AT&T Bell Laboratories in Murray Hill, NJ. There she worked on polymer solutions, fiber-optic cable compounds, and microelectronic packaging. At Berkeley, her research focuses on viscoelastic flows, rheology, polymer dynamics, and microfluidics of both biological and synthetic macromolecules, especially complex flows typical of materials processing operations in either macroscale or microfluidic devices. She and her group use a range of experimental techniques, including flow visualization, laser Doppler velocimetry, digital particle image velocimetry, rheometry, size-exclusion chromatography, light scattering, and microscopy.[199] Muller served as an Associate Dean in the UC Berkeley Graduate Division for two periods (2007-2010, 2013-2017).

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[198] Theodorou was a visiting professor in chemical engineering at the University of Patras from 1991-1994 while still affiliated with Berkeley.

[199] Research Interests, Susan J. Muller, College of Chemistry, University of California, Berkeley, consulted October 7, 2019. https://perma.cc/J6UT-2ASV

Rachel Segalman joined the faculty in 2004, following a PhD from the University of California, Santa Barbara (UCSB) and postdoctoral work at the Université Louis Pasteur in Strasbourg, France. Her interests are in controlling structure-property relationships in polymeric materials at the nanoscale level, with diverse and widespread applications. She moved back to UCSB in 2014.

Surface and Colloid Science and Engineering. Clayton Radke joined the faculty in 1975 to develop a program relating to the science and engineering of colloids and surfaces. He had received his PhD at Berkeley with Prausnitz in 1971, had spent a postdoctoral year at the University of Bristol, and then had been on the faculty at Penn State. A description[200] of his research states that it "focuses on combining principles of surface and colloid science towards engineering technologies where phase boundaries dictate system behavior. He employs modern spectroscopic tools along with molecular theory and simulation, and continuum transport and reaction engineering to provide quantitative description of interfacial behavior important to technology development. Specific areas of interest include: protein/polymer/surfactant adsorption from solution, two-phase enzymatic catalysis, interfacial surfactant transport, wetting and spreading, colloid stability, dynamics and stability of thin films, chromatography, multiphase and disperse phase flow in porous media, wettability of and chemical transport and reaction in porous media, electrokinetics, pore-level fluid mechanics, tear films, and contact-lens coating and physical design." Much of his porous-media research has been directed toward enhanced recovery of oil from underground petroleum reservoirs and was specifically recognized in the citation for his election to the National Academy of Engineering in 2015 as well as several awards from the Society of Petroleum Engineering. His research relating to contact lenses is more recent, has been recognized with the Ruben Medal of the International Society for Contact Lens Research, and has led to a joint faculty appointment in the UCB School of Optometry. The contact-lens research is another example where it has been valuable to go into an area where chemical engineering principles are

[200] Research Interests, Clayton J. Radke, College of Chemistry, University of California, Berkeley, consulted October 14, 2019. https://perma.cc/5UZP-GVAC

useful, but which has not yet been much visited by chemical engineering researchers.

NMR. While his initial research focus was on solar cell materials, Jeffrey Reimer maintained an interest and expertise in magnetic resonance methods, and NMR of solids in particular from his Caltech days. While at Berkeley Reimer undertook a wide and highly diverse variety of studies employing NMR and related techniques for applications in solar cells, in-situ catalyst conditions, liquid-crystal polymers, polymers adsorbed to surfaces, and electrochemical processes, gas separations, and NMR methods under conditions of controlled temperature, pressure, flow, and electrochemical potential. Indeed, Reimer brought NMR to virtually every aspect of the department and co-authored works with Balsara, Bell, Cairns, Clark, Graves, Iglesia, Long, Muller, and Smit.[201]

Reimer has, in fact, excelled in all three areas of faculty endeavor – research, teaching and service. He has devoted considerable time and effort to the design and use of insightful methods for teaching and learning, and he has received a number of teaching awards, including the UC Berkeley Distinguished Teaching Award. His introductory textbook with T.M. Duncan is now in its second edition (Appendix F), and his carbon-capture course yielded another book (see also Appendix F). He was Associate Dean of the Graduate Division, 2000-2005, and is now the longest-serving department chair for ChE/CBE (Appendix C).

Applications of Theoretical Chemistry. In 1988 the department made an addition specifically in the use of theoretical chemistry in research by hiring Arup Chakraborty at the Assistant Professor level. Following his PhD at the University of Delaware with Bischoff, Astarita, and Damewood on the molecular basis for substituent effects in amine-$C0_2$ reactions, Chakraborty had a postdoctoral position at the University of Minnesota with Ted Davis on theoretical aspects of polymer-metal interfaces. In his Berkeley research he focused his theoretical abilities on several areas, including polymer interfaces and sensor technology and catalysis, as well as collaborating with several faculty colleagues. He developed interests in understanding how the adaptive immune system is regulated in humans, and in utilizing that understanding to design

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[201] The Reimer Group, College of Chemistry, University of California, Berkeley, consulted October 14, 2019. https://perma.cc/N2HV-C27K

vaccines against diseases such as human immunodeficiency virus (HIV). He then focused his research almost exclusively on that area.[202] In 2005 he moved to MIT, which is located in the midst of the noted research hospitals of the Boston region. Chakraborty was elected to the National Academy of Engineering in 2004 while he was still at Berkeley, to the National Academy of Sciences in 2016, and the Institute of Medicine in 2017, making him one of extremely few people who are, or have been, members of all three U. S. national academies.

In 2007 the department attracted Berend Smit for an appointment at the full-Professor level. Smit received MSc degrees in both Chemical Engineering and Physics from the Technical University in Delft and the PhD in Chemistry from Utrecht in 1990. He had been with Shell Research, 1988-1997 and was then Professor of Computational Chemistry at the University of Amsterdam, 1997-2007. His research focused on the application and development of novel molecular simulation techniques, with emphasis on energy-related applications. He had co-authored a book on molecular simulations. At Berkeley, Smit furthered the connection to the Department of Chemistry by assuming a joint appointment, led the effort to incorporate modern molecular simulations and statistical methods throughout the department, and co-authored with Reimer and others the aforementioned book on carbon capture and sequestration. He assumed a professorship at the Swiss Federal Institute of Technology in Lausanne in 2014.

The department has continued interests in theoretical chemistry in further hires, notably bringing in Teresa Head-Gordon as a joint appointee with Chemistry (2011) and adding Kranthi Mandadapu (2017), Rui Wang (2019), and Karthik Shekhar (2020), a PhD graduate with Arup Chakraborty at MIT.

Process Systems and Control. Following the earlier work of the department in process systems and process control in the 1960s, 70s, and 80s, Ali Mesbah was added to the faculty in 2014 following a PhD and postdoctoral work at Delft University of Technology and further postdoctoral work at MIT. His research is

[202] Understanding the Adaptive Immune Response to Pathogens, Arup K. Chakraborty Group, Massachusetts Institute of Technology, consulted October 14, 2019. https://perma.cc/6CZ5-VSGH

at the intersection of control theory, applied mathematics, and process systems engineering with particular attention to complex systems that are stochastic and non-linear, with applications to chemical and biological systems and to energy.

The faculty members of the department as of the end of 1982 are shown in Figure 8. A sub-group at a College of Chemistry commencement is in Figure 9.

TRENDS OF RESEARCH OVER TIME

It is revealing to look at the trends in the nature of chemical engineering research over the seventy-five years that the department has been in existence. The department started in the days where the unit operations concept largely defined chemical engineering and the slide rule and mechanical calculators were the means of calculation. Research and the methodology of the discipline then swung to interpretation of phenomena in terms of mathematical models and measurable continuum properties such as viscosity, diffusivity, and phase equilibria. Research then further evolved to measurement and use of properties at the molecular level, such as the dipole moment and intermolecular forces, and then further to quantum mechanics and *ab initio* computations. Going along this path has been enabled by the enormous advances in digital computing capacity and speed (Moore's Law) that have occurred over the lifetime of the department, as well as the major advances in instrumentation that have enabled viewing actual structures and dynamics at molecular and even atomic levels. These changes over time are well described by Bell in his oral history.[203]

[203] Bell, 2020, pp. 102-104.

FIGURE 8. Berkeley Chemical Engineering Faculty on the front steps of Gilman Hall (December, 1982). Left to right, front row: Michael Williams, Ralda Sullivan, Dennis Hess, David Soane, Charles Wilke. Harvey Blanch (behind and to the left of Hess). David Lyon (behind Hess and Soane). Simon Goren (behind Wilke.). David Quady (behind Goren and Soane). Second row: Eugene Petersen, Alexis Bell, Morton Denn, Jeffrey Reimer. Third row: John Newman, John Prausnitz, Frank Valle-Riestra, Rolf Muller. Bud Blue (behind Denn). Fourth row: Scott Lynn, Judson King, Donald Hanson. Fifth row: Arthur Morgan, Edward Grens. Rear: Alan Foss, William Benjamin, Theodore Vermeulen. Not present: Elton Cairns, Clayton Radke

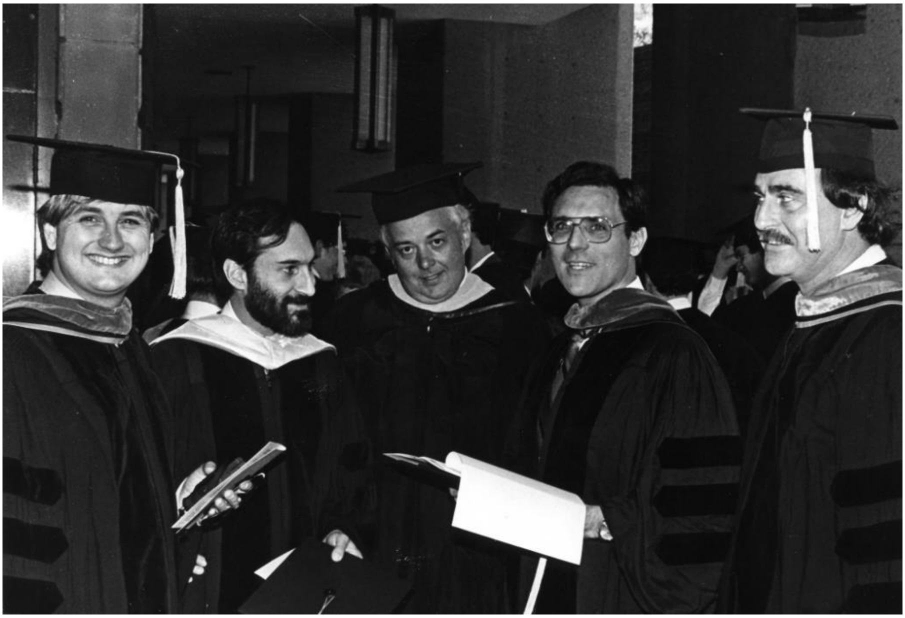

FIGURE 9. A Post-Commencement Faculty Group from the 1980s. Left to right: Jeffrey Reimer, James Michaels, Fred Vorhis, Alexis Bell, Paul Plouffe.

The movement toward the molecular in research has also meshed with the fact that many of the newer commercial uses of chemical engineering are more chemical in nature, starting with both the microelectronics and biotechnology industries. The trends fit well with the affiliation of the department with the College of Chemistry, since that structure brings chemical engineering and chemistry closer together. Indeed, over the same period of time the Department of Chemistry has also evolved so as to make the interests within the two departments more kindred, with the addition of activities relating to biological applications, polymers, surface coatings, improved separating agents, and the like. Thus, there are more joint research and more joint appointments between the two departments.

THE CONNECTIONS AMONG RESEARCH, PRACTICE, AND THE CURRICULUM

Alex Bell has indicated that the concentrated hiring of faculty with molecular interests (Reimer, Theodorou, Chakraborty) during his chairmanship of the department (1981-91) was controversial among the older faculty.[204] One issue was whether the lines of research were too removed from the chemical engineering curriculum, such that the department would find it difficult to cover that curriculum so as to prepare practicing engineers adequately. Another, related issue was whether the trend would remove the department too much from the interests of current employers of chemical engineers. Yet another way of expressing these issues is to ask how far research should be out in front of the needs and practices of employing industries. It should surely be out in front, but by how much?

What has happened over the years seems to confirm the wisdom of Berkeley ChE/CBE in choosing to lead the evolving directions of the field. As well, the trend toward more molecular-level bases for research is by no means specific to Berkeley. It has now occurred for chemical engineering at most other major research universities, having typically happened somewhat later than at Berkeley.

These issues play out in another way, which is the specificity of preparation of graduates for employment. Front-line supervisors in industry sometimes remark that graduates do not have practical engineering know-how, e. g., they don't know when different types of pumps should be used for what purposes. The matter is also complicated by the wide variety of industries in which graduates are employed and the very great differences among the practicalities of those various industries, as well as the fact that a substantial fraction of graduates go on to other careers rather than being practicing engineers. National data for the United States show that about half of those with their highest degree in chemical engineering go on to careers in other fields.[205]

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[204] Interview of Elif Kale Lostuvali with Alex Bell, 30 January 2007.

[205] Domenico Grasso & J. J. Helble, "Holistic Engineering and Educational Reform," Figure 7.7, p. 88, in Domenico Grasso & M. B. Burkins, eds., *Holistic Engineering Education: Beyond Technology*, Springer, 2010.

These dichotomies among research, curriculum and practice have been explored for chemical engineering by Reimer.[206] It is, in fact, an issue that pervades the various academic professional fields.[207] In the chemical engineering department awareness of these issues is a contributing factor to the use of Lecturers from the profession in the design course and now elsewhere in the curriculum. A delicate balance must be maintained between having research that is out in front leading the directions of a field and maintaining the very real benefits of engaging and utilizing the prominent research faculty in core teaching. For chemical engineering these issues are another variant of the Longhairs vs. Hairy Ears argument.

MULTIDISCIPLINARY RESEARCH AND COLLABORATIONS AMONG RESEARCHERS

Faculty research has become more collaborative over the lifetime of Berkeley chemical engineering. There are several reasons for this trend. While the field itself, and particularly the incorporation of mathematics and science into research, were still young in the early years of the department, the field has matured enough in later years so that many of the more interesting and compelling matters for research lie at the edges of the discipline, and increasingly at intersections of several disciplines, where the full powers of each of the component disciplines must be brought intimately together for progress. As well, with more integration of fundamental science, the useful means of instrumental measurement and analysis have become more complex. Expertise in any particular such method is centered in relatively few people. Hence two important drivers for collaboration are the need for complementary disciplinary backgrounds and expertise in particular methods of analysis and instrumentation. Another factor becoming more important is the need for

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[206] J. A. Reimer, "Chemical Engineering Apologetics," in K. Vaidya, ed., *Chemical Engineering for the Curious*, Ch. 9, The Curious Academic Publishing, 2015. https://perma.cc/2EEU-BHAC

[207] C. J. King, "A Provost for Professional Schools and Colleges," No. CSHE.3.13, Research and Occasional Papers Series, Center for Studies in Higher Education, University of California, Berkeley, February 2013. https://perma.cc/FG2R-Y6WZ

linking considerations of social science with those of natural science and engineering. Finally, there are cases where project design and obtaining financial support are facilitated by generating a large, multi-investigator project of kindred research.

There are also factors which complicate or oppose collaboration. These include difficulties of communication across distances and time zones (now much mitigated by information technology), the needs for bringing minds together in cases of disagreement, and even the fact that vocabularies are different for different fields.

Interactions within the Department. Collaborations develop more readily when the participants know each other well. Hence it was natural that the first collaborations started within the department, with the original case being that between Tobias (electrochemistry) and Wilke (mass transfer) leading to the well-regarded research of their student Morris Eisenberg on mass transfer in the vicinity of rotating electrodes. Later collaborations abound, with two important drivers having been uses of specialized monitoring techniques and linkages of methodology from other types of chemical-engineering research with biomolecular research. While not a comprehensive list, the following examples give the flavor.

- In his later career Prausnitz has collaborated with Radke and Blanch so as to place the analysis of bioprocessing systems and separations on a more fundamental, molecular basis, including the use of ionic liquids for separations.[208]
- As Dennis Hess started research on the processing of electronics materials he collaborated with David Soane (polymers), Alex Bell (plasmas), Harvey Blanch (biosystems), and Jeff Reimer (NMR).[209]
- As already observed, many faculty members have had collaborations with Reimer in which his knowledge of NMR and other sensing techniques have been important.

[208] Prausnitz, 2020, pp. 117-121.
[209] Dennis W. Hess, Personal Communication, September 7, 2019.

- Douglas Clark has had research with David Graves on utilizing low-temperature plasmas for medical applications[210] and with David Schaffer on stem-cell fate.[211]
- Alex Bell in his oral history[212] notes collaboration with Shen on plasma deposition of polymers and with Theodorou and then with Chakraborty on theoretical aspects of adsorption and catalysis.
- As has already been noted, Chakraborty had many collaborations where his knowledge of theoretical chemistry was useful.

Interactions with Chemistry. Despite the origin within the College of Chemistry, in the early years of the Berkeley chemical engineering program there were relatively few intellectual or research interactions between the chemical engineering faculty and those in chemistry. An exception was the relationship between John Prausnitz and Joel Hildebrand, resulting in the book revision mentioned above. One important effort to draw the departments together intellectually was the College Research Conference, held weekly since the time of Gilbert Lewis in Chemistry with the speaker being a College faculty member. As the Chemical Engineering program came into being, these were attended by faculty and students from both departments. Sometimes the interests of the two departments seemed far apart, as the author discovered in giving two of these presentations, one on mass-transfer mechanisms within irrigated packed columns and the other on freeze-drying of turkey meat. The disparate interests were one of the causes of the abandonment of the venerated Research Conference in the mid-1960s.

The growth over the years in collaborations between chemical engineering and chemistry faculty members has been rationalized in at least two different ways.

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[210] See, e. g., M. J. Traylor, M. J. Pavlovich, S. Karim, P. Hait, Y. Sakiyama, D. S. Clark & D. B. Graves, "Long-term Antibacterial Efficacy of Air Plasma-activated Water," *J. Phys. D: Appl. Phys*., v. 44, 472001, 2011.

[211] See, e. g., G. J. Nierode, B. C. Perea, S. K. MacFarland, J. F. Pascal, D. S. Clark, D. V. Schaffer, and J. S. Dordick, "High-Throughput Toxicity and Phenotypic Screening of 3D Human Neural Progenitor Cell Cultures on a Microarray Chip Platform," *Stem Cell Reports*, v. 7, pp. 970-982, 2016.

[212] Bell, 2020.

In 1998 interviews,[213] Charles Wilke noted that "as chemical engineering became more microscopic in nature, more collaboration [between Chemistry and Chemical Engineering] followed," and Alex Bell observed that "over the past twenty years, shared interests have grown as chemical engineering has moved into research at the frontiers of chemistry, and chemistry has moved toward catalysis, biotechnology and materials synthesis."

A prime example of intellectual reinforcement between chemistry and chemical engineering faculty members over nearly fifty years now has been between Chemistry Professor Gabor Somorjai and Chemical Engineering Professor Alex Bell in the areas of catalysis and surface science. There have not only been joint projects in areas such as the uses of synthesis gas,[214] but also general interactions between the research groups such as members attending both group seminars.[215] As described above, Bell's research has moved toward involvement of theoretical chemistry in recent years, and in that regard he has collaborated with Martin Head-Gordon of Chemistry.[216]

Another collaborator with Chemistry has been Jeff Reimer, who has worked with Chemistry professor Alex Pines in areas where their mutual expertises on NMR are complementary. More recently, Reimer and Jeffrey Long of Chemistry (and now with a 0% joint appointment in CBE) have collaborated on *in-situ s*pectroscopic and diffraction methods to investigate how metal-organic frameworks with coordinately unsaturated metal sites adsorb target gas molecules with high affinity and selectivity.[217]

Another form of evidence of the growing intellectual closeness of the two departments lies in faculty appointments that are joint between the departments. The first of these was Arup Chakraborty in 1998 and has been followed by Jean Fréchet, Jeffrey Long, Teresa Head-Gordon, Berend Smit, and Michelle Chang. Joint faculty appointments are not limited to those within the

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[213] Greg Butera, College of Chemistry Newsletter, 1998.
[214] Bell, 2020, pp. 106-108.
[215] Butera, 1998, *loc. cit*.
[216] Bell, 2020, pp. 234-237, 248-255.
[217] The Reimer Group, College of Chemistry, University of California, Berkeley, consulted November 7, 2019. http://india.cchem.berkeley.edu/~reimer/topics/topics2019.html

College of Chemistry. Jay Keasling and David Schaffer of CBE have 0% joint appointments with Bioengineering, and Sanjay Kumar from Bioengineering has a 0% joint appointment in CBE.

Interactions with Other Disciplines and Outside Berkeley. Research collaborations outside the College of Chemistry in the earlier years of the department were hampered by both a lack of tradition of such interactions and organizational boundaries. Interest in interdisciplinary or multidisciplinary research arose in the early 1970s as greater awareness of issues of environment and energy created rationales for doing so. The Energy and Resources Group was created on the Berkeley campus in 1973-74 as a degree-giving body.[218] A small core group of faculty appointees in the Group was complemented by a large number of affiliate appointments of faculty members from other departments. Elton Cairns is one such affiliate. Roya Maboudian has been a member of the Berkeley Sensors and Actuator Center,[219] funded by NSF and a consortium of industries. Within chemical engineering, one driver toward interdisciplinary research collaborations was the movement of the profession into applications pertaining to a large variety of industries rather than just heavy chemicals and petroleum, and in particular the move toward biological applications. Another driver was the move toward research more on the scientific and molecular level. As already noted, access to, and utilization of, specialized instrumentation also has led to collaborations.

Ad-hoc Collaborations. There have been many ad-hoc research collaborations by individual CBE faculty members with faculty from other disciplines and/or outside the Berkeley campus. Two examples among many are the joint program that Dennis Hess developed with Michael Lieberman in Electrical Engineering during the years before his 1991 departure[220] and the collaboration between

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[218] It is actually an Augmented Graduate Group. Graduate groups can give approved graduate degrees, and "augmented" refers to the unusual status for a Graduate Group of having its own budget.

[219] Berkeley Sensor and Actuator Center, University of California, Berkeley, CA. http://www-bsac.eecs.berkeley.edu

[220] Dennis W. Hess, personal communication, September 7, 2019.

Alexis Bell and Bruce Gates of the UC Davis campus on the use of x-ray absorption spectroscopy for catalysis studies.[221]

Structured Institutes and Collaboration beyond the Berkeley Campus. The Berkeley campus and the University of California were pioneers in the creation of Organized Research Units (ORUs)[222,223] in the period after World War II. These were formed for the specific purpose of bringing together researchers from different disciplines, often for the purpose of facilitating proposals for government grants. Chemical Engineering, through Vermeulen and then the author, was a participant in the Sea Water Conversion Laboratory which later became the Water Thermal and Chemical Technology Center, with Vermeulen as Director.

In 2000 an initiative of Governor Gray Davis led to the California Institutes on Science and Innovation, now the Governor Gray Davis Institutes on Science and Innovation.[224,225] These are four large multi-campus, multi-disciplinary research units spread throughout various combinations of the UC campuses. The Berkeley campus is involved in two of them, the California Institute for Quantitative Biosciences (QB3) and the Center for Information Technology Research in the Interest of Society (CITRIS). These large institutes provide for housing of research within institute buildings, symposia and other interactions among the investigators, and an administrative structure that facilitates proposals and research. Within CBE, Michelle Chang, Douglas Clark, Teresa Head-Gordon, Jay Keasling, Sanjay Kumar, Markita Landry, David Schaffer, Karthik Shekhar, and Wenjun Zhang are nine of the 112 faculty members involved with QB3, and Roya Maboudian and Ali Mesbah have been involved with CITRIS. As of 2020, CBE's David Schaffer is Director of QB3 at Berkeley.

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[221] Bell, 2020, pp. 179-180.
[222] R. L. Geiger, *Research and Relevant Knowledge: American Research Universities since World War II*, pp. 48-57, 75-76, Oxford University Press, 1993.
[223] King, 2018, pp. 517-522.
[224] California Institutes for Science and Innovation: A foundation for California's future, University of California. https://perma.cc/Y4RQ-KE8D
[225] King, 2018, pp. 523-526.

Another, smaller initiative in the year 2000 was a solicitation by BP (formerly British Petroleum) for proposals relating to research on fundamental aspects of catalysis. It ended up as the previously mentioned Methane Conversion Collaborative, covered work in homogeneous catalysis at Caltech and heterogeneous catalysis at UC Berkeley, both funded at a level of $1 million per year. The Berkeley work involved Bell,[226] Iglesia,[227] and Chakraborty of CBE.

The existence of QB3 and the organizational and administrative structures within it greatly facilitated the preparation of the proposal leading to the Energy Biosciences Institute,[228] a competition held by BP in 2006 which was won by a team headed by the University of California, Berkeley and including the Lawrence Berkeley Laboratory and the University of Illinois, Urbana-Champaign. The Institute sought innovative means of creating and producing fuels from biological sources and was funded at $500 million over ten years. Some of the funding was devoted to BP personnel and purposes at the site. Among the Berkeley CBE faculty participating in the Institute were Nitash Balsara, Alexis Bell,[229] Harvey Blanch, Douglas Clark, John Prausnitz, and Wenjun Zhang.[230]

There have been many other organized research structures at Berkeley that involve biomolecular engineering as an important component. One of the first was the Helen Wills Neuroscience Institute,[231] which was formed in 1997, funded by the estate of Helen Wills Moody, eight times Wimbledon tennis champion, 1927-1938, and a Berkeley graduate. Following voter passage in 2004 of California Proposition 71, which provided for three billion dollars of general-obligation bonds over ten years for stem cell research and research facilities, the campus formed the Berkeley Stem Cell Center.[232] CBE Professor

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[226] Bell, 2020, pp. 190-193.
[227] Iglesia, 2014, pp. 66-68.
[228] King, 2018, pp. 644-650.
[229] Bell, 2020, pp. 200-209.
[230] Publications, Energy Biosciences Institute, University of California, Berkeley, consulted November 12, 2019. https://perma.cc/3S7V-2UQX
[231] Berkeley Neuroscience, Helen Wills Neuroscience Institute, University of California, Berkeley, consulted November 11, 2019. https://neuroscience.berkeley.edu/
[232] The Berkeley Stem Cell Center, University of California, Berkeley, consulted June 14, 2020. https://perma.cc/7TUC-QV55

David Schaffer has been director of that center, and Sanjay Kumar, Markita Landry, and Karthik Shekhar of CBE are other members. The Joint BioEnergy Institute (JBEI) (SynBERC)[233] was formed in 2006 with CBE professor Jay Keasling as Director and was funded for ten years by the National Science Foundation.

In 2007, the U. S. Department of Energy conducted a competition for three Bioenergy Research Centers (BRCs) for the development of advanced, next-generation biofuels. One of the winners was the Joint BioEnergy Institute (JBEI),[234] led by the Lawrence Berkeley Laboratory. There are five other national laboratory partners and six university partners which include Berkeley and three other University of California campuses. The location is Emeryville, CA (near Berkeley), and funding for the first ten years was $25 million per year. A new competition was held in 2017, in which JBEI was also a winner, with continued funding intended at $19 million per year for five years. CBE Professor Jay Keasling has been CEO of JBEI from the start.

The California Research Alliance by BASF (CARA),[235] formed in 2014, brings together university researchers at Berkeley and elsewhere in California working on new inorganic materials and their applications, biosciences, and related technologies. BASF counterparts also participate in this research. The program works through a hub-and-spokes model in which the research projects and activities are coordinated from UC Berkeley's College of Chemistry as the hub. Some of the research projects are carried out at Stanford University, Caltech, and other UC campuses. Current participants from Berkeley CBE are Enrique Iglesia and Markita Landry.

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[233] Synberc, Synthetic Biology Research Center, University of California, consulted November 10, 2019. https://perma.cc/B5LJ-6PDW

[234] JBEI, Joint BioEnergy Institute, Office of Science, U. S. Dept. of Energy. https://perma.cc/U8QE-TJUE

[235] CARA, California Research Alliance by BASF, University of California at Berkeley. https://perma.cc/AX5Y-PYYZ ; California Research Alliance, BASF. https://perma.cc/M3GA-UZU7 ; Mark S. Reisch, "A new model for industry-sponsored research on university campuses," *Chem. & Eng. News*, v. 86, no. 34, pp. 21-23, August 27, 2018.

The Chan-Zuckerberg BioHub,[236] formed in 2016, is a $600 million commitment for research to be carried out at UC San Francisco, UC Berkeley, and Stanford on forefront biomedical research. CBE researchers funded by it so far are Markita Landry,[237] David Schaffer,[238] and Wenjun Zhang.[239]

FUNDING BASES, INTERACTIONS WITH INDUSTRY, DEVELOPMENT, AND FACILITIES

These seemingly disparate subjects form an interacting web and hence are treated together in this section.

Sources of Funding Over the Years. A simplistic view of the funding of the University of California over the years since its founding entails several successive eras, as follows.[240] From the 1868 founding of the university until the end of the nineteenth century financial support was meager and was as much or more from private sources as from the state. With the arrival of Benjamin Ide Wheeler as President in 1899 public support became *per capita* based upon enrollment and much more substantial. This situation pertained until World War II, with a substantial dip during the depression years of the 1930s. The university received substantial research funding from the federal government during World War II dedicated to specific purposes, notably those related to the Manhattan Project.

The two decades after World War II brought large funding in three ways. The state of California had amassed a large budget surplus during World War II through its many defense-oriented industries. The GI Bill supplied funds for returning veterans to undertake higher education and swelled enrollments.

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[236] Chan Zuckerberg Biohub. https://perma.cc/A5G3-ZHS6
[237] Robert Sanders, "CZ Biohub awards nearly $14.5 million to Berkeley researchers," February 8, 2017. https://perma.cc/RAF9-LMC7
[238] Berkeley Neuroscience News, "David Schaffer funded by Chan Zuckerberg Biohub Intercampus Research Award," October 16, 2018. https://perma.cc/E5F9-EDWW
[239] Sanders, 2017, *loc. cit.*
[240] King, 2018, pp. 21-29, 31-70.

Sustained federal research funding increased markedly with the establishment of the National Science Foundation, the Basic Energy Science program within the Department of Energy, and major research-funding operations in other government agencies. Consequently, the resources were available to the university for much development, including three entirely new campuses (San Diego, Irvine, Santa Cruz) and conversion of three other previously specialized campuses (Davis, Santa Barbara, Riverside) to become full general campuses. Student activism, which arose at Berkeley in 1964, became a main political issue for Ronald Reagan, who became Governor in 1967 and whose influence led to the dismissal of Clark Kerr as UC President that same year.[241] That episode and further student activism on other UC campuses,[242] coupled with a tightening state budget, made state funding much more stringent for the next sixteen years.

In 1984 new UC President David Gardner was able to convince new Governor George Deukmejian that a 30% increase in the state budget for UC was warranted. This remains the largest one-year percentage increase that the university has ever received from the state. The budget dropped again in the early 1990s, and state funding for UC fell by 20% between 1990 and 1996. The university was able to mitigate the effects of this sharp drop in a one-time-only way through three successive waves of a retirement-incentive program, utilizing what at the time was plentiful funding in the University of California retirement system brought about by a highly successful investment history.[243] State funding for the university was relatively strong during the presidency of Richard Atkinson (1995-2003), but then declined again, the decrease being accentuated by the recession of 2008. In all, state funding per student declined precipitously by a factor of two(!) during the decade from 2000-01 to 2010-11.[244]

[241] Seth Rosenfeld, *Subversives: The FBI's War on Student Radicals, and Reagan's Rise to Power*, Farrar, Straus and Giroux, 2012.
[242] See, e. g., William McGill, *The Year of the Monkey*, McGraw-Hill, 1982.
[243] The funding that had developed within the retirement system was large enough so that there was a twenty-year suspension of employee and state contributions to it from 1990 to 2010.
[244] King, 2018, Figure 2-8, p. 67.

There is also extreme volatility from year to year in the state budget. This is associated with the fact that Proposition 13 (the Jarvis-Gann initiative, passed in 1978) has greatly limited revenue from property taxes, with a consequent shift of local funding needs (e. g., public schools) from local budgets to the state budget. In addition, about 90% of the state budget (but not higher education) is pre-determined rather than being subject to the annual legislative process. This is a result of actions such as Proposition 98 of 1988, which mandated the state budget for schools and community colleges.[245] State revenue is heavily based upon income tax from high-wage earners, which varies from year to year.

This history has made it necessary for the university to build other revenue streams in addition to the state support that remains (about 11% of total UC income as of 2019). The principal sources, all now individually exceeding state support, have been student fees (now finally called tuition), federal-government funding of research, and development (raising funds from the private sector). The fee/tuition increases have been accompanied by a 1/3 return to student financial aid, the federal research funding is of course restricted as to use, and private contributions are usually for specific purposes identified by the donor as a condition for the gift.

Funding of Faculty Positions. Historically, back over the past century, salaries for all faculty positions in the University of California were state-funded. As federal funding of research grew in the latter part of the twentieth century, a few academic units, such as the Berkeley School of Public Health, were allowed to make faculty appointments with salaries on grant funds with the understanding that there was no guarantee of continued employment. As of 1999 the only allowable sources other than the state budget for faculty appointments are endowment income and fee income from either high-fee graduate professional programs or fully self-supporting graduate degree programs. There is also an upper limit of 7% on the total number of faculty positions on a UC campus that may be funded from non-state sources and a limit of 15% per college or school. As well, at least 10% of the faculty funding base for a UC campus must be maintained for temporary faculty

[245] King, 2018, pp. 46-48.

appointments.[246] The Department of Chemical and Biomolecular Engineering is starting to make use of the latitude that is provided by these provisions.

Interactions with Industry. The first new source of private funds during the years after World War II was industry. The tradition of the College of Chemistry through the G. N. Lewis era was to discourage interactions with industry so as to keep research free of undue influences. This stance reflected the personal predilections of Lewis, again probably affected by the rancor that he had lived with at MIT during the contentions between William H. Walker and Arthur A. Noyes. With the growths of chemical engineering and organic chemistry after World War II came more interests in interactions with industry. One of the first actions taken by the author when he became Chair of the Department of Chemical Engineering in 1972 was to initiate an industrial Advisory Board for the department. Members of the initial Board represented typical employing industries at the time and included Richard Emmert of DuPont, Chair; Walter Benzing of Applied Materials; Thibaut Brian of Air Products; David Brown of Halcon International; W. Kenneth Davis of Bechtel; former President H. D. Doan of Dow Chemical; Bryce MacDonald of Kennecott Corp.; John W. Scott of Chevron; and Berkeley PhD graduate Frank B. Sprow of Exxon.

The departmental advisory board functioned for many years in a very helpful fashion. As already noted, one of the first recommendations of the Advisory Board was for development of graduate-level instruction in process economics. Another was for further instruction in written and oral communication (see below). During his deanship of the College of Chemistry (1994-99) Alexis Bell created an Advisory Board for the College of Chemistry as a whole, at which point the separate departmental Advisory Board was discontinued.

In the 1970s decisions were taken by many corporations to limit, redirect, and/or downsize their in-house research operations.[247] Following an initial meeting in Midland, MI called by Vice President Malcolm E. Pruitt of Dow Chemical Company in 1979, the Council for Chemical Research (CCR) was

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[246] King, 2018, p. 716.

[247] An early example was the decision to relocate the Shell Development Company from Emeryville, CA to Houston, TX in 1972 and narrow its mission.

formed in 1980 as an organization bringing academic chemistry and chemical engineering department chairs together with industrial leaders and to encourage and facilitate industrial sponsorship of academic research.[248] The author was a member of the Founding Board, and he, Alexis Bell, and Jeffrey Reimer became Chairs of CCR over the years.

A variety of new arrangements occurred between industry and universities and/or individual faculty members, thereby creating new needs for policies that would govern relations of universities with industry. One early such instance occurred close to home in 1980 when Engenics Corporation[249] was formed by Channing Robertson of Stanford and Harvey Blanch of Berkeley, both chemical engineering faculty members. Engenics would support the university research of the two faculty members in addition to its commercial efforts aimed at growing cells to make protein products such as lactic acid and poly-lactic acid. The Berkeley campus was almost totally without relevant policies at the time and had to address the issues in a *de novo* manner. This and other situations led the Berkeley campus and the University of California as a whole to move along expeditiously in developing policies for interactions with industry, including ones pertaining to conflicts of interest, conflicts of commitment, openness of research, university patenting, and licensing of inventions.[250]

As the years have gone on, faculty entrepreneurism and faculty involvement with the formation and start-up of companies have become much more common. One of the reasons has been the short time period between university research and the development and commercialization of products in industries such as biotechnology and the development and improvement of batteries. Another has been active encouragement by the university for start-ups, using mechanisms such as SkyDeck[251] and other incubators and start-up

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[248] J. I. Legg, "The Council for Chemical Research: Developing the Trust Factor," Ch. 2, pp. 5-15, in J. E. McEvoy, ed., *Partnerships in Chemical Research and Education*, ACS Advances in Chemistry Series, v. 478, 1992.

[249] See Martin Kenny, *Biotechnology: The University-Industrial Complex,* pp. 48-49, Yale University Press, New Haven, 1986.

[250] King, 2018, pp. 652-656.

[251] Berkeley SkyDeck, University of California, Berkeley, consulted November 12, 2019. https://perma.cc/52AL-97PL

accelerators.[252] Many corporate start-ups have now come out of Berkeley chemical engineering. Examples are the involvements of Jay Keasling[253] with Amyris (2003), Codon Devices (2004),[254] LS9 (2005), Lygos (2010),[255] and Demetrix (2015)[256]; Nitash Balsara with Seeo (2006) and Blue Current (2014) [257]; David Schaffer with Valitor (2010), 4D Molecular Therapeutics (2012), and IGNITE Immunotherapy (2016)[258]; and Jeffrey Long with Mosaic Materials (2014).[259] Members of the CBE department thereby have become substantial players in the start-up culture of the San Francisco Bay Area. These activities directly demonstrate the importance of research universities for the economy, but also pose the new dimension of making sure that faculty involvement with corporations does not detract from their performance of their duties as faculty members.

The encouragement of the university for start-ups and the interests of faculty and students in doing so reflect a major change from the days of G. N. Lewis where involvement with industry and commerce was discouraged, and the time when public universities were primarily concerned with protecting their reputation as not favoring any one private entity over others. The change has come about by degrees over the past forty years as a result of several factors –

[252] King, 2018, pp. 656-658.
[253] James Temple, "The scientist still fighting for the clean fuel the world forgot," *Technology Review*, May 10, 2018.
[254] "Synthetic Biologists Assemble Codon Devices," BioIT World, 2005. https://perma.cc/YF9L-PVEZ
[255] Julie Chao, "JBEI Startup Takes Aim at Petrochemicals," Berkeley Laboratory, February 28, 2012. https://perma.cc/46FJ-EZCD
[256] "Demetrix, Inc. and UC Berkeley enter exclusive licensing agreement for cannabinoid production," Ciston PR Newswire, May 4, 2019, consulted November 12, 2019. https://perma.cc/9KEP-3PVN
[257] Marge d'Wylde, "Nitash Balsara: Graduates, Postdocs, and the Startup Culture," *Catalyst*, v. 14, no. 1, pp. 18-19, Spring/Summer 2019. https://berkeley.app.box.com/v/catalyst-14-1
[258] Marge d'Wylde, "David Schaffer: Putting Research to Work for the Public Good," *Catalyst*, v. 14, no. 1, pp. 20-21, Spring/Summer 2019. https://berkeley.app.box.com/v/catalyst-14-1
[259] "Mosaic Materials: Capturing CO_2 Directly from the Atmosphere," *Chem. & Eng. News*, v. 97, no. 44, pp. 38-39, November 11, 2019.

the desire of research universities to be recognized as the major contributors to economic growth that they are, the closer and more interactive ties between academic research and the commercial arena that started with the biotechnology surge and the Bayh-Dole Act (see below) around 1980, the desire of universities to replace shrinking state financial support, and the lure to individuals of economic gain. Despite the benefits it remains important to assure that the openness, fundamental purposes, and nature of university education are not distorted by commercial interests.[260]

Sources of Research Support. The Berkeley chemical engineering program began in earnest in the immediate post-World-War-II period during which federal-government support of civilian research developed. The National Science Foundation (NSF) was launched in 1950. As already noted, the block grant from the Nuclear Chemistry Division of the Lawrence Berkeley Laboratory provided welcome start-up support within chemical engineering from the initiation of the grant in 1953 well into the 1960s.

The Arab Oil embargo of the early 1970s, the formations of the Energy Research and Development Authority (ERDA) in 1975 and then the U. S. Department of Energy (DOE) in 1977, the initiatives of a number of prominent scientists within LBL, such as UCB physicist Arthur Rosenfeld,[261] and the synfuels initiative of the Carter Administration brought the Lawrence Berkeley Laboratory into alternative-energy areas of research. There was corresponding DOE support through LBL for research within Berkeley chemical engineering on new energy sources, battery development, conservation, catalysis, synfuels, and clean-up of synfuels wastewaters.

In 1979, the *Gilman Hall Newsletter* reported a breakdown in funding sources for department graduate students for that year. LBL (hence, DOE) accounted for support of 46% of the department's graduate students. The next largest

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[260] See, e. g., Derek Bok, *Universities and the Marketplace*, Princeton University Press, 2003.

[261] Dana Buntrock, Ashok Gadgil, David B. Goldstein & Jonathan Koomey, "In Memoriam, Arthur H. Rosenfeld," *In Memoriam*, Academic Senate, University of California, 2018. https://perma.cc/47DY-CVND

source was NSF for 26% of graduate students, followed by combined resources from the Office of Naval Research (ONR), the Environmental Protection Agency (EPA), National Institutes of Health (NIH), U. S. Department of Agriculture (USDA), and National Aeronautics and Space Agency (NASA) for 7%. A category labeled "other" covered the funding for 17% of graduate students, while support for the final 4% of graduate students came from industry.[262] The lead roles of DOE through LBL and then NSF have been sustained over the years, along with increases in the support from the National Institutes of Health (NIH) as activities in biomolecular engineering related to human health increased.

Funding from the federal government has consistently provided the bulk of research support. However, those funds are dedicated to specific projects, thereby engendering very little flexibility. Grants do end, and funding of any specific proposal is not assured. Thus, other funds for tiding students over between grants are useful. The department thereby sought and received uncommitted support from industrial corporations with a typical annual donation of $5,000, a practice that was more common in the late 1960s, 1970s, and 1980s than it is today. In 1976, industrial contributors included Ametek, Bechtel Power, Chevron Research, Dow USA, DuPont, Exxon, General Electric, Hooker Chemical, Shell, Standard Oil of California (Chevron), Stauffer, Texaco and Union Carbide.[263]

In the 1970s, as already noted, a downturn of the economy and other judgements regarding research brought many major companies to reduce the size and scope of their in-house research operations. One rationale was that research results could be gleaned from universities and brought into further development and commercialization by the company. Another factor leading in that direction was the Bayh-Dole Act of 1980, which established that ownership of patents and inventions stemming from federal government support of research would remain with the grantee rather than belonging to the federal government and thereby being in the public domain. Thus, a company could license an invention from a university that had performed the research. This, in

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[262] "Department News," *Gilman Hall Newsletter* 4 (December 1979), p. 3.
[263] *Gilman Hall Newsletter*, Vol. 1, No. 2, p. 10. Note the preponderance of large chemical and petroleum companies here, which corresponded to the times.

turn, enabled exclusive ownership by the company, an important criterion when the company would have to invest substantially to bring the invention to commercialization. The percentage of industry's R&D funds devoted to basic research declined from 6.3% in 1966 to 3.7% by 1976.[264] The aforementioned formation of the Council for Chemical Research, the Bayh-Dole Act, and the change in corporate outlook became catalysts for considerable increases in project-oriented industrial support of academic research in chemical sciences and engineering as well as other fields.

In 1981, still early in this period, funding from private industry to Berkeley chemical engineering totaled $400,000 in grants and gifts to individual faculty members. Another $133,500 from industry came to the Department as unrestricted funds, in addition to $60,000 for graduate student fellowships and $27,500 for undergraduate scholarships.[265]

For the three academic years 1988-89 through 1990-91 total extramural funding to Berkeley chemical engineering was between $5.2 and $6.2 million per year, divided as 64-70% LBL and 16-19% from other federal agencies, for a total of 83 to 86% from the federal government; 13 to 16% from industry, of which about ¾ was project funding; and about 1% from foundations, alumni, and friends.[266]

The success rate of proposals to the National Science Foundation in 2005 was 20%, having dropped from 30% in 2000.[267] For the Engineering Directorate of NSF the proposal success rate for FY2019 was 28%.[268] Thus the majority of proposals are not funded, and that fact creates uncertainty for faculty researchers. Having multiple sources of support, including non-governmental, is one approach for faculty members to stabilize their research funding.

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[264] Bruce L. Smith and Joseph J. Karlesky, *The State of Academic Science: The Universities in the Nation's Research Effort* (New York: Change Magazine Press, 1977), p. 20.
[265] *Gilman Hall Newsletter*, Vol. 7, No. 2, p. 7, 1982.
[266] Data from *Gilman Hall Newsletter*, Vols. 9-16 (December 1984-December 1991).
[267] Report to Advisory Committees (PowerPoint), Impact of Proposal and Award Management Mechanisms (IPAMM) Working Group, National Science Foundation, 2007, consulted October 31, 2019. https://perma.cc/R4S7-UCJF
[268] Engineering (ENG) Funding Rates, National Science Foundation, consulted October 31, 2019. https://perma.cc/4WM6-SACZ

Participation in the large campus research units mentioned above, such as QB3 and the Energy Biosciences Institute, is also attractive for the same reasons.

Buildings and Facilities. Two photographs of College of Chemistry buildings over the years are shown in Figure 10a&b.

Figure 10a. The College of Chemistry complex viewed looking east, ca. 1948 (two years after the start of chemical engineering). The building in the front is Gilman Hall (1917). Behind it is the roof of the Old Chemistry Building (1891), a jagged pattern of gables. The high, light-colored building behind that is the newly completed Lewis Hall (1948). The lower, flat-roof building on the right-hand side between the Old Chemistry Building and Lewis Hall and adjacent to the roadway with parked cars is the Chemistry Annex (1915), known familiarly as the “Rat House.” In the left of the photo, the peaked-roof building adjacent to Gilman Hall is the original Radiation Laboratory, built in 1885 as the Civil Engineering Testing Laboratory and occupied by Ernest Lawrence’s cyclotrons as of 1931 when they became too large for his earlier space in Room 319 LeConte Hall. The lighter-colored building with the dark, flat roof behind and to the left, the square rear of it taller than the front, is the Crocker Laboratory (1937), used for Lawrence’s 60-inch cyclotron as of 1938. Behind the Crocker Laboratory is the taller Freshman Chemistry Laboratory (1915). Behind Lewis Hall is the large bowl of the outdoor Greek Theater (ca. 1901-02). Source: Lawrence Berkeley National Laboratory photo archive, https://photos.lbl.gov/bp/#/search/7068856?q=old%20chem%20building&filters=%257B%257D

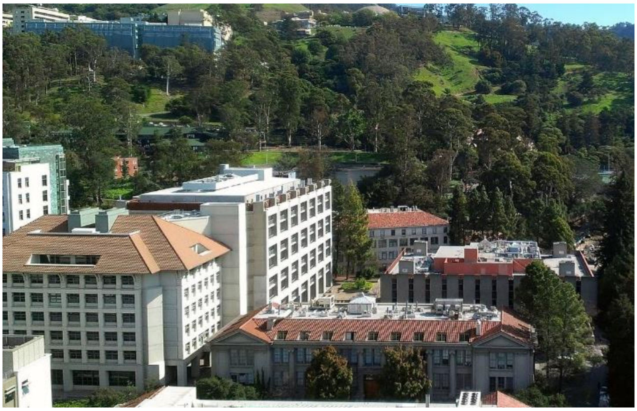

Figure 10b. A similarly placed view of the College of Chemistry complex taken in 2015, 67 years later, from a greater elevation. Gilman Hall (front, center) and Lewis Hall (further back) are the only two of the 1948 buildings still standing. To the left of Gilman Hall is the taller Tan Hall (1997) with a slot in the front roofline to provide a Bay view from the Ross McCollum Room on the top floor. The very large building with a block of fans atop the center roof that appears as an extension to the rear of Tan Hall is Latimer Hall (1963). Behind Gilman Hall, in front of Lewis Hall and to the right of Latimer Hall is Hildebrand Hall (1966). Barely visible in white with green trim on the very left behind Tan Hall is the new Stanley Hall (2007), home of the Berkeley part of QB3, which contains laboratory space for several CBE faculty members. Buildings of the Lawrence Berkeley National Laboratory are on the hill above. Wikimedia Commons, https://commons.wikimedia.org/wiki/File:UC-Berkeley-018-college-of-chemistry.jpg

The original offices for chemical engineering were on the second floor of Gilman Hall,[269,270] completed in 1917 as part of the arrangement for G. N. Lewis to come from MIT to Berkeley as Dean of the College of Chemistry. In 1966 Gilman Hall became a Registered Historic Landmark by virtue of the fact that Glenn Seaborg and associates had first isolated man-made plutonium in Room 307 in 1941.

[269] Merle Randall, "Gilman Hall: The Research Unit of the Chemistry Group at the University of California," *J. Ind. & Eng. Chem.*, v. 16, pp. 634-640, Aug. 1918.
[270] Helfand, 2002, pp. 93-95.

Because of the Manhattan Project work carried out on the third floor of the building, Gilman Hall had security gates and guard booths limiting access to the third floor from 1945[271] until 1960. Latimer and Hildebrand Halls, both part of the wave of buildings erected during the heyday of state funding following World War II, greatly increased the research and office space available to the College of Chemistry. When the opening of Latimer Hall in 1963 decompressed the College of Chemistry space situation, Gilman Hall was renovated in its entirety to enable occupancy by chemical engineering. As Hildebrand Hall opened in 1965, chemical engineering obtained additional laboratory and office space in Lewis Hall, which had been constructed 1946-48.[272]

The size of the faculty, space needs for research, and needs for new types of space grew such that by 1980 it was apparent that the College needed more space and that the most logical approach would be a new building. However, the building boom that had led to the construction of Latimer and Hildebrand Halls had utilized the plentiful state funding that had been available after World War II, and state finances were now much tighter. Furthermore, the Berkeley campus at that point had launched a very large endeavor to construct two new biology buildings and renovate a third[273] as part of a major initiative to restructure and re-equip the biological sciences to meet the needs and opportunities afforded by the rapid advances that were occurring in those areas.[274] It was apparent that a new building would need to have substantial private funding. This fact, along with the success that had been achieved by private fund-raising efforts in Business, Law, and Engineering, led to the establishment of the College of Chemistry development effort in 1982 (see next section) with the priority effort for it being to create the wherewithal for a campaign for a new building.

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[271] The system of gates and guards had not been established earlier in World War II because of concern that they would call attention to the Manhattan Project work.
[272] Helfand, 2002, pp. 25, 95-96.
[273] The Valley Life Sciences Building, at the time the largest academic building west of the Mississippi.
[274] King, 2018, pp. 461-467.

It took fifteen years from this start to the opening of Tan Hall[275] in 1997. The time was consumed successively by getting the development operation up to speed, preliminary phases of building design, fund-raising, architectural design, securing state funds, the complex process of bringing together state funding and private funding at the same point in time, and finally construction. Chemical engineering laboratories and offices related to biomolecular engineering were among the initial occupants of Tan Hall. The ultimate funding was two-thirds private and one-third state.

In the latter part of the decade of the 2000s the state ceased funding building projects for the university altogether, except for some seismic corrections. This led to the need for further buildings to be totally privately funded. The College was able to satisfy its growing space needs for a while by utilizing opportunities that faculty had to use space belonging to large Organized Research Units (ORUs) in places such as the new Stanley Hall built for QB3 and opened in 2007, the Joint Bioenergy Institute in Emeryville also opened in 2007, and the Energy Biosciences building opened in 2012.

Aging space is space that is less useful for the special needs of current-day research, and for those reasons the space needs of the College continue. With the campus becoming crowded, locating building sites has become a challenge, as is the need for private funding. The current (2020) project of the College is for a high-rise building at the corner between Latimer Hall and Lewis Hall. The building, Heathcock Hall, will be funded in part by a $25 million lead gift from Terry and Tori Rosen. Plans call for that project to be followed by a replacement of Lewis Hall, which has been determined to be seismically deficient as well as inadequate for research needs.

Development. Serious efforts to raise private funds at Berkeley arose in the modern era only in the late 1970s and early 1980s. Previously the tradition was that public universities were largely funded by the state and therefore fund-raising from the private sector was more the purview of private universities. At Berkeley, development is more decentralized than at other universities, one reason being that when development operations did start in earnest it was at

[275] Helfand, 2002, pp. 96-98.

the level of certain professional schools – Business, Law, and Engineering – rather than campus-wide. Development at the campus level was started in earnest in 1983 at the time of the large project for modernization of the biological sciences. In the same year, development operations began for the College of Chemistry, with the looming need for private funding of the Tan Hall project.

To launch the development program the College hired Jane Scheiber, formerly Editorial Director and Associate Project Director of Courses by Newspaper, an adult education program at UC San Diego. She had also been involved in community-outreach activities at UCSD. Scheiber had no direct background in development. However, she was able to learn the field fast and produced all the elements of a successful development program that matured in time to fund the major portion of the construction budget for Tan Hall. The elements included tracking and organization of alumni, utilization of ties with industry, and identification of the types of relationships and development structures that would work best for the College, with an organization that reported to Scheiber as she became Assistant Dean for College Relations for the College of Chemistry. Over the years, she has been succeeded in this function by Mindy Rex and then Laurent (Lo) de Janvry, along with a capable staff.

An initial gift that enabled starting in earnest on the planning and design for what became the Tan Hall project was from Ross and Irma McCollum. Ross McCollum, a 1917 Berkeley Chemistry graduate, had been a successful businessman in California oil. The major part of the private fund-raising for Tan Hall was spearheaded by Chancellor Chang-Lin Tien, Berkeley Chemistry Professor and Nobel Laureate Yuan T. Lee, and Professor Phua Kok Khoo of World Scientific Publishing and the National University of Singapore. The lead gift was one-third of the total private funding of $25 million and was comprised of individual gifts from donors who wanted to recognize the humanitarian accomplishments of Tan Kah Kee[276] (1874-1961), a pioneering industrialist,

[276] Ching-Fatt Yong, *Tan Kah-Kee: The Making of An Overseas Chinese Legend*, rev. ed., World Scientific Publishing Co., Singapore, 2014.

philanthropist, and social reformer in Southeast Asia and Singapore in particular.[277]

UNDERGRADUATE CURRICULUM

The accrediting agency for engineering programs in the United States is ABET.[278] It sets numerous criteria for degree requirements, with the result that engineering curricular are remarkably similar across the U. S. Furthermore, since engineering is the one major professional degree primarily accredited at the bachelor's level, engineering curricula are very full, with little room for breadth. These features are particularly true for chemical engineering curricula, which must include substantial aspects of chemistry as well as engineering.

ABET requirements and guidance do change over time but do so slowly and with much deliberation. That is probably the main reason why there has been relatively little change in the structure of the Berkeley chemical engineering curriculum over the years. A comparison of the requirements for the B. S. in chemical engineering in 1969-70[279] with those fifty years later in 2019-20[280] shows surprisingly little structural change despite this having been the era of so much change due to the rapid development of information technology and the diversification of the employment of chemical engineers. Four additional courses are required in 2019-20:

- CBE 40, an introductory Lower-Division chemical engineering course;
- CBE 162, dynamics and control of chemical processes, a former elective that became required in view of the general utility of the subject;
- An introductory biology course, either Biology 1A or Bioengineering 11, added in view of the growing biological applications of chemical

[277] Tan Hall Dedication Booklet, 1997.
[278] ABET, https://www.abet.org/. ABET once stood for Accreditation Board for Engineering and Technology, but now the name is simply the acronym.
[279] University of California, Berkeley 1969-1970 General Catalogue, v. 2, pp. 194-198, May 15, 1969. https://perma.cc/89TJ-3H3K
[280] Chemical Engineering Major, College of Chemistry, University of California. https://perma.cc/LQW3-7ZXY

engineering and the growth of biomolecular engineering within the field;
- Engineering 7, an introduction to computer programming for scientists and engineers.

CBE 40 was launched in the 1970s as an optional course. The aim was to display the nature of chemical engineering itself early in the curriculum, thereby informing student choices of majors and better displaying how the rest of the curriculum tied in. Starting in 2012 CBE 40 became required for CBE majors who entered as freshmen, and that requirement was extended to transfer students in 2018, even though CBE 40 is not likely to be available within community colleges. The content is design, design choices such as among separation strategies, and mass and energy balances. Especially with the latter subject it assumes some material that had been in the former introductory, junior-year course (CBE 140), and it thereby is a prerequisite for CBE 140.

Correspondingly, four courses were subtracted from, or condensed in, the curriculum over the same fifty-year period,

- CBE 152, Separation Processes, created under the quarter system (see below). The content has now been folded into CEB 150B, Transport Processes.
- Chemistry 125, Physical Chemistry Laboratory;
- Chemistry 14, a Lower-Division course on chemical thermodynamics;
- A five-quarter sequence of physics courses has now been condensed to two semester courses.

Even though the structure of the curriculum has not changed much, the contents of individual courses have continually evolved, following trends of greater engineering science content, the growth of information technology and reference sources, and problems and examples couched in a much wider variety of applications.

Technical Communications. Recognizing the importance of writing and oral-communication skills for engineers in industry and following up on continual advice from its Advisory Board, the department initiated in 1979 a two-unit course in Technical Communication (ChE 185) which soon became required for graduation. The course was initiated by Lecturer Patricia Whiting and evolved though the guidance of Lecturers Ralda Sullivan,[281] who oversaw the course from 1981 until 1994, and then Paul Plouffe,[282] who had taught in the course starting 1983 and oversaw it from 1994 until his untimely death in 2007.[283] The course was increased to three units in 1988.

Plouffe[284] described the form to which the course had matured, starting with an explanation of the physical principles underlying a familiar phenomenon for an audience of non-scientifically trained adults, and followed by assignments calling for (a) written and oral explanation of a laboratory instrument or procedure for an audience of students re-entering college, (b) a report analyzing data for presentation to an audience of chemical engineers, preparatory for the laboratory course, (c) analysis and presentation of recommendations (written and oral) concerning an ethical situation in chemical engineering, and (d) oral and written presentation of a literature research project of the student's choice.

After Plouffe's death, Department Chair Jeffrey Reimer assumed the role and then chemical engineering students learned communication skills through a related course in the College of Engineering. However, continuation of the arrangement with Engineering would have required budget from the department, and as a result of the reductions of state funding in the late 2000s that arrangement was discontinued in 2010. The course within the department was started again briefly with the hiring of Lecturer Shannon Ciston in 2011, but was discontinued, again for budgetary reasons, after 2017.

Options/Concentrations. In 1987 the department instituted undergraduate options, designed to enable graduates to focus their electives in certain areas and obtain recognition of that fact on their transcripts. Initially, there were four

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[281] See profile, *Gilman Hall Newsletter*, v. 14, no. 2, December 1989, pp. 3-4.
[282] Uncle of David Plouffe, political advisor to President Barack Obama.
[283] Michael Barnes, "Obituary Paul Plouffe," UC Berkeley News, January 16, 2008. https://perma.cc/KV83-WRE8
[284] P. Plouffe, "The Technical Writing Program – Chemical Engineering 185: Past and Present, or 'Where are You Now, Elvis'," in *Fiftieth Anniversary of Chemical Engineering*, Dept. of Chemical Engineering, University of California, Berkeley, 1998, pp. 8-9.

such areas – biochemical engineering, materials science and engineering, chemical processing, and microelectronics.[285] As of 2019 the term "options" had been changed to "concentrations;" biochemical engineering had become biotechnology; materials science and engineering had become materials science and technology; applied physical science, energy and environment, and business and management had been added; and microelectronics had been dropped.[286] The 247 students completing bachelor's degrees in 2018-19 and 2019-20 were distributed among concentrations as follows.[287]

Business and Management - 16%

Biotechnology - 9%

Applied Physical Science - 9%

Materials Science and Technology - 6%

Energy and Environment - 6%

Chemical Processing - 2%

No concentration - 52%

Semesters, Quarters, Semesters. When the department was formed, the Berkeley campus was on the semester system and had been so since its founding. In 1966 the university as a whole switched from semesters to the quarter system. The primary reason for the change was the serious attention being given to year-round operation as a way of responding to enrollment pressures.[288] The argument was that the physical plant was largely idle for instruction in the summer. Since the summer was about the same length as an

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[285] Arup K. Chakraborty, P. B. Plouffe, and Stacey Shulman, "ChE Department: University of California, Berkeley," *Chem. Eng. Educ.*, v. 37, no. 3, pp. 162-167 (specifically, bottom of p. 165), Summer 2003.
[286] Chemical Engineering Upper Division Requirements, College of Chemistry, University of California, Berkeley, consulted November 16, 2019. https://chemistry.berkeley.edu/ugrad/degrees/cheme/upper-courses.
[287] Korshid Tarin, College of Chemistry Adviser, personal communication to Shannon Ciston, October 21, 2019.
[288] "Report by President Clark Kerr on Proposed Year-Round Operation of the University," *University Bulletin*, University of California, v. 12, no. 16, Nov. 18, 1963.

academic-year quarter, there could be four quarters of academic operation per year, with students typically attending some three of the four.

The chemical-engineering curriculum is highly sequenced. The quarter system affords half again as many slots in the sequence as the semester system does. The units per course were typically higher with quarters, with fewer courses being taken simultaneously. That fact was used to advantage in the layout of course sequencing for the chemical-engineering major. Student attitudes toward the quarter system varied, with some seeing the instructional year as being more pressure-some because of less slack time and others valuing the lesser number of courses and more frequency changes in instructors.

The summer quarter turned out not to be a draw for enrollment of full-time students. Hence, seventeen years later in 1983, the Berkeley campus returned to the semester system, even though it was the only University of California general campus choosing to do so at the time. The Merced campus, when it opened in 2005, elected to use the semester system, as do some professional schools, e. g., Law and Medicine, throughout the university.

Switching from one calendar system to the other is not simple, since the structure of the entire curriculum needs to be addressed when a change is made. The change from quarters to semesters is more difficult because of the reduction in sequencing slots.

Education Abroad. Since 1962 the University of California has had a single, university-wide Education Abroad Program (EAP), now with 170 locations in over 40 different countries. Historically, very few chemical engineering students have taken part in this program because of the extremely full and structured in-house curriculum. The EAP has made efforts to be more accommodating to the needs of engineering students and now typically between one and five CBE undergraduates are in the Education Abroad Program at any point in time.[289] In the past decade the department has signed agreements for student exchange with Zhejiang University in Hangzhou, China, and RWTN Aachen University in

[289] Shannon Ciston, personal communication, December 19, 2019.

Germany. Only a handful of students have participated so far, however, again owing to the difficulties is matching degree-credit courses.

Online Education. The complexity and the highly interactive nature of undergraduate engineering courses has made it difficult to adapt them to online education, and the department has taken no steps yet in the direction of online degrees. There are sometimes online modules associated with courses. Some non-CBE courses lend themselves more toward online instruction. Mathematics 53, Multivariable Calculus,[290] is given online in the summer, and is often taken that way by CBE majors.[291]

With the arrival of the coronavirus pandemic in March, 2020, all instruction went online with essentially no advance notice. This provided an intensive, trial-and-error period for faculty to devise and improve methods of online instruction and for students and faculty to evaluate them. The experience will probably result in both more effective and more rapid integration of online aspects into the curriculum.

GRADUATE PROGRAMS

Graduate programs were active from the start. Formal approval by the Graduate Council of the Academic Senate and the campus administration of the chemical engineering MS and PhD programs in 1947 actually preceded formal approval of the BS program in 1948.

PhD Program. Following the G. N. Lewis model and the pre-existing nature of the College of Chemistry, primary emphasis in graduate education from the start has been on research and doctoral-level education. Students typically take graduate courses during their first year and then few courses from then on as they concentrate upon research and the ultimate dissertation.

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[290] Math 53, Department of Mathematics, University of California, Berkeley. https://perma.cc/J8DN-TRCS

[291] Shannon Ciston, personal communication, December 19, 2019.

As of 2019, CBE department degree requirements state,

> "Two departmental examinations are required in the course of the degree. The first, an oral preliminary examination, is held at the beginning of the second semester to ensure adequate knowledge of fundamental graduate and undergraduate course material. The results of this examination, performance in course work, and a statement from the student's research director are used by a committee of the faculty to evaluate the student's progress toward the Ph.D. The second examination, the oral qualifying examination taken at the beginning of the fifth semester in residence, consists of a written technical manuscript and a formal presentation of students' research to a committee, including review of the most relevant literature, research accomplishments to date, and a future plan. After passing the examinations students advance to candidacy and will spend most of their time on their dissertation research projects."[292]

In earlier years, until the mid-1980s, the oral qualifying exam was built around presentation and defense of an original research proposition developed by the candidate, with a faculty member other than the dissertation overseer in a solely advisory role. This requirement served as an independent exercise for developing creativity and sometimes led to publications.

Master's Programs. The Berkeley campus allows for two types of Master's degrees, designated Plan I and Plan II. Plan I involves a research-based Master's thesis. Plan II is based more on coursework and entails either a comprehensive final examination or a capstone project.[293] From the start and well onto the 1960s the department admitted students to both the Plan I and Plan II programs, requiring a capstone research project for Plan II. Admissions to the Plan II program were then ended around 1970. In the mid-1960s the department also briefly had an evening MS program, wherein one class of

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[292] CBE Doctorate Degree Program & Requirements, College of Chemistry, University of California, Berkeley, consulted November 18, 2019. https://perma.cc/K6MJ-4N8B

[293] Degrees Policy, Berkeley Graduate Division, University of California, Berkeley, consulted November 19, 2019. https://perma.cc/5C7G-9PS6

students working at full-time jobs was admitted, one or two core graduate courses (different ones in different quarters) were given in the evening, and a thesis (Plan 1) was required. The evening program drew only a small number of students and was discontinued. Research Master's degrees were deemphasized as of the 1990s, and the department has now gone back to Plan II degrees, emphasizing the two professional Master's programs described below.

As state funding for the university has dropped over the past three decades the University of California has allowed for professional degree programs that involve higher tuition. The first such policy, developed in 1994, enabled supplemental tuition for certain approved professional degree programs.[294] Another policy, originally created in 2011, allowed for self-supporting graduate professional degree programs.[295] The CBE department has created two such programs, one in each category.

Professional Master's Degree in Product Development. In 2006 the department launched a new Professional Master's Degree in Product Development. As it matured, the degree became a supplemental-tuition program. The rationale for the program is the enlargement of the scope of chemical engineering from being primarily a process-based discipline, as is characteristic of the petroleum and heavy-chemical industries, to one for which chemical engineering is intimately involved in the design and development of the product itself. As Executive Director for the program the department hired Keith Alexander (PhD 1983 with King), who had had a very successful industrial career, becoming Senior Vice President for Planning with CH2M Hill. He has now been joined by Steve Sciamanna (PhD 1986 with Lynn) and Sudhir Joshi as Lecturers.

The program consists of an academic year of coursework followed by a two-month field study assignment related to product development practice in an

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[294] Regents Policy 3103: Policy on Professional Degree Supplemental Tuition, Board of Regents, University of California, consulted November 19, 2019. https://perma.cc/KM2X-W4XQ

[295] Self-supporting Programs, Institutional Research and Academic Planning, Office of the President, University of California, consulted November 19, 2019. https://perma.cc/BV8P-3UCQ

industrial setting.[296] It is now typically well over-subscribed, and incoming classes have been held to a maximum of 30 or 40. Four different emphases are available – Biotechnology, Microelectronics/Nanotechnology, Consumer Products, and New Ventures. As of 2019, there had been 225 graduates of the Product Development Program.[297]

Professional Master's Degree in Bioprocess Engineering.[298] Approved in 2019 as a self-supporting degree program, the Professional Master's Degree in Bioprocess Engineering is intended to prepare graduates who will work on process creation and scale-up in the bio-based industries. These include biotechnology, pharmaceuticals, foods, and bio-based chemicals and fuels. The one-year program makes use of the Advanced Biofuels Processing Demonstration Unit of the Lawrence Berkeley National Laboratory. The program also partners with industrial companies for intern experiences. Adjunct Professor Jason Ryder is Executive Director of the program.

SIZE, COMPOSITION, AND ORGANIZATION OF RESEARCH GROUPS

The sizes of faculty research groups are influenced by many factors. Among them are the following:

- how many co-workers the faculty member can oversee and provide with good tutorial education given the faculty member's own time management ability and working style,
- the number and size of grants that the faculty member has and can manage effectively for support of research,
- how the faculty member wants to organize the research group,
- facilities needs and availability, and

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[296] PDP Program Description, College of Chemistry, University of California, Berkeley. https://perma.cc/S3BR-R7T9

[297] PDP Letter to Applicants, Department of Chemical and Biomolecular Engineering, University of California, Berkeley. https://perma.cc/JL7A-6TZC

[298] Master of Bioprocess Engineering, Berkeley College of Chemistry, University of California, Berkeley, consulted November 20, 2019. https://perma.cc/R72R-6CXL

- ultimately, the number of incoming students, postdocs, visitors, etc., who want to work with the faculty member.

A survey was made of research-group web pages for CBE faculty in January 2020. This was limited to faculty members who had been present for at least a year, whose faculty appointments are 100% within CBE, who listed group members on their web sites, and who were not retired or within a year or two of retirement. Counting only graduate students, postdocs, and visiting scholars, group sizes ranged widely over a factor of nine from 3 to 27, with the average being slightly over 12 and the median 10. Of the 196 researchers counted, slightly under 60% (117) were graduate students, slightly under 31% (60) were postdocs, and slightly over 9% (19) were Visiting Scholars. The total number of graduate students is not the same as the actual number of graduate students in the department since there are CBE graduate students with faculty research directors outside the department and *vice versa*, and since the groups of certain types of faculty members were not included, as noted above.

These numbers reflect several trends over time, as follows.

- The wide variability in group sizes has been a consistent feature over the decades.
- The number of postdocs has markedly grown. In the 1960s and 1970s there were very few of them. Postdoctoral experience was neither needed nor expected for chemical engineering faculty positions. The few postdocs that did exist were mostly foreign, seeking a U. S. topping to their education. Perceived values and expectations for postdoctoral research experience grew as knowledge continually deepened, more needs for fundamental science came into play, and various new specialties came into CBE. Now nearly all new faculty members have had some sort of postdoctoral experience. Rapid increases in graduate student tuition and benefits, which are funded by individual professors, along with stipend increases to match extreme housing costs in the Berkeley area, have made the cost to grants for a postdoc salary nearly competitive with the costs of supporting a graduate student.
- Research groups, although highly variable in size, are on the whole larger than they were several decades ago. In the 1970s 10 to 15 was a

large group. In 2020 the department has three faculty members with groups having 20 or more members.

- As noted above, the thesis Master's degree was eliminated in the 1990s so that now essentially all research-performing graduate students are PhD students. Previously the department had a substantial research Master's program, and group compositions reflected that fact.
- The number of Visiting Scholars has also grown to some extent over time, but not percentwise to the same degree that postdocs have.

The January 2020 survey of research groups also showed that about 70 undergraduates are involved with faculty research groups. This is one of the primary benefits of undergraduate education at a major research university. Given that recent CBE undergraduate graduating classes have been in the range of 100 to 125 (see below), this means that well over half of undergraduate CBE students have done supervised research, a fact confirmed by surveys that have been made through the Student Experience in the Research University (SERU) project.[299]

There are two structural ways in which faculty members can gain efficiencies in research-group operation, at the expense of some of the interactions that would otherwise occur directly between students and the faculty member. One is that undergraduate students can work under the daily or week-to-week supervision of graduate students or postdocs, an arrangement which is also valuable for instruction in the basic needs for doing research. This does not imply that the graduate student is the sole supervisor of the undergraduate; the undergraduate and the graduate student can meet periodically with the faculty research director as well. Another organizational arrangement can be to have a senior staff member who provides continual in-laboratory consultation and oversight. From the January 2020 survey, four CBE groups have such a position, with titles such as Lab Director and Chief Administrator.

[299] Student Experience in the Research University, Center for Studies in Higher Education, University of California, Berkeley. https://cshe.berkeley.edu/seru

GOVERNANCE AND SUPPORT OF RESEARCH AND TEACHING

During the first thirty-five years of the chemical engineering program, all deans of the college were chemistry faculty members. The role of the Chair of the Chemistry Department had not been differentiated as much from that of the Dean of the College of Chemistry as the role of the Chair of the Chemical Engineering Department had been. Internal governance of the Department of Chemical Engineering was left with the department chair and the department. In those days the governance was highly collegial, built around committee functions and weekly department meetings, often over lunch.

With the appointment of the first chemical engineer as Dean of the College of Chemistry (the author from 1981 to 1987), the Chair of the Chemistry Department shouldered the remainder of the usual department-chair load. The College remains in the mode of two fully functioning departments, and there have now been two subsequent deans from chemical engineering, Alexis Bell (1994-1999) and Douglas Clark (from 2013 to date).

There has been much change over time in what deans actually do. The most substantial change is that development (fund-raising) needs and functions have now become pervasive and form a large part of the duties of a dean, as well as being a significant component of the functions of department chairs. Gilbert Lewis could operate during his thirty years (1912-1942) as dean in a mode of doing much research and intellectual leadership himself, with the faithful Miss Kittredge by his side to take down and pursue administrative thoughts and decisions as he dictated them. By 1981 when the author became dean it had become apparent that the College should start its own development operation, as described above, if it was to pursue what became the Tan Hall project. The development role then took perhaps 15% of the time of the dean. Now, with the considerable diminishment of state funding that occurred in the latter half of the decade of the 2000s, all building renovation or construction projects and significant parts of other aspects of the College require private funding, and well over half of the time of the dean goes into fund-raising.

Staff Support. Most of the support staff of the College of Chemistry report at the college level, to the dean's office. This is true for support services such as shops, analytical facilities. stores, and receiving. In recent years, starting from a campus-wide review by Bain and Associates in 2009-10, the Berkeley campus has pursued a path known as Shared Services, whereby certain services that were formerly carried out at the college/school or departmental level are carried out at the campus-wide, and now precinct,[300] level. These services include Human Resources/Academic Personnel, Research Administration, Information Technology (IT) support, and Purchasing and Reimbursements.[301,302] Going back as far as the 1960s, the College of Chemistry has found it effective to have a senior staff member for whom a substantial portion of duties is coordinating campus services and helping them work well for both faculty and the college administration.

The department has had, and continues to have, dedicated and capable staff of its own. That started with the secretarial support of Edith Taylor, who joined the department in its early days and retired in 1969. There then became a principal assistant to the Chair who also functioned as overall office supervisor in a Management Services Officer (MSO) position. That position was originally held by Ruth Fix, starting about 1961. Fix was followed by Gloria (Gege) Muse in the early 1980s, and she was in turn succeeded by Jean Fitz in the later 1980s and most of the 1990s, followed in turn by Nikki Humphreys, Richard Braren, and now Kim Eastman.[303] That position has now become Administrative Manager.

The graduate program is supported by the Graduate Student Affairs Officer, a position held by Dee Hersh in the 1960s, Anne Uetz in the early 1970s, Gloria (Gege) Muse in the later 1970s, and Kay Ekman during the 1980s. Ekman was

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300 The College of Chemistry is, as of 2019, part of the ChaMPS (Chemistry and Mathematical & Physical Sciences) precinct [Berkeley ChaMPS Regional Services, https://perma.cc/KV3E-HB3P]. The precinct concept was created after problems of size and remoteness were recognized for campus-wide services.

301 King, 2018, pp. 204-205.

302 Andrew J. Szeri, Richard Lyons, Peggy Huston, and John Wilton, "Doing Much More with Less: Implementing Operational Excellence at UC Berkeley," Paper No. CSHE.10.13, Center for Studies in Higher Education, University of California, Berkeley, June 2013. https://perma.cc/6GW2-KTUW

303 These lists leave out some short-term and temporary occupants.

followed by Ferne Kasarda, Aileen Harris, Rocio Sanchez, Fred Deakin, and currently Carlet Altamirano.

After his time as MSO, Braren became Chair's Assistant and Academic Personnel Analyst, in which he was followed by Christine Balolong and now Jamie Eagan. Vonis Moore was Chair's Assistant before Braren.

What were originally secretaries to faculty members evolved over the years to become Faculty Support Administrators, as personal computers obviated needs for typing and as research administration became more and more involved.

In the earlier years there was a departmental technician position held by Bob Waite from 1948 to 1958. As of 1964 Howard Wood headed the Student Shop that served to let students carry out their own supervised shop projects for their research. In 1988 Wood was succeeded in that position by Ron Dal Porto, who oversaw it until that shop was discontinued in the 1990s. Steve Willett also started in 1964 and had a career of over forty years supporting equipment and experiments in the unit operations/chemical engineering laboratory (ChE 154). He ultimately received a chemical engineering bachelor's degree of his own.[304] His functions were assumed by Esayas Kelkile in 2006, with the title R&D Engineer and the addition of several other duties as well.

EMPLOYMENT OF GRADUATES

In the early years of the department employment opportunities for graduates were primarily in the petroleum, petrochemical, and heavy chemical industries, and the employment market followed the ups and downs of those industries. Employment then became more diversified in the 1970s and 1980s, and the diversity of employment in turn served to stabilize the job market. Employment in the electronics industry increased substantially along with further opportunities for graduates in the food and pharmaceutical and biotechnology industries, other consumer-products industries, alternative energy, environmental control, and improved materials. The facts that the electronics

[304] *Gilman Hall Newsletter*, June 1991.

and biotechnology industries developed heavily within the Bay Area and that the department had developed early interests in these fields spurred this trend. Also, as mentioned previously, a significant fraction of graduates has always gone into careers that are not conventional chemical engineering at all.

At the PhD level, graduates also take university faculty positions. About 30% of Berkeley chemical engineering PhD graduates did so in the 1970s, while about 20% did in the 1990s. In the 1970s the leading employing industries for PhD graduates were petrochemical and chemical, with only small contributions from food/pharmaceutical and electronics. By the 1990s the largest employing industry for PhD graduates had become electronics, followed closely by each of chemical and bio/food/pharmaceutical, with petrochemical at less than half the levels of those three areas individually.[305]

ENROLLMENT AND SOCIAL AND DEMOGRAPHIC FACTORS

Undergraduate Enrollments and Numbers of Graduates. In the early years the annual number of B. S. graduates built steadily up to 72 in 1950, representing the peak of the enrollment surge from returning World War II veterans and the GI Bill. Following a drop to 20 graduates in 1956, the size of the graduating class increased again, fluctuating around 40 in the years from 1959 to 1972. Attitudes stemming from the period of Vietnam War protests and concomitant negative views of technology brought a dip to 30 in the 1974 graduating class. This was followed by a large and steady surge to a high of 144 in 1983. The growth in total undergraduate enrollment for the Berkeley campus was only about 27% over these same nine years, so the increase from 1974 to 1983 primarily reflects the change to a positive view of engineering and technology, recognition of the value of chemical engineering as a career choice, and the growth of high-tech industry in California. Undergraduate enrollments then fell again such that the size of the graduating class dropped to about 50 in 1991 before rising again to about 100 in 1998.[306] The graduating classes from 2011

[305] Blanch & Wilke, 1998, pp. 4-5.
[306] Blanch & Wilke, 1998, figure on p. 7.

through 2013 were in the 80 to 90 range, preceding a rise to 124 in 2014, graduating classes in the range 95 to 115 from 2015 to 2018, and 126 in 2019. As of 2018-19 CBE is the tenth most popular undergraduate major on the Berkeley campus, as measured by student registrations.[307]

Total enrollments of students who have declared a chemical-engineering major increased steadily from 346.5 in 2010-11 to 515.5 in 2018-19, an increase of 49% over nine years.[308] In addition to following the career interests of today's students, this upward trend reflects recent admissions policies of the Berkeley campus as a whole. As already noted, the state budget for the University of California per enrolled student eroded by a factor of about two in the decade of the 2000s. As a means of offsetting this, the university and the campus adopted a policy of increasing the percentage enrollment of full-tuition-paying out-of-state and international students, following a rough estimate that two such students enrolled with the concomitant fee income[309] would "buy" a spot for a California resident. Those additional out-of-state and international students have tended to concentrate into those STEM areas that have high employment prospects, and chemical engineering is thereby one of the top four majors for them. Over the period from 2011 to 2019, 20% of chemical engineering graduates were international, and 13% were out-of-state domestic, numbers which are substantially higher than in earlier years. The bulk of the international students are from China and also other Asian countries.

Twenty-seven percent of Berkeley chemical engineering bachelor's graduates for the nine years from 2011 to 2019 entered Berkeley as transfer students (250 transfers out of 926 total bachelor's graduates).[310] This figure is similar to data for the entire Berkeley campus during this period,[311] indicating that transfer is

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[307] Enrollment, Our Berkeley, Office of Planning and Analysis, University of California, Berkeley, consulted November 20, 2019. https://opa.berkeley.edu/campus-data/our-berkeley

[308] Total enrollments fluctuate less year-to-year than do the annual numbers of graduates, since enrollments include multiple years' worth of students.

[309] Non-resident tuition for the University of California as of 2019-20 in round numbers is another $30,000 on top of the in-state tuition of $14,250.

[310] Our Berkeley, *loc. cit.*, November 20, 2019.

[311] Our Berkeley, *loc. cit.*, November 20, 2019.

viable for CBE majors even with the large sequencing of the curriculum and the lack of CBE 40 and to some extent some other required Lower-Division courses in community colleges.

Graduate Enrollments. The capacity of the department for graduate students has been set over the years by the collective capacity of the faculty for supervision of PhD and MS research students plus the sizes of non-research Master's programs. The number of PhD degrees did not exceed ten per year until 1964 and then fluctuated between 10 and 22 per year until 1983, when it rose to an average of about 25, lasting until 1995.[312] From 2010 through 2019 PhD degrees have averaged 18 per year.[313] These trends roughly parallel the size of the faculty, at one degree per year per ladder-rank faculty member.

Master's degrees have fluctuated even more over the years as departmental policies pertaining to them have changed. As the Plan II Master's rose in the 1960s and the research (Plan I) Master's retained emphasis, the degree output at the Master's level was in the range 20 to 30 per year. With de-emphasis of the Master's degree around 1983 the annual output dropped to ten and less. Then as the Product Development Program came into being in 2006 the output at the Master's Level increased again to about 30 per year,[314] and with the Professional Masters in Bioprocess Engineering it will rise still further

Social and Demographic Factors. At the start of the Berkeley chemical engineering program the students and faculty were all male, a situation that was generally true nationally at the time. Since engineering should draw, and needs to draw, from all sectors of the population, gender and racial diversity have long been major issues with regard to engineering education. These needs are recognized by national programs such MESA (Mathematics, Engineering and Science Achievement) which started in the Berkeley College of Engineering through the efforts of Wilbur H. Somerton and others around 1970,[315] the

[312] Blanch & Wilke, 1998, p. 7.
[313] Our Berkeley, *loc. cit.*, November 20, 2019.
[314] Our Berkeley, *loc. cit.*, November 20, 2019.
[315] W. H. Somerton, M. P. Smith, Robert Finnell & Ted Fuller, *The MESA Way: A Success Story of Nurturing Minorities for Math/Science Based Careers*, Caddo Gap Press, 1994;

Society of Women Engineers, the Engineer Girl program of the National Academy of Engineering, the Minority Affairs Committee of AIChE, and Project SEED of the American Chemical Society.

Gender Diversity. Marie H. Lavering (nee Johnson), the first female graduate, received her B. S. degree in 1950, and then taught chemistry and physics at Vallejo High School. As best can be determined from available records, the second female bachelor's graduate was Wanda Clearwaters in 1966. She became the co-author of several patents for the U. S. Navy. During the early- to mid-1970s the proportion of women grew substantially, such that the class graduating in 1977 contained 8% women and the freshman class that same year contained 13% women.[316] By 1978 enrollment in the major at all undergraduate levels was 14% female and nearing 20% in the freshman class.[317] The sharp growth in the percentage of women as students over those relatively few years was not unique to Berkeley, chemical engineering, or even engineering itself. Data cited by Grasso and Helble[318] show similar trends for professional degrees in engineering, medicine, law, and business. From 2010-11 to 2018-19 classes at the bachelor's level contained an average of 29% women, fluctuating from 23% to 34% without any evident trend across those years.[319] Of 574 undergraduate students in CBE as of Fall 2019, 38% were women.[320]

The growth in the number of women graduate students in Berkeley ChE followed the national growth at the bachelor's level with about a four- to five-year lag. At least three of the early women PhD graduates from Berkeley chemical engineering have gone on to singular and outstanding careers in very different fields of endeavor.

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[316] *Gilman Hall Newsletter*, v. 2, no. 1, p. 13, 1977.
[317] *Gilman Hall Newsletter*, v. 3, no. 1, p. 6, 1978.
[318] D. Grasso & J. J. Helble, "Holistic Engineering and Educational Reform," Ch. 7 in D. Grasso & M. B. Burkins, eds., *Holistic Engineering Education*, Figure 7.6, p. 87, Springer, 2010.
[319] Degree Recipients by Major and Demographics, Our Berkeley, University of California, Berkeley, consulted November 18, 2019. https://pages.github.berkeley.edu/OPA/our-berkeley/degree-recipients-by-major.html
[320] Shannon Ciston, personal communication, December 19, 2019.

Frances Arnold (PhD 1985 with Blanch), Figure 11, left, won the 2018 Nobel Prize in Chemistry "for the directed evolution of enzymes," her own creation which has immensely aided the development of new enzymes for various purposes. She is only the second chemical engineer and fifth woman to win the Chemistry Nobel Prize, with two of her female predecessors being Marie Curie and Irene Joliot-Curie. Arnold is a Professor of Chemical Engineering at Caltech, where she has been for her entire career.[321]

Ellen Pawlikowski (Prusinski) (PhD 1981 with Prausnitz and Newman), Figure 11, center, is one of only three women ever to hold the rank of four-star General of the U. S. Air Force. In her last assignment before retirement, she served as the Commander of Air Force Materiel Command at the Wright-Patterson Air Force Base. She is now Judge Widney Professor at the University of Southern California (USC) Viterbi School of Engineering and a member of the Raytheon Corporation Board of Directors.[322]

FIGURE 11. Three outstanding PhD Graduates of the Department from the 1980s: Frances Arnold (left), Ellen Pawlikowski (center), Gail Greenwald (right) [left & center from Wikimedia Commons; right courtesy of Gail Greenwald]

[321] Frances H. Arnold, The Nobel Prize in Chemistry, 2018. https://perma.cc/3YHH-G3F9
[322] Alumna General (Ret.) Ellen Pawlikowski named Judge Widney Professor at USC, College of Chemistry, University of California, Berkeley, consulted November 17, 2019. https://perma.cc/M77M-WRGC

Gail Greenwald (Green) (PhD 1980 with King), Figure 11, right, became Vice President and Managing Director of Technology and Product Development for Arthur D. Little Co. From there she went on to be Chief Operating Officer of Caveo Technologies and Executive Vice President of Foliage. She is now heavily in venture capital and angel investing as a principal of the Launchpad Venture Group, an *emerita* member of the Clean Energy Venture Group, and a board member or observer for three of her portfolio companies. She is also Vice Chair of the Sierra Club Foundation and a board member for the Woods Hole Research Center, both following her interests in climate change.[323]

D'Wylde[324] provides more information on Ellen Pawlikowski and also gives information on Georgianna Scheuerman (Lobien) (PhD 1980 with Prausnitz), who has had a very substantial career with Chevron. Of a slightly later vintage, Karen Gleason (PhD 1987 with Reimer) has had a very successful faculty career at MIT, with research on chemical vapor deposition and service as an Associate Provost.

Nationally, data for 2017 showed that 33% of bachelor's graduates in chemical engineering were women. In this regard, chemical engineering ranks relatively high among the engineering majors, for all of which collectively 21% of bachelor's degrees were awarded to women. At the master's and doctoral levels, the percentages of women in chemical engineering nationally for 2017 were 35% and 31%, respectively, showing relatively little difference from one degree level to another.[325]

The first woman tenure-track faculty member in Berkeley chemical engineering was Susan Muller, hired in 1991. She has been followed by Roya Maboudian (1994), Wenjun Zhang (2011), and Markita Landry (2016). For a current faculty size of 20 FTE, that is 20% women, still lower than the proportion of women in undergraduate and graduate student enrollment. In addition, Teresa Head-

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[323] Team, Launchpad Venture Group. https://perma.cc/GM3T-6GY9

[324] Marge D'Wylde, "150 Years and Counting: Women Join Chemical Engineering," *Catalyst*, v. 15, no. 1, pp. 22-23, 2020. https://perma.cc/X9ZW-ZWSY

[325] Brian L. Yoder, "Engineering by the Numbers," American Society for Engineering Education, 2017. https://perma.cc/U692-AX65

Gordon and Michelle Chang hold 0% joint appointments in CBE. In 2017 19% of chemical engineering faculty members across the United States were women.[326]

Racial Diversity. In the nine-year period from 2010-11 through 2018-19, 51% of the 926 Berkeley CBE students identified as Asian or Asian-Americans, including Pacific Islanders.[327] This figure compares with 14% nationally for all forms of engineering in 2016,[328] reflecting the high Asian-American population of California, and the attractiveness of Berkeley to students from China. For the same year only 5.4% of bachelor's graduates were under-represented minorities (African-American, Hispanic,[329] American Indian). By contrast, 3.9% of bachelor's degree graduates in all forms of engineering nationally in 2016 were African-American, and 10.7% were Hispanic.[330] The portions of Berkeley CBE majors who were Hispanic for subsequent years were 7.8% (2017) and 12.4% (2019). The low percentage of Hispanic graduates in CBE at UC Berkeley contrasts with the high (39% in 2019) Hispanic population of California. Further outreach efforts to minority students are vital, along with continued scrutiny of individual admissions criteria for fairness.

The first Berkeley ChE Chinese-American faculty member was Mitchel Shen, hired in 1969. Following his untimely death in 1979, the next to be hired were David Soane (1979), Jei-Wei Chu (2006), Wenjun Zhang (2011), and Rui Wang in 2019. This is still a small percentage in comparison with the high fraction of Chinese-Americans within the CBE student body. Several Indian-American faculty members have been added, starting with Arup Chakraborty in 1988. Markita Landry, Enrique Iglesia, and David Schaffer identify as Latinx, comprising 15% of the faculty, though a far lower fraction than the California population. The one African-American faculty member so far is Keith Alexander, hired in 2005 to lead the Product Development Program.

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[326] Yoder, 2017, *loc. cit*.
[327] Degree Recipients by Major and Demographics, Our Berkeley, *loc. cit.*
[328] Yoder, 2017, *loc. cit.*
[329] Denoting Hispanic, Chicano/a, and Latino/a/x.
[330] Yoder, 2017. *loc. cit.*

Student Activities. Extracurricular activities for undergraduate student majors have usually centered around the Student Chapter of the American institute of Chemical Engineers (AIChE). In earlier days this took the form of evening meetings, often with a speaker from local industry. In recent years activities have become more varied, in part because of the existence of national student competitions set up through the AIChE Annual Student Conference (ASC). The UC Berkeley team won the AIChE National ASC Jeopardy competition, based upon the television quiz show, in 2017,[331] and teams of UC Berkeley chemical engineers have regularly and effectively competed in the ChemE Car competitions held regionally and then at the national ASC (Figure 12).[332] Other events include "keggers," and even synthetic food contests.

Figure 12. The 2016-17 ChemE Car Student Team at the Western Regional Conference, University of California, San Diego, April 2017.

[331] Sarah Ewing, "And the Winner of 2017 ASC ChemE Jeopardy Is …," American Institute of Chemical Engineers. https://perma.cc/QV85-G6XE

[332] UC Berkeley ChemE Car, https://perma.cc/5CZD-SZ2Q. "Chemical Engineering Car," University of California, Berkeley. https://perma.cc/57HS-PM2S

For graduate students, research groups often have their own activities. A scan of research-group websites shows activities such as hikes, backpacking trips to the Sierra Nevada mountains, sailing on San Francisco Bay, etc.

Student Activism. During the era of the Free Speech Movement (1964-65) the CBE students were, in effect, uninvolved. During the period of the largest protests against the Vietnam War (1966-68), chemical engineering students were still mostly uninvolved, but with the invasion of Cambodia in 1970 a substantial group of graduate students (Figure 13) formed for protest activities such as picketing at Chevron, Stauffer Chemical, and Dow Chemical nearby. As Chair, Charles Tobias took an understanding approach toward the group.[333]

FIGURE 13. UC Chemical Engineers Against the War, 1970. The placard on the right is held by Bryan Rogers (PhD 1971 with Prausnitz), who went on to a multidimensional career in art and design, education and practice that culminated in his being Dean of the School of Art and Design at the University of Michigan. The placard on the left is held by Peter Cukor (also PhD 1971 with Prausnitz) whose career was with Teknekron and his own companies.

[333] Bell, 2020, p. 71-72.

The coronavirus pandemic of 2020 and simultaneous national issues of police brutality have heightened concerns among students who are working with the faculty to define steps that can be taken to address racism on campus and awareness of it.

Department Culture. Faculty members who were present in the department in the first thirty-five years recall a remarkably cohesive group, dedicated to the success of the department and notably free of inter-personal conflicts.[334] To some extent this may have stemmed from the decade of vying with Process Engineering for recognition as the sole Berkeley chemical engineering program, but it also reflected the particular people and the manner of governance. Prausnitz[335] noted that Wilke "deserves credit for setting the tone of the department. A note of cooperation was sent around that presented an air of teamwork rather than competitiveness. Chemical engineering faculty help each other at Berkeley instead of developing rivalries. We have a cooperative spirit because of Wilke." Bell[336] notes that the author, department chair during the 1970s and his predecessor as chair, had a "style of consultation and doing what I called administration by walking about. He would come into my office, come into the office of colleagues, and ask if he could spend a few minutes talking about an issue that related to the department. And after he had heard you out—and he listened very, very well—he would summarize all these things. And so when we had a faculty meeting, he pretty much knew what to expect from each individual, and he knew who was going to be very articulate and passionate about something and who, you know, more or less didn't care, at the other extreme. And I found that that was very effective, and I tried to adopt his style in that sense."

It was also a less pressure-some life. Government grants for research were coming into being but had not reached the scale that they and grants from industry and other sources have now. An interesting phenomenon was the daily

[334] See, for example, Tobias, 1994, p. 40; King, 2013, pp. 255-256; Bell, 2020, p. 64.
[335] "A History of Chemical Engineering at Berkeley," *Newsletter of the College of Chemistry*, v. 6, No. 2, April 1998.
[336] Bell, 2020, p. 270.

hearts game[337] at the Faculty Club. This was built around George Maslach, who was Dean of Engineering, then Provost - Professional Schools and Colleges, and then Vice Chancellor for Research (the initial occupant of both of the latter two positions.) The hearts game occurred at The Faculty Club during lunch and until 2 or 3 in the afternoon. Tobias was a regular participant, with Petersen at times as well. Although no business was taken up, the interpersonal bonding probably did as much as anything to overcome what could have remained of the antipathies of the Process Engineering years.

The marked cohesiveness of the departmental faculty waned in the 1980s and has continued to do so. This phenomenon is not primarily a result of different personalities and working styles. It is instead reflective of the changing dimensions of faculty careers over the years and is not at all unique to Berkeley or to chemical engineering. The change can be seen in nearly all science and engineering departments at major research universities. It reflects the pressures associated with individual faculty members running what are, in effect, medium-sized businesses. Grants in support of research have become more competitive and thereby harder to get. Faculty members have to have multiple sources of support, so as to have a sufficiently diversified portfolio to maintain support of their research groups in case a grant application fails. As already noted, postdoctoral experiences have become a much more important aspect of training, especially for academic posts, and thereby research groups contain more postdoctoral scholars and some even have permanent research staff. With these additions and also more undergraduate research participants, research groups have become much larger. These larger group sizes require more money for support, but in a time when getting grants is more competitive. Therefore, the labors of securing research grants and nurturing the relationships that surround them have become much greater. There are also more competing interests within a department. For example, in Berkeley CBE there can be tensions between biomolecular faculty and those in catalysis regarding areas in which to recruit, space, etc.[338] Finally, raising families has changed since the department was formed; in the middle 20th century most professors

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[337] Bell, 2020, p. 264.
[338] Prausnitz, 2020, p. 122.

were male and cultural norms placed the wife at home raising children and taking care of the home. In the 21st century it is common that both spouses are employed and both parents participate in home upkeep child-rearing, furthering the complex time-management pressures that often vex academic parents.

APPENDIX A

PORTIONS OF *FORTUNE* EDITORIAL[339]

CITED BY THE COMMITTEE ON BUDGET AND INTER-DEPARTMENTAL RELATIONS OF THE ACADEMIC SENATE IN THE MINUTES OF THEIR NOVEMBER 28, 1945 MEETING, AND ALSO TRANSMITTED BY JOEL H. HILDEBRAND TO PRESIDENT ROBERT GORDON SPROUL ON NOVEMBER 7, 1945.

Comments by the author are in italics.

… The idea that the longhairs did things that engineers could not do is no monopoly of young and brash scientists. It is believed also by some scientists of long experience and by a good many engineers of all ages.

For example, it was a distinguished communications engineer, Professor E. A. Guillemin of M. I. T., who recently told engineering students that their profession at large "was woefully unable" to meet the war's technical demands. Physicists, he believes, had to be recruited because the engineering craft did not supply enough men[340] "trained to have a broad understanding of the physical laws and mathematical tools essential to doing creative work."

> *Guillemin was a highly respected "father" of modern network theory and a strong proponent of more mathematics and science in engineering education. His ideas are developed in E. A. Guillemin, "The role of applied mathematics in the electrical engineering art,"* Electrical Engineering*, 78 (5) (1959) 414–461, and* The Mathematics of Circuit Analysis*, MIT Press, 1949. Another similar quote from Guillemin is, "At the beginning of World War II, when engineers were presented the problem of developing radar, they were (except in very few cases) found woefully lacking in an ability to cope with such an unconventional*

[339] "Longhairs vs. Hairy Ears," *Fortune*, v. 32, p. 115, November 28, 1945.
[340] The use of gender-specific language throughout this passage is a sign of the times.

> *situation; and physicists, both theoretical and experimental, had to be called in to do what was essentially an engineering job."*[341]

Similar testimony has come from another engineer, Dr. Frank B. Jewett, long head of the Bell Telephone Laboratories, and now President of the National Academy of Sciences.

> *Jewett was a PhD physicist but also very much an engineer. His role in defining and building the Bell Telephone Laboratories is well described by Jon Gertner,* The Idea Factory: Bell Labs and the Great Age of American Innovation*, Penguin Books, 2012. The structure and modes of operation of Bell Labs were designed so as to enable constant intellectual interactions among scientists and engineers of all disciplines, resulting in impressive new technologies such as the transistor, masers and lasers, the telephone repeater, zone refining, and much of the information theory underlying digital computation*.

Dr. Jewett is authority for the story that when it became necessary to build a war plant to manufacture a dangerous rocket powder, skilled engineers said that the job was too dangerous to try on the required scale. Thereupon men from an educational institution built the plant and ran it without serious accident.

> *In his cover memo to President Sproul, Hildebrand points out that this project was carried out under the direction of William N. Lacey, Professor of Chemical Engineering at Caltech, and an early G. N. Lewis PhD graduate from the Berkeley Chemistry Department.*[342]

None of these men had real industrial or engineering experience but all "knew their basic science firsthand."

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[341] E. A. Guillemin, *Proc. Inst. Radio Engrs*., v. 50, pp. 872-878 (1962), cited by Scott Hamilton, *An Analog Electronics Companion: Basic Circuit Design for Engineers and Scientists*, p.91, Cambridge University Press, 2007.

[342] See, e. g., Bruce H. Sage & William N. Lacey, U. S. Patent No. 2628561A, "Propellant Powder Grain for Rocket Motors," Filed March 17, 1943, Granted February 17, 1953. https://patents.google.com/patent/US2628561

Now Drs. Jewett and Guillemin are not cocky youngsters but highly reputable engineers. Dr. Jewett criticizes the nature of training for engineering, the large-scale practical application of fundamental scientific knowledge. He believes that a man can best be fitted to tackle problems in all engineering fields if his basic training in physics, chemistry, mathematics, and scientific research methods is more adequate. He proposes that the time given to engineering courses be cut, that engineering training always be closely linked to graduate research, and that indoctrination in transiently standard practice be largely left to industry.

Dr. Guillemin also complains that engineering fails to teach flexible and analytical methods of thought. Teaching rules of practice should be incidental, with emphasis on what is harder to learn and absorb – abstract concepts. Students should not be trained primarily in how to design a piece of equipment whose only distinguishing characteristic will be a competitive market price. Rather their training should stress designing to improve performance, apart from cost. In short, curriculums should be on a par with those in basic science and mathematics.

Whether or not desirable educational reforms are being held up by shortsighted "practical" engineers is another matter. In any case, here is an important question for American industry. If basic scientists were able to perform important war engineering jobs that were beyond engineers, something is wrong somewhere.

> *[This is the essential point, which led to the introspection by engineering educators that in turn led to the introduction of much more science and mathematics into engineering education after World War II. It would have been particularly cogent at Berkeley, where so many members of the science faculty had been principals of the Manhattan Project.]*

APPENDIX B

TIMELINE

1849 California Gold Rush.

1850 Admission of California as a state, as part of the Compromise of 1850.

1868 University of California founded.

1868 Robert A. Fisher appointed as the first Professor of Chemistry, Mining and Metallurgy.

1869 The first transcontinental railway completed, connecting California to the Eastern U. S.

1872 The College of Chemistry founded.

1873 The first building of the Berkeley campus, South Hall, completed, housing Chemistry and other sciences, as well as the library.[343]

1888 First curriculum in Chemical Engineering offered at MIT.

1902 Frederick G. Cottrell appointed as an instructor in Chemistry at Berkeley.

1906 Cottrell invented the electrostatic precipitator.

1908 American Institute of Chemical Engineers (AIChE) founded.

1911 Cottrell resigned to set up the San Francisco Office of the U.S. Bureau of Mines.

1912 Cottrell founded the Research Corporation.

1912 Gilbert N. Lewis left MIT for Berkeley and became Dean of the College of Chemistry, a position he held with only two brief interruptions until his mandatory retirement in 1941 upon reaching age 65.

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[343] Helfand, loc. cit., p.42, 2002.

1912 Lewis instituted a chemical technology major, subsequently directed by Merle Randall.

1917 Gilman Hall opened.

1917 The Announcement of Courses lists lecture and laboratory courses in chemical technology, a course in the chemistry of the silicate industries, and a course in applied electrochemistry.

1937 Glenn T. Seaborg completed his PhD and began work as a research assistant to Lewis.

1939 Seaborg joined the College of Chemistry faculty.

1939 George Alves (B.S. in Chemistry, 1939) enrolled in the Unit Process Option established in the Department of Mechanical Engineering by Llewellyn Boelter.

1941 Alves completed the requirements of the Unit Process Option and received an M.S. in Mechanical Engineering.

1941 Isolation and identification of plutonium by Seaborg and co-workers in Room 307 Gilman Hall.

1941 Latimer became dean.

1942 Donald McLaughlin (Dean of the College of Engineering), Wendell Latimer (Dean of the College of Chemistry), Llewellyn M. K. Boelter (Professor of Mechanical Engineering) and Merle Randall (Professor of Chemistry) formed a Graduate Group to offer the M.S. degree in Chemical Engineering.

1942-45 Substantial involvement of the University of California (Lawrence, Oppenheimer, Alvarez, others) and the College of Chemistry (Seaborg, Latimer, Connick, others) in the Manhattan Project.

1945 Academic Senate Committee on Budget and Interdepartmental Relations recommended that chemical engineering be established in the College of Chemistry rather than the College of Engineering, following the “Longhairs vs. Hairy Ears” argument. Provost Monroe Deutsch authorized the establishment of a Chemical Engineering program in the College of Chemistry.

1946 Philip Schutz, Charles Wilke and LeRoy Bromley hired.

1946 Undergraduate instruction began in the College of Chemistry with complementary work in the College of Engineering.

1947 Schutz's death. Vermeulen appointed as the director of the program. Hanson and Tobias hired.

1947 PhD and M. S. programs approved.

1948 Lewis Hall completed as the first project of the large post-war building boom of the university.

1948 B.S. program approved.

1949 U. S. S. R. sets off that country's first atomic bomb. Debates within the U. S. on whether to proceed with the hydrogen bomb. Pitzer appointed Director of Research of the Atomic Energy Commission.

1949 Hildebrand replaced Latimer as Dean.

1949 The Chemistry Department renamed the Department of Chemistry and Chemical Engineering.

1949 Nevin Hiester received the first PhD in Chemical Engineering.

1950 Marie H. Johnson, first female graduate, received her B.S. in Chemical Engineering.

1950 Wilke and Tobias were the first in chemical engineering to obtain a research grant from the Office of Naval Research. The subject was mass transfer effects in electrolysis.

1951 Pitzer returned from the AEC and replaced Hildebrand as Dean, a position that he held, except for 1955-56, until 1960 when he departed for the presidency of Rice University.

1952 A Division of Chemical Engineering was created within the Department of Chemistry and Chemical Engineering, with Vermeulen as the chairman.

1952 The Chemical Engineering program received limited accreditation for two years.

1953 Wilke succeeded Vermeulen as chairman of the Division.

1953 Petersen hired.

1953 Seaborg arranged a substantial, essentially unrestricted block grant for chemical engineering research under the Nuclear Chemistry Division of the Radiation Laboratory.

1954 Giauque Low Temperature Laboratory constructed. Acrivos hired.

1955 Prausnitz and Oldershaw hired.

1957 Dispute with the College of Engineering finally resolved by Clark Kerr.

1957 Chemical Engineering became a full department of the College of Chemistry.

1957 Wilke became chairman of the Department of Chemical Engineering.

1963 Hanson became chairman.

1963 Latimer Hall was completed for the Department of Chemistry, whereupon Chemical Engineering occupied Gilman Hall fully.

1963 Andrew Grove, who would be the first hire by Gordon Moore (B.S. Chemistry 1950) and Robert Noyce (younger brother of UCB Chemistry Professor Donald Noyce) into the Intel Corporation, received his PhD.

1965 Chemical Engineering expands into portions of Lewis Hall as Hildebrand Hall is completed.

1966 First broad national rankings of academic departments by the American Council on Education, based on a survey done in 1964. UCB Chemical Engineering was rated fourth for Effectiveness of Graduate Program and fifth for Quality of Graduate Faculty.

1966 Room 307 Gilman Hall designated a registered National Historic Landmark by the U.S. Department of the Interior in recognition of it having been the location for the isolation of plutonium.

1966 UC switched to the quarter system in the fall.

1967 Tobias became department chair.

1968 Berkeley granted its 100th PhD in Chemical Engineering.

1972 King became department chair.

1972 Industrial Advisory Board created.

1976 About 12% of the freshman class were women.

1980 First year that Chemical Engineering granted more than 100 B.S. degrees.

1980 Bayh-Dole Act became law.

1981 King became the first member of the ChE faculty to be Dean of the College of Chemistry.

1981 Bell became department chair.

1982 Development office launched for College of Chemistry.

1983 Berkeley campus reverted to the semester system.

1991 Susan Muller hired as the first female ChE tenure-track faculty member.

1992 Berkeley granted its 500th PhD in Chemical Engineering.

1993 Construction of Tan Hall began.

1997 Tan Kah Kee Hall completed.

2001 Governor Gray Davis Institutes on Science and Innovation launched.

2006 Professional Master's Degree in Product Development Program initiated.

2010 Department name changed to Chemical and Biomolecular Engineering.

2020 Professional Master's Degree in Bioprocess Engineering launched.

APPENDIX C

CHAIRS OF ChE/CBE AND DEANS OF THE COLLEGE OF CHEMISTRY, 1946-2020

[Acting or Interim positions not included.]

Chairs of Chemical Engineering/Chemical and Biomolecular Engineering

1946-47	Philip Schutz (Director)
1947-53	Theodore Vermeulen (Director until 1952)
1953-63	Charles R. Wilke
1963-66	Donald N. Hanson
1966-72	Charles W. Tobias
1972-81	C. Judson King
1981-91	Alexis T. Bell
1991-94	Morton M. Denn
1994-97	Simon L. Goren
1997-2001	Harvey W. Blanch
2001-05	Arup K. Chakraborty
2005-06	Alexis T. Bell
2006-11	Jeffrey A. Reimer
2011-13	Douglas S. Clark
2013—	Jeffrey A. Reimer

Deans of the College of Chemistry (Chemical Engineers in Capitals)

Prior to 1896 the College of Chemistry came under the Dean of the College of Letters and Colleges of Science, held from 1886 to 1896 by Irving Stringham.

Chemical engineers in CAPITALS.

1896-1901	Willard Rising
1901-12	Edmond O'Neill
1912-41	Gilbert Newton Lewis
1941-49	Wendell M. Latimer
1949-51	Joel H. Hildebrand
1951-60	Kenneth S. Pitzer
1960-65	Robert E. Connick
1966-70	Harold S. Johnston
1970-75	David H. Templeton
1975-81	Norman E. Phillips
1982-87	C. JUDSON KING
1987-88	Robert E. Connick
1988-94	C. Bradley Moore
1994-99	ALEXIS T. BELL
1999-2005	Clayton H. Heathcock
2005-2007	Charles. B. Harris
2008-2013	Richard Mathies
2013—	DOUGLAS S. CLARK

APPENDIX D

TENURE-TRACK ChE/CBE FACULTY AT BERKELEY, 1946-2020

(† - primary appointment in another department)

Philp Schutz, 1946-47 (death)
LeRoy A. Bromley, 1946-76 (retired)
Charles R. Wilke, 1946-87 (retired)
Theodore Vermeulen, 1947-83 (death)
Donald N. Hanson, 1947-89 (retired)
Charles W. Tobias, 1947-91 (retired)
F. Campbell Williams, 1948-52 (resigned)
Kenneth F. Gordon, 1952-54 (resigned)
Eugene E. Petersen, 1953-91 (retired)
Andreas Acrivos, 1954-62 (resigned)
John M. Prausnitz, 1955-2004 (retired)
Donald R. Olander, 1958-61 (transferred)
Alan S. Foss, 1961-94 (retired)
Michel Boudart, 1961-64 (resigned)
Richard A. Wallace, 1961-65 (resigned)
Simon L. Goren, 1962-2002 (retired)
Edward A. Grens II, 1963-87 (resigned)
C. Judson King, 1963-2003 (retired)
John S. Newman, 1963-2011 (retired)
Richard J. Ayen, 1963-68 (resigned)
Robert P. Merrill, 1964-77 (resigned)
David N. Lyon, 1965-82 (retired)
Michael C. Williams, 1965-89 (resigned)
Robert L. Pigford, 1966-75 (resigned)
Scott Lynn, 1967-94 (retired)

Alexis T. Bell, 1967—
Mitchel M-C. Shen, 1969-79 (death)
Lee F. Donaghey, 1969-77 (resigned)
Thomas K. Sherwood, 1969-76 (death)
Douglas W. Fuerstenau, 1971-1987†
Clayton J. Radke, 1975—
Dennis W. Hess, 1977-91 (resigned)
Elton J. Cairns, 1978-2004 (retired)
Harvey W. Blanch, 1978-2014 (retired)
David S. Soane, 1979-1994 (resigned)
Edward Reiff, 1979-82 (resigned)
Morton M. Denn, 1981-99 (resigned)
Jeffrey A. Reimer, 1982—
James N. Michaels, 1982-89 (resigned)
Douglas S. Clark, 1986—
David B. Graves, 1986-2020 (retired)
Doros Theodorou, 1986-95 (resigned)
Arup K. Chakraborty, 1988-2005 (resigned)
Susan J. Muller, 1991—
Jay D. Keasling, 1992—
Enrique Iglesia, 1993—
Roya Maboudian, 1993—
David V. Schaffer, 1999—
Alexander Katz, 2000—
Nitash P. Balsara, 2000—
Rachel A. Segalman, 2004-14 (resigned)
Jean M. J. Fréchet, 2005-10 (resigned)†
Jei-wei Chu, 2006-13 (resigned)
Berend Smit, 2007—
Danielle Tullman-Ercek, 2009-2016 (resigned)
Wenjun Zhang, 2010—
Teresa Head-Gordon, 2011—†

Bryan D. McCloskey, 2014—
Ali Mesbah, 2014—
Sanjay Kumar, 2015—†
Jeffrey R. Long, 2015—†
Markita D. Landry, 2016—
Kranthi K. Mandadapu, 2017—
Rui Wang, 2019—
Michelle C. Chang, 2019—†
Karthik Shekhar, 2020—

APPENDIX E

SOME MAJOR CROSS-DISCIPLINARY RECOGNITIONS FOR CBE FACULTY MEMBERS[344]

American Academy of Arts and Sciences

John Prausnitz (1988)
Andreas Acrivos (1993)
Jean M. J. Fréchet (2000)
Morton M. Denn (2001)
Alexis T. Bell (2007)
Arup K. Chakraborty (2007)
Enrique Iglesia (2015)
Jay D. Keasling (2016)

Distinguished Teaching Award (Berkeley Campus)

David N. Lyon (1978)
Donald N. Hanson (1986)
Michael C. Williams (1988)
Clayton J. Radke (1994)
Jeffrey A. Reimer (2003)

[344] Major Awards and Honors, College of Chemistry, University of California, Berkeley. https://chemistry.berkeley.edu/awards-honors

National Academy of Engineering

Thomas K. Sherwood (1964)
Robert L. Pigford (1971)
Charles R. Wilke (1975)
Douglas W. Fuerstenau (1976)
Andreas Acrivos (1977)
Michel Boudart (1979)
John M. Prausnitz (1979)
C. Judson King (1981)
Charles W, Tobias (1983)
Morton M. Denn (1986)
Alexis T. Bell (1987)
John S. Newman (1999)
Jean M. J. Fréchet (2000)
Arup K. Chakraborty (2004)
Harvey W. Blanch (2005)
Enrique Iglesia (2008)
Jay D. Keasling (2010)
Clayton J. Radke (2015)
Douglas S. Clark (2019)

National Academy of Inventors

Jay D. Keasling (2014)

National Academy of Medicine

Arup K. Chakraborty (2017)

National Academy of Sciences

Thomas K. Sherwood (1958)
Robert L. Pigford (1972)
John M. Prausnitz (1973)
Jean M. J. Fréchet (2000)
Alexis T. Bell (2010)

Arup K. Chakraborty (2016)

National Medal of Science

John M. Prausnitz (2003)

Noyce Prize for Excellence in Undergraduate Teaching, Physical Sciences

Clayton J. Radke (1993)
Jeffrey A. Reimer (1998)
Enrique Iglesia (2005)
Susan Muller (2012)

APPENDIX F

BOOKS BY BERKELEY CHEMICAL & BIOMELECULAR ENGINEERING FACULTY WHILE AT BERKELEY[345]

Hanson, Donald N., John H. Duffin and Graham F. Somerville, *Computation of Multistage Separation Processes*, Reinhold, 1962.

Petersen, Eugene, *Chemical Reaction Analysis*, Prentice Hall, 1965.

Prausnitz, John M., Charles A. Eckert, Robert V. Orye & John P. O'Connell, *Computer Calculations for Multicomponent Vapor-Liquid Equilibria*, Prentice-Hall, 1967; **Prausnitz, John M.**, Timothy F. Anderson, **Edward A. Grens II**, Charles A. Eckert, R. Hsieh and J. P. O'Connell, *Computer Calculations for Multicomponent Vapor-Liquid and Liquid-Liquid Equilibria*, Prentice-Hall, 1980.

John M. Prausnitz and Ping L. Chueh, *Computer Calculations for High-Pressure Vapor-Liquid Equilibria*, Prentice-Hall, 1968.

Prausnitz, John M., *Molecular Thermodynamics of Fluid-Phase Equilibria*. Englewood Cliffs, Prentice Hall, 1969; 2nd ed., with Ruediger N. Lictenthaler & Edmundo Gomes de Azevedo, 1986; 3rd ed., 1999.

Hildebrand, Joel H., **John M. Prausnitz**, and Robert L. Scott, *Regular and Related Solutions: The Solubility of Gases, Liquids and Solids,* Van Nostrand Reinhold, 1970.

King, C. Judson, *Separation Processes*. McGraw-Hill, 1971; 2nd ed., 1980; Dover, 2013. Open access: https://escholarship.org/uc/item/1b96n0xv

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345 Does not include books edited by faculty or books written while the faculty member was elsewhere.

King, C. Judson, *Freeze-Drying of Foods*, CRC Press, 1971.

Newman, John S., *Electrochemical Systems*, Prentice Hall, 1972; 2nd ed., 1991; 3rd ed., with Karen E. Thomas-Alyea, Wiley-Interscience, 2004; 4th ed., with **Nitash Balsara**, Wiley, 2019.

Aklonis, John J., William J. MacKnight and **Mitchel C. Shen**, *Introduction to Polymer Viscoelasticity*, Wiley-Interscience, 1972.

Sherwood, Thomas K., **Robert L. Pigford** and **Charles R. Wilke**, *Mass Transfer*, McGraw-Hill, 1975.

Reid, Robert C., **John M. Prausnitz** and **Thomas K. Sherwood**, *Properties of Gases and Liquids*, McGraw Hill, 3rd ed., 1977; 4th ed., Reid, **Prausnitz** and Bruce E. Poling, 1987; 5th ed., Poling, **Prausnitz** and John P. O'Connell, 2000.

Valle-Riestra, J. Frank, *Project Evaluation in the Chemical Process Industries*, Mc-Graw-Hill, 1983.

Blanch, Harvey W. and **Douglas S. Clark**, *Biochemical Engineering*, M. Dekker/CRC Press, 1995; 2nd ed., 1997; 3rd ed., 2021.

Duncan, T. Michael, and **Jeffrey A. Reimer**, *Chemical Engineering Design Analysis: An Introduction*, Cambridge University Press, 1998, 2019.

Denn, Morton M., *Process Modeling*, Longman, 1986.

John Hatton and **Paul B. Plouffe**, eds., *Science and Its Ways of Knowing*, Addison-Wesley, 1996.

V. M. Starov, M. G. Velarde, and **C. J. Radke**, *Wetting and Spreading Dynamics*, CRC Press. 2007

Berend Smit, **Jeffrey A. Reimer**, Curt M. Oldenburg, and Ian C. Bourg, *Carbon Capture and Sequestration*, World Scientific Press, Singapore, 2013

King, C. Judson, *The University of California: Creating, Nurturing, and Maintaining Academic Quality in a Public University Setting*, Center for Studies in higher Education, University of California, Berkeley, 2018. Open access: https://escholarship.org/uc/item/6rj182v7

APPENDIX G

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