Chemical Engineering at . . .

the University of Louisville

Ernst Hall, home of the Department of Chemical Engineering.

J.R. Fried. J.C. Watters, J. Gerstle, and G. Willing

Louisville, named after the French King Louis XVI, was founded in 1778 by Col. George Rogers Clark on the south bank of the Ohio River. It is the largest city in the Commonwealth of Kentucky. In 2014 the Louisville metro area, comprised of the city of Louisville, Jefferson County, and 12 surrounding counties in Kentucky and southern Indiana, had a population of more than 1.2 million, ranking the Louisville Metropolitan Statistical area 43rd nationally in population. In addition to the University of Louisville, the city is the home to Churchill Downs (annual host of the Kentucky Derby), Yum! Brands (parent of Kentucky Fried Chicken), the Louisville Bats (The Cincinnati Reds' AAA team), and three Fortune 500 companies. United Parcel Service's international air hub, Worldport, is located at the Louisville airport.

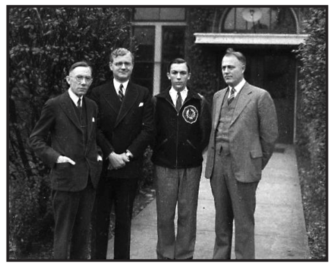
THE UNIVERSITY

The University of Louisville (UofL), established shortly after the founding of the city, is one of Kentucky's two major state-supported research universities. It was the oldest private municipal university in America until it joined the state system in 1970. The university has three campuses the largest of which is the 287-acre Belknap Campus, the home of the J.B. Speed School of Engineering where the Department of Chemical Engineering is located. Current total student enrollment exceeds 22,000, including 5,600 graduate students in 12 schools, with approximately 7,000 faculty and staff, more than 141,000 alumni, and an operating budget of $1.2 billion. The University (the Cardinals) is affiliated with the Atlantic Coast Conference (ACC) and has particularly strong programs in football, men's and women's basketball, softball, and baseball.

THE SPEED SCHOOL OF ENGINEERING

In 1923, Mr. A.Y. Ford, the then-president of the University of Louisville, asked Bennett M. Brigman, who would become first dean of Speed School, to prepare a proposal for a school of engineering. In 1924, Mr. Ford learned that Dr. William S. Speed and his brother-in-law, Senator Frederic M. Sackett, wanted to do something for the school. Mr. Ford suggested an engineering school and showed them the report that

Brigman had prepared. They were satisfied with the plan and as a result an endowment of $250,000 was made by William S. Speed and Mrs. Olive Speed Sackett in memory of their father, Louisville industrialist James Breckinridge Speed. Consequently, Speed Scientific School came into existence in 1924 as a unit of the University of Louisville with Brigman serving as its first dean. Simultaneous with the announcement of the endowment, the university moved to the Belknap campus. It was decided that the Speed Scientific School would offer courses in chemical, civil, electrical, and mechanical engineering leading to the degrees of Bachelor of Science in the respective disciplines. It was also decided to adopt the co-operative form of education, with the curriculum extending over four years, 12 months to a year, thus allowing the students to have one year of industrial experience while in school. Initially, the school used a quarter system and the Speed Scientific School opened its doors on Sept. 25, 1925, to its first class, with an enrollment of 89 students. In 2004, the name was changed to the J.B. Speed School of Engineering to reflect its engineering focus.



Pictured on the left is Bennett M. Brigman who was the founding dean of the Speed School of Engineering.

The Speed School of Engineering currently has approximately 2,100 undergraduate, 250 M.Eng., and 300 M.S. and Ph.D. students. The College offers ABET accredited B.S. and M.Eng. degrees in bioengineering; chemical, civil, electrical, industrial, and mechanical engineering; and computer engineering and computer science; as well as M.S. and Ph.D. programs in all disciplines.

Early research activity for local distilleries took place in the ChE department in 1936.

LOUISVILLE'S CHEMICAL INDUSTRY

Whiskey and distilling have been almost synonymous with Louisville since the late 1700s and formed a large portion of the "chemical" industry in the early part of the 20th century. Prohibition in the 1920s dealt a death blow to many smaller Louisville distilleries but some did survive through strategic creativity. For example, the local powerhouse and bourbon whiskey manufacturer Brown-Forman (established in 1870) survived prohibition by bottling bourbon for medicinal purposes. The repeal of prohibition in 1933 saw a growth in the local production of bourbon whiskey that continues to this day as well as a close relationship between UofL's ChE Department and the bourbon producers. Early research activity in chemical engineering for the whiskey industry focused on areas of testing and control. Today the bourbon whiskey business is booming in worldwide sales with many of our alumni finding employment as part of this expansion.

Around 1918, the industrial complex in west Louisville began with construction by Standard Oil of Kentucky of an oil refinery in the area. In the 1930s, Aetna Oil and Louisville Refinery also developed oil refineries producing fuel, gasoline, kerosene, naphtha, oil, and petroleum coke. These refineries have since been torn down and replaced by petroleum terminals.

The war years saw the establishment of chemical manufacturing as a pillar of local industry, located in what became known as "Rubbertown" in west Louisville, so named because so many of the companies produced rubber and related products. The location of Louisville, on the Ohio River and far enough inland to be safe from enemy bombing, made it an ideal location to produce materials for the war effort. In 1941, the U.S. Office of War Production contracted with National Carbide to construct a calcium carbide/acetylene gas plant. The B.F. Goodrich Corporation built an adjacent plant. In 1941 DuPont built a Neoprene synthetic rubber plant. In 1945 Union Carbide built a plant to make butadiene from grain alcohol that was supplied by local distilleries. Also in 1945, a consortium of tire manufacturers called National Synthetic Rubber constructed a styrene-butadiene rubber plant to manufacture tires for the war effort. This plant was operated by the federal government until 1955. Much of the plant thereafter in southwest Louisville operated as American Synthetic Rubber until its acquisition by Michelin, which runs it today. Other Defense Department wartime plants devolved to civilian use and Louisville continued as a center of the rubber and polymer industries. Also in 1955, DuPont built a Freon production facility next to its Neoprene plant with the later addition of a vinyl fluoride facility. In 2007, DuPont closed its Louisville Neoprene Rubber manufacturing facilities transferring operations to a sister plant in Louisiana.

The 1950s saw the establishment of GE's 900-acre Appliance Park in south central Louisville. The GE Louisville plant owed its existence to Louisville being a river, road, rail, and later air hub, as well as a center of polymer, and later Freon, production. At its peak, in the early 1970s, Appliance Park employed about 23,000 people and was the largest employer in Kentucky. GE's Applied Research and Design Building at Appliance Park was the center of polymer research for their appliance division and employed several chemical engineers as well as promoting collaborative research with the ChE faculty. By 1983, employment at Appliance Park had dropped to 11,800 and further dwindled to 4,200 by 1999. Among other cuts, polymer research had been moved elsewhere. In 2016, the remaining assets and operations at GE Appliance Park were acquired by Chinese appliance company Haier.

In 1961, the Union Carbide plant was sold to Rohm and Haas Co., which made acrylic plastic products. After considerable reduction in force in the 2000s, Rohm and Haas, including its Louisville plant, was acquired by Dow Chemicals in 2009. In 1979, Borden Chemical Inc. opened a manufacturing facility to produce formaldehyde, urea-formaldehyde resins, phenolic resins, and adhesives. This plant later was operated by Hexion and is now owned by Momentive. The rubber and chemical industries provided employment for many of our graduates down through the years; however, the 2000s saw a general decline in these industries as a result of recession and increased local environmental regulation, as well as national and international changes in the industry. However, it was the growth of the chemical industry in Louisville in the post-war years that served as a catalyst for the establishment of the Ph.D. program in chemical engineering in 1951, making it the first Ph.D. program in engineering at University of Louisville, and the only one for the next 30 years.

EARLY HISTORY OF THE DEPARTMENT

Although the chemical engineering department started in 1925, it wasn't until 1933 that it became a major program under the direction of Dr. Robert C. Ernst, one of the first chemical engineering doctoral graduates from University of Minnesota, and it received initial accreditation by AIChE in 1935. We were the first ChE department south of the Ohio River to receive such recognition. In 1937, the accreditation procedure was absorbed by ECPD (Engineer's Council for Professional Development) and departmental accreditation by that group and its successor, ABET, Inc., has continued unbroken through the present. In 1967, the department moved to its new building and current home, Ernst Hall. At the time, the department had eight faculty members including Prof. R.C. Ernst who had by then been appointed dean of the Speed Scientific School. Four of Speed School's eight deans since its inception have been chemical engineers (Ernst, Gerhard, Hanley, and Pinto). It was through the encouragement of Dr. Ernst that the first graduate work was begun with the introduction of the master's degree in 1935—and later the Ph.D. program in 1951. By 1967, when the current home of the ChE Department—Ernst Hall—was completed, the department had graduated 632 B.ChE, 235 M.ChE and M.S.ChE students, and 10 Ph.D.s.

A STATE-SUPPORTED INSTITUTION

The Engineers' Council for Professional Development (ECPD), the predecessor of ABET, was founded in 1932 as an engineering professional body dedicated to the education, accreditation, regulation, and professional development of

The J.B. Speed building.

engineering professionals and students in the United States. ECPD began accrediting engineering programs in the United States in 1936 and UofL's B.ChE degree was among the first group to be accredited, as previously mentioned. Full accreditation of the B.ChE degree continued until the early 1970s when some major changes occurred within the university and Speed School. Prior to 1970, the University of Louisville was a private, municipally funded college. The movement of tax-paying citizens from the city to the suburbs during the 1950s and 1960s caused a damaging drain on the school's revenue. As early as 1965, a governor's task force suggested the possibility of the university's joining the Kentucky State System, which it did in 1970. One result of this was that the state legislature looked very closely at what it considered to be "duplicate programs" with colleges already in the state system.

As a way of avoiding the perception of duplication between Speed School's B.S. degree programs and those at the University of Kentucky, Harry Saxe—Speed School's dean at the time—proposed the development of the Master of Engineering degree as the primary accredited program at University of Louisville. There were some moves nationally at this time, particularly among civil engineers (Saxe was a civil engineer), to promote the master's degree as the primary degree for entering engineering practice, so there was also some academic basis for this move, and potential prestige to be gained by being among the first schools to introduce it. By that time, the B.S. degree had expanded in credit hours so much that they almost constituted enough hours to make a master's degree feasible with very few further additions. Another driving force for change at the time was the fact that while most of UofL operated on the semester system, the Speed School had used the quarter system since its inception. This led to anomalies such as Speed School faculty teaching many arts and sciences classes themselves because of the mismatch between academic calendars. With the move of Speed School to semesters in 1970, many classes more traditionally taught in Colleges of Arts and Sciences could be "exported" and the Speed School could focus more on its engineering core.

The M.Eng. degrees in the four core disciplines of civil, chemical, electrical, and mechanical engineering were first accredited by ECPD in 1973. The school continued to offer B.S. degrees in applied science with specialization in chemical engineering and the other engineering disciplines since some students choose not to continue to a master's degree for academic or financial reasons. These graduates typically accepted initial employment locally and had very successful engineering careers despite the lack of a traditional ECPD/ABET-accredited degree. The early years of the M.Eng. program are discussed in some detail in: P.B. Deshpande and C.A. Plank, "A Combined Bachelors-Masters Program", *CEE*, Summer 1979, pp 138-140 and 144, with a follow-up in 1996: J.C. Watters, "The Master of Engineering as the First Accredited Degree", Session 1213, *ASEE Annual Conference Proceedings*, 1996.

The influx of state funding as well as the national move to more research-based engineering programs made the 1970s a decade of expansion for all engineering programs at Speed, including ChE. New faculty were hired into research sub-disciplines such as bio (Fleischman) and environmental (Spencer, Nakamura, Doyle, Holdren, Mitsch), as well as into traditional ChE areas (Collins, Deshpande, Harper, Laukhuf, and Watters). In 1977, the department was renamed the Department of Chemical and Environmental Engineering with the goal of developing a stand-alone track in environmental engineering; however, this effort was short-lived as the environmental track failed to attract a critical mass of students, and the name reverted back to Department of Chemical Engineering in 1985. Shortly thereafter, the civil engineering program assumed the environmental mantle and changed to the name Civil and Environmental Engineering that it uses to the present day.

By 2000, any threat of loss of the engineering programs at Speed School because of duplication had disappeared, so discussion arose again over whether we should maintain the status quo, revert to a more traditional B.S./M.S./Ph.D. model or opt for something in between. Mickey Wilhelm, dean of Speed School in the 2000s, was responsible for many advances in the school. He shepherded the school's name change from Speed Scientific School to the more modern J.B. Speed School of Engineering. He oversaw the establishment of a Bioengineering Department and promoted the idea of dual-level accreditation at ABET Inc., the successor to ECPD. This became a reality in 2008. The Speed School immediately opted to seek accreditation of our B.S. programs, which was achieved by some minor curriculum adjustments to the existing non-ABET-accredited B.S. degrees. The ABET visit in 2009 led to the accreditation of all engineering B.S. degrees, which joined the already accredited M.Eng. degrees and allowed the J.B. Speed School of Engineering to boast the distinction of having the only dual-level, ABET-accredited programs in the world. Both B.S. and M.Eng. programs were reaccredited in 2012 allowing us to continue in this fashion.

TODAY'S DEPARTMENT

The ChE program shares approximately 48,000 sq. ft. of laboratory and classroom space in Ernst Hall alongside the CONN Center for Renewable Energy Research. The program offers B.S., M.Eng., M.S., and Ph.D. degrees. There are approximately 270 undergraduates and 44 graduate students (19 Ph.D. students) in chemical engineering. The department currently has 12 faculty including our newest assistant professor, Vance Jaeger, who joined in fall 2017. Research activities encompass a broad range, focusing on energy, materials, and bio-related areas. In addition to the extensive research facilities available in Ernst Hall, major shared facilities include the Rapid Prototyping Center and the Micro/Nano Technology Center in the Shumaker Research Building that incorporates a 10,000 -sq.-ft. advanced cleanroom facility.

Co-op students at Louisville Water Company.

Co-Operative Education Program. Our co-op program is one of only a dozen in the United States that is mandatory and is part of our ACCE accreditation. Our students normally co-op with the same employer for three alternating semesters for a total of 50 weeks, beginning in their fifth semester of study. There is neither a contract for the employer nor a fee to participate. The co-op program is fully integrated into our students' curriculum to allow B.S. graduation in four years. To enable this, our students attend year-round alternating employment and academic studies during the second and third years of their undergraduate career. These rotations have the added benefit to the employer of having a co-op student year-round while only needing to recruit a co-op student annually. Many employers prefer having experienced students return versus one-time internships.

Speed School has experienced very strong enrollment growth in recent years, both in quantity and quality of students. Twenty percent of our incoming students are in the 99th percentile on the ACT exam and our average student is in the 95th percentile. The strong enrollment growth has put pressure on our mandatory co-op program to grow with the size of our student population. Since 2010, after the impact of the economic recession, Speed's overall number of students on co-op has increased almost 10% annually while the number of ChE students on co-op has increased just over 18% annually. The success of our program is reflected in a 97% placement rate of our students with a permanent position within 90 days of graduation. More than 100 different companies have hired at least one ChE co-op student in the last five years. While a majority of our students find co-op placement in Kentucky and Indiana, we have placed ChE students in 16 different states since 2012. The top employers since 2012 include Ashland Chemicals, Brown-Forman Distillers, Clariant, Dow Corning (now

Dow), ExxonMobil, Marathon, Michelin, SABIC, Toyota, and local utilities including Louisville Gas & Electric and the Louisville Water Company.

The Curriculum. The ChE curriculum has two specific components that drive its continual development. The first is our mandatory co-op program discussed in the previous section. In order to more closely tie the co-op experience with the classroom experience, the academic terms in which the students are away from campus are distributed throughout their degree program. The alternating terms help students gain a greater depth of understanding of core concepts taught in the curriculum as they are able to apply those concepts almost immediately in the practical, hands-on environment of their co-op employer. Additionally, students tend to develop an insight into the curriculum that they may not otherwise develop as they are often required to learn concepts on the job that they have not yet encountered in their coursework.

Since the first co-op term occurs very early in the students' career (spring semester sophomore year), the curriculum must ensure that the students have a sufficient depth of knowledge to perform adequately at their chosen co-op position, whether that is in a process engineering, research and development, or design engineering position. Recent changes in the curriculum for both the Engineering School as a whole and the department in particular, are focusing on skill development and application early on to help ensure the students are co-op ready. On the school side, the newly redesigned freshman engineering course has become a two-course sequence that is spread between the 1st and 2nd semester of the students' first year. In the first course, ENGR 110 – Engineering Methods, Tools, and Practice 1, students work on skills development including programming, spreadsheet development, engineering graphics, and design analysis, all of which have a focus on the development of a student's critical-thinking skills. The second course, ENGR 111 – Engineering Methods, Tools, and Practice 2, focuses on the further development and application of these skills by designing and building functioning systems using the Arduino platform.

The ChE Department follows up this series of courses with Introduction to Chemical Engineering, CHE 205, and Computer Applications in Chemical Engineering, CHE 230, in the summer term. This set of courses mimics an ENGR 110 and 111 sequence in that the students develop skills in CHE 205 and then apply those skills while using specific computer applications in CHE 230. In this case, the skills developed focus on ChE problems that students will encounter in future classes and during their co-op experience. While the entire theory and development of these concepts cannot be covered in depth during a 10-week summer course, the meaning behind the equations and how they can be manipulated to solve engineering problems certainly can be. These same problems are then discussed in CHE 230 where students use different computer applications to actually solve the problems, further

TABLE 1
Faculty

Faculty	Research Areas
Delaina Amos (Berkeley), Assoc. Prof.	Advanced nanomaterials; inkjet deposition & inks; quantum dots; alternative energy materials
Eric Berson, (Louisville), Assoc. Prof.	CFD modeling of chemical & biological processes; modeling of multiphase & complex flow fields; enzymatic kinetics
Joel R. Fried (UMASS, Amherst), Prof. & Chair	Polymers; biomimetic materials; membrane transport; computational chemistry & molecular simulations
Xiao-An (Sean) Fu (Case), Assoc. Prof.	Microfabrication; micro/nano sensors; MEMS for harsh environments; surface modification of nanomaterials
Jim Gerstle (Tennessee), Asst. Prof.	Process control; risk identification & management
Gautam Gupta (New Mexico), Assoc. Prof.	Photovoltaics; heterogeneous catalysis; biomaterials; energy sustainability
Vance Jaeger (Washington), Asst. Prof.	Molecular simulations; protein-protein interactions; protein crystallization; ionic liquids
Noppadon Sathitsuksanoh (VPI), Asst. Prof.	Biomass upgrading; catalysis; advanced spectroscopy; bio-inspired materials
Thomas Starr (Louisville), Prof. & Director of the Rapid Prototyping Center	Rapid prototyping; powder injection molding; 3-D printing; atomic layer deposition
Mahendra Sunkara (Case), Prof. & Director of the Conn Center	Semiconductor nanorods/tubes; electrochemical materials; alternative energy materials
James C. Watters (Maryland), Prof.	Membrane separations; green engineering
Gerold Willing (Auburn), Assoc. Prof. & Assoc. Chair	Colloid and surface science; directed self-assembly; hydrogels, nanofluids; water utility infrastructure materials
Associate Faculty	Jacek Jasinski (University of Warsaw), Joshua Spurgeon (Cal Tech), Jagannadh Satyavolu (Ohio State)
Emeriti Professors	Dermot J. Collins, Pradeep B. Deshpande, Marvin Fleischman, Dean O. Harper, Kyang Kang, Walden Laukhuf, Hugh T. Spencer

developing the students' skill set and helping them become co-op ready. The remainder of the curriculum follows that typically found at many other institutions, namely material and energy balances, two thermodynamics courses, fluid mechanics, a combined heat and mass transfer course, kinetics and reactor design, separation operations, two process design courses, and a process control course. The difference is that these courses are interspersed between different co-op terms so that the two experiences, classroom and job site, help to reinforce the basic ChE concepts.

The second component driving our curriculum development is the integrated one-year M.Eng. program that follows the B.S. program. Like the Bachelor's degree, the M.Eng. degree is ABET-accredited, but at the advanced level. Currently, about 30-40% of graduating seniors elect to stay on for the M.Eng. All M.Eng. students are required to take the same core courses taken by all graduate students in the department, namely ChE Analysis, Advanced Thermodynamics, Advanced Reactor Design, and Transport Phenomena, along with 12 credit hours of technical electives. The students have the choice of following either a thesis or a non-thesis alternative. In the thesis option, the students are required to take six credit hours of M.Eng. Thesis. For these credits, the student works with a faculty member in developing and completing a 1-year research project, at the end of which they must write and defend a thesis. For those following the non-thesis option, the thesis credits are replaced by a two-course sequence, Engineering Project Fundamentals I and II (CHE 698 and 699). During this two-course sequence, students learn how to develop a project proposal with a focus on the processes used in industry, create a budget for the project, protect intellectual property, and then develop a business plan. These courses are intended to help students cultivate the skills they will need to succeed as a process or project engineer, as almost all of the students that take the non-thesis alternative intend to pursue a career in industry.

Research Activities in the Department. Research focus areas in the Chemical Engineering Department include bioenergy, biomaterials, biomimetic systems, bioprocessing, biofuels & bio-products, adsorption & catalysis, complex fluids, computational fluid dynamics, fuel cells, membranes, microfabrication, microreactors, molecular simulations, nanomaterials & nanochannels, photovoltaic materials, polymers, and sensors. Table 1 lists faculty in ChE and their research areas.

Research Centers. There are several significant research centers located on the Belknap campus that help to support research groups working within our department as well as the broader university community. Two of these centers, the Conn Center for Renewable Energy Research and the Rapid Prototyping Center, are directed by ChE faculty—Mahendra Sunkara and Tom Starr, respectively.

Arising from the Institute for Advanced Materials and Renewable Energy established in 1997 by Sunkara, the Conn Center for Renewable Energy Research was founded with a $20 million gift from alumni Hank and Rebecca Conn in 2009. Its vision is to become a nationally recognized center of excellence with transformational-translational research on renewable energy challenges. The Conn Center centers on four thematic pillars (solar, storage, biofuels, and efficiency) for conducting both grand challenge-driven applied and use-inspired basic research. The key aspect is to ensure scalability of concepts necessary for commercialization and addressing global challenges. By 2016, the Conn Center had assembled a team consisting of 12 permanent center staff members including eight theme leaders, research support staff, and administrative support staff. Three of the theme leaders also serve as associate ChE faculty who teach and advise students. The four thrust areas are focused through the following technical thematic areas: Advanced Energy Materials Manufacturing and Characterization; Solar Energy Conversion; Power Electronics; Solar Fuels; Energy Storage; Biofuels/Biomass Conversions; and Energy Efficiency. Every other year, the Conn Center awards the Leigh Ann Conn Prize ($50,000), which recognizes outstanding accomplishments worldwide in the field of renewable energy research.

The UofL Rapid Prototyping Center (RPC) is an internationally recognized leader in development and application of additive manufacturing (AM) and 3D printing. This center has a dual mission to serve as a user facility for university researchers and as an innovation resource for industrial clients throughout the United States. The RPC was established in 1993 when the first commercial polymer AM equipment became available and was the first U.S. university to acquire a commercial metal laser melting system in 2009. Senior staff and faculty associated with the center have been active leaders in this technology development for more than 20 years. The center currently supports faculty and graduate student researchers throughout the engineering school. The RPC maintains a 11,000-sq.-ft. facility with state-of-the-art AM equipment and an experienced professional staff. Equipment resources include selective laser sintering (3D Systems 2500plus and High Temperature 2500 CI) and fused deposition modeling (Stratasys uPrint) for polymers; selective laser melting (EOS M270 Dual Mode) and electron beam melting (Arcam EBM S400) for metals; and 3D Printing (ExOne MLab) for metal, polymer, or ceramics. Supporting capabilities include particle size analysis for metal and polymer powders, mechanical testing (tensile, compressive, and fatigue) and metallographic sample preparation and analysis. ❐