**Chemical and Biomolecular Engineering**

http://www.lehigh.edu/~incheme/

The Chemical and Biomolecular Engineering Department offers a Bachelor of Science degree in chemical engineering to undergraduate students and offers graduate programs leading to the master of science, master of engineering, and doctor of philosophy degrees in Chemical Engineering, and master of engineering degrees in Biological Chemical Engineering and Chemical Energy Engineering.

Modern chemical engineering is built around the fundamental enabling sciences of biology, chemistry, physics, and mathematics. Its curriculum encompasses three basic organizing principles: Molecular Transformations, Multi-scale Analysis, and System Approaches. Chemical engineers serve a wide variety of technical and managerial functions within the chemical processing industry. For a lifetime of effectiveness they need a sound background in the fundamental sciences of chemistry and physics; a working capability with mathematics, numerical methods, and application of computer solutions; and a broad education in humanities, social sciences and managerial techniques. These bases are applied in a sequence of chemical engineering courses in which logic and mathematical manipulation are applied to chemical processing problems. With the resulting habits of precise thought coupled to a broad base in scientific and general education, Lehigh graduates have been effective throughout industry and in advanced professional education. No effort is made toward any specific industry, but adaptation is rapid and the fundamental understanding forms the base for an expanding career.

The program is also designed to prepare a student for graduate study in chemical and biomolecular engineering. Further study at the graduate level leading to advanced degrees is highly desirable if an individual wishes to participate in the technical development of the field. The increasing complexity of modern manufacturing methods requires superior education for men and women working in research, development, and the design fields for teaching.

**PHYSICAL FACILITIES**

The Chemical and Biomolecular Engineering Department is the only engineering department located on Lehigh's 780 acres Mountaintop Campus. Here the department occupies approximately one-third of Iacocca Hall, the 200,000-square-foot flagship building that contains offices, classrooms, and laboratories. Additional plant facilities, and the undergraduate chemical processing laboratory occupy approximately 10,000-square-feet in the nearby Imbt building.

These facilities provide excellent support for a wide range of general and special laboratory equipment for undergraduate and graduate studies of the behavior of typical chemical processing units; bioengineering research; nanotechnology; energy; biochemical engineering; polymers; digital computation for process dynamics research; and study of thermodynamics, kinetics, heat transfer, and mass transfer.

The chemical engineering department has established a senior design laboratory in Iacocca Hall featuring 35 PCs, which is dedicated to undergraduate process design courses.

**Professors.** Hugo S. Caram, PHD (University of Minnesota); Manoj K. Chaudhury, PHD (University at Buffalo, SUNY); James F. Gilchrist, PHD (Northwestern University); Tsai-An Hsu, PHD (Northwestern University); Anand Jagota, PHD (Cornell University); Christopher J. Kiely, PHD (University of Bristol); Mayuresh V. Kothare, PHD (California Institute of Technology); William L. Luyben, PHD (University of Delaware); Anthony J. McHugh, PHD (University of Delaware); Steven McIntosh, PHD (University of Pennsylvania); Jeetain Mittal, PHD (University Texas, Austin); Arup K. Sengupta, PHD (University of Houston University Park); Israel E. Wachs, PHD (Stanford University)

**Associate Professors.** Javier Buceta Fernandez, PHD (National University of Distance Education); Mark A Snyder, PHD (University of Delaware)

**Assistant Professors.** Jonas Baltrusaitis, PHD (University of Iowa); Angela C Brown, PHD (Drexel University); Srinivas Rangarajan, PHD (University of Minnesota); Kelly Schultz, PHD (University of Delaware)

**Professors Of Practice.** Vincent G. Grassi, PHD (Lehigh University); Kemal Tuzla, PHD (Istanbul Technical University)

**Emeriti.** Marvin Charles, PHD (Polytechnic University); Mohamed S El-Aasser, PHD (McGill University); Arthur E. Humphrey, PHD (Columbia University); William E. Schiesser, PHD (Princeton University); Cesar A. Silebi, PHD (Lehigh University); Fred P. Stein, PHD (University of Michigan Ann Arbor)

**UNDERGRADUATE PROGRAM**

The mission of the undergraduate program is "to educate students in the scientific principles of chemical and biomolecular engineering and provide opportunities to explore their applications in the context of a humanistic education that prepares them to address technological and societal challenges."

**PROGRAM EDUCATIONAL OBJECTIVES**

To achieve its educational mission, the Department of Chemical and Biomolecular Engineering has established the following set of Program Educational Objectives: Graduates of the Undergraduate Program in Chemical Engineering will:

1. Apply their broad education in chemical engineering to pursue careers in industry, government agencies, consulting firms, educational institutions, financial institutions, business, law, and medicine.
2. Pursue graduate studies, research, or continuing education.
3. Be sensitive to the social, ethical, and technical implications of their work as it affects the environment, safety, and health of citizens worldwide.

In order to achieve these program educational objectives, the chemical engineering program ensures that the graduates are capable of the following Student Outcomes proposed by the accreditation organization ABET:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

**MINOR IN BIOTECHNOLOGY**

The department of Chemical and Biomolecular Engineering encourages engineering students to broaden their education by taking a minor. In this regard, a Biotechnology Minor is offered to students majoring in Engineering College. The Biotechnology minor requires 16 credit hours. A detailed listing of the required courses for the Biotechnology Minor can be obtained from the Chemical and Biomolecular Engineering Department.

**MINOR IN CHEMICAL ENGINEERING**

Minoring in Chemical Engineering provides students both biomolecular and chemical engineering knowledge that they do not
acquire in their major, such as knowledge of bio-chemical systems, transport phenomena, reaction engineering. This will widen their
skills and help to increase the cooperation between the disciplines, which will lead to increased possibilities for employment. For further
information please contact the department.

CAREER OPPORTUNITIES
Chemical engineers play important roles in all activities bearing
on the chemical process industry. These include the functions of
research, development, design, plant construction, plant operation
and management, corporate planning, technical sales, and market
analysis.

The industries that produce chemical and/or certain physical changes
in fluids, including petroleum and petrochemicals, rubbers and
polymers, pharmaceuticals, bioengineering, metals, industrial
and fine chemicals, foods, and industrial gases, have found chemical
engineers to be vital to their success. Chemical engineers are also
important participants in pollution abatement, energy resources,
national defense programs, and more recently in the manufacture
of microelectronic devices and integrated circuits.

SPECIAL PROGRAMS AND OPPORTUNITIES
Co-op Program
The department, in conjunction with the P.C. Rossin College of
Engineering and Applied Science, operates a cooperative program
that is optional for specially selected students who are entering their
junior year. This program offers early exposure to industry and an
opportunity to integrate an academic background with significant
periods of engineering practice. Our program is unique in offering two
work experiences and still allowing the co-op students to graduate in
tyre four years with their class.

OSI Program
The Opportunities for Student Innovation (OSI) program seeks to
develop students’ propensities for critical assessment and innovative
solution of meaningful problems. The OSI program offers selected
seniors an opportunity to experience team research leading toward
technological benefits. Some projects are hosted by industrial
companies and carried out under the supervision of a Lehigh faculty
members.

Minors and Specializations
Technical minors are available in biotechnology, energy engineering,
computer science, environmental engineering, manufacturing
systems, materials science and engineering, and polymer science and
engineering. Minors are also available from the Business College and
the College of Arts and Sciences.

Overseas
Study abroad is available in exchange programs that have been
established by the department for the junior year at the University of
Nottingham (United Kingdom) and for the summer following the
junior year at the University of Dortmund (Germany). Please visit
http://www.aaa.tu-dortmund.de/cms/en/International_Students/
International_Summer_Program__ISP_/index.html

Requirements of the Major
131 credit hours are required for graduation with the degree of
bachelor of science in chemical engineering.

First Year

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Total Credits: 128-134

<sup>1</sup> Required natural science courses, one taken fall semester and the other
taken in spring

There are six types of electives:

1. Humanities/Social Sciences: See the requirements
(http://catalog.lehigh.edu/coursesprogramsandcurricula/
engineeringandappliedscience) set by the P.C. Rossin College of
Engineering and Applied Science. Note that ECO 001 is required,
as well as Freshman English.

2. Bio-Elective: Students must have AP BIO credits or must pick
one from BIOS 041, BIOE 321, BIOE 349, CHE 341, CHE 345, or
CHM 371.

3. Three credit hours from approved courses in other engineering
departments (BioE, CEE, CSE, ECE, ISE, MEM, MSE).

4. Chemistry: 3 credit hours of CHM 300-level or higher, or CHE 380.

5. Chemical Engineering: 3 credit hours of CHE 300 level or higher.

6. Free electives: 6 credit hours in any subject area.

Electives in (2) to (5) above can be combined with any technical minor
in RCEAS.

GRADUATE PROGRAMS
The Department of Chemical and Biomolecular Engineering offers
graduate programs leading to the master of science, master
of engineering, and doctor of philosophy degrees in Chemical
Engineering and master of engineering degree in Chemical
Engineering, Biological Chemical Engineering and Chemical Energy
Engineering. The programs are all custom tailored for individual
student needs and professional goals. These individual programs are
made possible by a diversity of faculty interests that are broadened
and reinforced by cooperation between the department and several
research centers on the campus.

A free flow of personnel and ideas between the centers and academic
departments ensures that the student will have the widest choice
of research activities. The student is also exposed to a wide range
of ideas and information through courses and seminars to which
both faculty and center personnel contribute. In addition, strong
relationships with industry are maintained by the department and
the research centers, some of which operate industrially-sponsored liaison programs whereby fundamental non-proprietary research is performed in areas of specific interest to participating sponsors. While the department has interacted with most of the centers on campus, it has had unusually strong and continuing liaisons with Emulsion Polymers Institute, Process Modeling and Control Research Center, and Materials Research Center. The Department also has a strong relation with the Bioengineering Program.

In addition to interacting with the centers, the department originates and encourages programs that range from those that are classical chemical engineering to those that are distinctly interdisciplinary. The department offers active and growing programs in adhesion and tribology; emulsion polymerization and latex technology; bulk polymer systems; process control; process improvement studies; rheology; computer applications; environmental engineering; thermodynamics; kinetics and catalysis; enzyme technology; and biochemical engineering.

Career Opportunities
Master of science, master of engineering, and doctor of philosophy graduates in the chemical engineering area are sought by industry for activities in the more technical aspects of their operations, especially design, process and product development, and research. Many of these graduates also find opportunities in research or project work in government agencies and in university teaching and research.

Physical Facilities
The department is well equipped for research in bioengineering, nanotechnology, energy, colloids and surface science, adhesion and tribology, polymer science and engineering, catalysis and reaction kinetics, thermodynamic property studies, fluid dynamics, heat and mass transfer, process dynamics and control, and enzyme engineering and biochemical engineering.

The departmental and university computing facilities include PCs and workstations, connected by a university-wide high speed network, which in turn provides worldwide networking via the Internet.

All of these facilities can access a wide variety of general purpose, and scientific and engineering software via the university and local networks, including software specifically for the steady state and dynamic simulation of chemical engineering systems. The networks are extended as needed to ensure the chemical engineering department has access to the latest computing technology.

Special Programs
Polymer Science and Engineering. The polymers activity includes work done in the Department of Chemical and Biomolecular Engineering as well as the Departments of Chemistry, Materials Science, and Physics, the Materials Research Center, the Center for Polymer Science and Engineering, and the Emulsion Polymers Institute. More than 20 faculty members from these organizations or areas have major interests in polymers and cooperate on a wide range of research projects. For students with deep interest in the area, degree programs are available leading to the master of science, master of engineering, and doctor of philosophy degrees in polymer science and engineering.

There are three major polymer research thrusts in which chemical engineering students and faculty are involved. These are polymer colloids (latexes), polymer interfaces, and polymer materials. The Emulsion Polymers Institute, with strong industrial support, sponsors projects in the preparation of monosize polymer particles, in mechanisms and kinetics of emulsion, miniemulsion and dispersion polymerization, in latex particle morphology and film-formation, and in rheological properties of latexes and thickeners. The Engineering Polymers Laboratory investigates the behavior of bulk polymer materials, focusing on multicomponent polymers and composites.

Distance Education
The Department offers some of its regular credit courses each semester via satellite and the World Wide Web for engineers in industry and government. These offerings, which are administered by the Distance Education Office, can lead to the Master of Engineering degree in Chemical Engineering, Biological Chemical Engineering, or Chemical Energy Engineering.

Major Requirements
All Ph.D. students must complete eight courses in consultation with his/her committee, although CHE 400, CHE 410, CHE 415 and CHE 452 are required. In addition to approved courses, all Ph.D. students must pass a qualification examination given during the second year of residence.

Candidates for Master of Science degree are required to complete 30 credits hours of course work which must include CHE 400, CHE 410, CHE 415 and CHE 452, and a research report or thesis for which six hours of graduate credits are earned.

Candidates for the Master of Engineering degrees do not do research; all 30 credit hours are fulfilled by course work. Course selection is done individually for each student within the University requirements for a master’s degree.

The requirements for each of the Master degrees is slightly different. For more information on all of our Master degrees, please visit the Thesis, Dissertation, and Program Requirements for Chemical and Biomolecular Engineering page at http://www.lehigh.edu/~inchem/stu_graduate_thesis_progreq.html

Courses
CHE 031 Material and Energy Balances of Chemical Processes 3 Credits
Material and energy balances with and without chemical reaction. Introduction to phase equilibrium calculations. Applications in chemical process calculations and in design of staged separations: binary distillation, liquid-liquid extraction. Plant trips and special lectures introducing the profession.

Prerequisites: ENGR 010 and CHM 030
Can be taken Concurrently: ENGR 010, CHM 030

CHE 044 Fluid Mechanics 3 Credits

CHE 085 Undergraduate Research 1 Credit
Independent study of a problem involving laboratory investigation, design, or theoretical studies under the guidance of a faculty. Consent of the department chair.

Repeat Status: Course may be repeated.

CHE 151 Introduction to Heat Transfer 3 Credits
Fundamental principles of heat transfer. Fourier’s law, conduction, convection and radiation. Analysis of steady and unsteady state heat transfer. Evaporation and condensation. Applications to the analysis and design of chemical processing units involving heat transfer.

Prerequisites: CHE 031 and CHE 044 and CHE 210

CHE 171 (CEE 171, EMC 171, ES 171) Fundamentals of Environmental Technology 4 Credits
Introduction to water and air quality, water, air and soil pollution. Chemistry of common pollutants. Technologies for water purification, wastewater treatment, solid and hazardous waste management, environmental remediation, and air quality control. Global changes, energy and environment. Constraints of environmental protection on technology development and applications. Constraints of economic development on environmental quality. Environmental life cycle analysis and environmental policy. Not available to students in RCEAS.

CHE 179 Professional Development 1 Credit
Elements of professional growth, registration, ethics, and the responsibilities of engineers both as employees and as independent practitioners. Proprietary information and its handling. Patents and their importance. Discussions with the staff and with visiting Lecturers. A few plant trips.

CHE 185 Undergraduate Research 1-3 Credits
Independent study of a problem involving laboratory investigation, design, or theoretical studies under the guidance of a faculty member.

Repeat Status: Course may be repeated.
CHE 186 Undergraduate Research II 1-3 Credits
A continuation of the project begun under CHE 185. Consent of department chair.
Repeat Status: Course may be repeated.
Prerequisites: CHE 185

CHE 201 Methods of Analysis in Chemical Engineering 4 Credits
Analytical and numerical methods of solution applied to dynamic, discrete and continuous chemical engineering processes. Laplace Transforms, MATLAB based computations. Methods of analysis applied to equilibrium, characteristic value and non-linear chemical engineering problems.
Prerequisites: CHE 044 and CHE 210 and MATH 023 and MATH 205
Can be taken Concurrently: MATH 205

CHE 202 Chemical Engineering Lab I 3 Credits
The laboratory study of chemical engineering unit operations and the reporting of technical results. One three-hour laboratory and one lecture period per week. Independent study and both group and individual reporting.
Prerequisites: CHE 151 and CHE 211 and CHE 244

CHE 203 Chemical Engineering Laboratory II 2 Credits
Laboratory experience with more complex chemical processing situations including processes involving chemical reactions and those controlled automatically.
Prerequisites: CHE 202

CHE 210 Chemical Engineering Thermodynamics 4 Credits
Prerequisites: CHE 031

CHE 211 Chemical Reactor Design 3 Credits
The theory of chemical kinetics to the design and operation of chemical reactors. Plug flow and continuous stirred tank reactors. Homogeneous and heterogeneous reaction kinetics. Design of isothermal and adiabatic reactors.
Prerequisites: CHE 210

CHE 233 Process Design I 0.3 Credits
Design of chemical plants incorporating traditional elements of engineering economics and synthesis of steady-state flowsheets with (1) both heuristic and rigorous optimization methods and (2) consideration of dynamic controllability of the process. Economic principles involved in the selection of process alternatives and determination of process capital, operating costs, and venture profitability. Energy conservation, pinch techniques, heat exchanger networks, and separation sequences. Considerations of market limitations, environmental and regulatory restrictions, and process safety. Use of modern computer aided software for steady-state and dynamic simulation and optimization. Group design projects.
Prerequisites: (CHE 211 and CHE 242 and CHE 244)
Can be taken Concurrently: CHE 242

CHE 234 Process Design II 3 Credits
Continuation of CHE 233.
Prerequisites: CHE 233
Can be taken Concurrently: CHE 233

CHE 242 Introduction to Process Control and Simulation 3 Credits
Prerequisites: CHE 201 and CHE 151 and ENGR 010

CHE 244 Mass Transfer and Separation Processes 3 Credits
Prerequisites: CHE 031 and CHE 044 and CHE 210

CHE 280 Unit Operations Survey 3 Credits
The theory of heat, mass and momentum transport. Laminar and turbulent flow of real fluids. Heat transfer by conduction, convection and radiation. Application to a wide range of operations in the chemical and metallurgical process industries.

CHE 281 Chemical Engineering Fundamentals I 4 Credits
Fundamentals of material balances, fluid mechanics and heat transfer. Must have undergraduate degree in a scientific or engineering discipline or one semester undergraduate level general chemistry, one semester undergraduate level physics (statics and dynamics), and two semesters undergraduate calculus. Consent of department required.

CHE 282 Chemical Engineering Fundamentals II 4 Credits
Fundamentals of heat and mass transfer, process energy balances and unit operations. Consent of department required.
Prerequisites: CHE 281

CHE 300 Apprentice Teaching 1-4 Credits
Repeat Status: Course may be repeated.

CHE 306 Introduction to Biomedical Engineering and Mathematical Biology 3 Credits
Prerequisites: MATH 205

CHE 321 Biomolecular & Cellular Mechanics 3 Credits
Mechanics and physics of the components of the cell, ranging in length scale from fundamental biomolecules to the entire cell. The course covers the mechanics of proteins and other biopolymers in 1D, 2D, and 3D structures, cell membrane structure and dynamics, and the mechanics of the whole cell.
Prerequisites: MATH 205 and MATH 231 and PHY 022 and (PHY 013 or PHY 021)

CHE 331 Separation Processes 3 Credits

CHE 334 (MAT 334) Electron Microscopy and Microanalysis 4 Credits
Fundamentals and experimental methods in electron optical techniques including scanning electron microscopy (SEM), conventional transmission (TEM) and scanning transmission (STEM) electron microscopy. Specific topics covered will include electron optics, electron beam interactions with solids, electron diffraction and chemical microanalysis. Applications to the study of the structure of materials are given. Consent of department required.

CHE 339 Neuronal Modeling and Computation 3 Credits
Neuroscience in a computational, mathematical, and engineering framework. Literature surveys and case studies with simulations. Computational aspects of information processing within the nervous system by focusing on single neuron modeling. Single neurons and how their biological properties relate to neuronal coding. Biophysics of single neurons, signal detection and signal reconstruction, information theory, population coding and temporal coding.
Prerequisites: ENGR 010 and MATH 205

CHE 341 (BIOE 341) Biotechnology I 3 Credits
Applications of material and energy balances; heat, mass, and momentum transfer; enzyme and microbial kinetics; and mathematical modeling to the engineering design and scale-up of bio-reactor systems. Closed to students who have taken CHE 441 (BIOE 341 and BIOE 441).
Prerequisites: MATH 205 and CHE 031 and (CHM 031 or CHM 041)
CHE 342 (BIOE 342) Biotechnology II 3 Credits
Engineering design and analysis of the unit operations used in the recovery and purification of products manufactured by the biotechnology industries. Requirements for product finishing and waste handling will be addressed. Closed to students who have taken CHE 442 (BIOE 442).
Prerequisites: MATH 205 and CHE 031 and (CHM 031 or CHM 041)

CHE 344 (BIOE 344) Molecular Bioengineering 3 Credits
Kinetics in small systems, stochastic simulation of biochemical processes, receptor-mediated adhesion, dynamics of ion-channels, ligand binding, biochemical transport, surface Plasmon resonance, DNA microarray design, and chemical approaches to systems biology. Senior standing in ChE.
Prerequisites: MATH 205 and MATH 231

CHE 345 (BIOE 345) Quantitative Biology 3 Credits
Basic concepts in molecular and cellular biology as well as biochemistry. Connects these to engineering principles in order to (1) develop a quantitative understanding of biological systems and (2) understand how applications of methods and principles in biology are used in modern engineering. Topics include protein structure and function, enzymology, membrane transport and trafficking, transcription/translation, signal transduction and models for cellular processes. An important part of this course is also taking topics discussed in lecture and translating them into practice.
Prerequisites: MATH 205

CHE 346 Biochemical Engineering Laboratory 3 Credits
Laboratory and pilot-scale experiments in fermentation and enzyme technology, tissue culture, and separations techniques. Consent of instructor required. Closed to students who have taken CHE 446.
Prerequisites: CHE 341
Can be taken Concurrently: CHE 341

CHE 350 Special Topics 1-3 Credits
A study of areas in chemical engineering not covered in courses presently listed in the catalog.
Repeat Status: Course may be repeated.

CHE 363 (BIOE 363) Numerical Methods for Scientists and Engineers 3 Credits
Introduction to numerical methods in science and engineering. Expose students to the numerical solution of a variety of commonly encountered problems, enhance their numerical programming skills, and provide a broad base on which to build more specialized knowledge of computational methods. Topics include solution of linear and nonlinear sets of algebraic equations, linear and logistic regression, ordinary differential equations, Fourier analysis, eigenvalues, partial differential equations by finite difference and finite element methods.
Prerequisites: MATH 205

CHE 365 Molecular Modeling and Simulation 3 Credits
Introduction to molecular modeling and simulation techniques. Expose students to programming environments and give a broad overview of molecular simulation methods used in chemical engineering. Topics include density functional theory including periodic systems, molecular dynamics, Monte Carlo techniques, review of statistical mechanics and ensembles, biased sampling and free energy methods, and microkinetic modeling. Student will use existing software as well as develop their own computer codes in this class.

CHE 373 (CEE 373) Fundamentals of Air Pollution 3 Credits
Introduction to the problems of air pollution including such topics as: sources and dispersion of pollutants; sampling and analysis; technology of economics and control processes; legislation and standards. Must have senior standing in the College of Engineering and Applied Science.

CHE 374 Environmental Catalysis 3 Credits
Pollution emissions in the USA (NOx, SOx, NH3, CO, VOCs, PM, heavy metals and persistent bioaccumulative chemicals) and their sources and fate. Fundamental concepts of catalysis (surface and their characterization, physical adsorption, surface reaction mechanisms and their kinetics). Application of catalysis to a wide range of environmental issues (catalytic combustion of VOCs, automotive catalytic converter, selective catalytic conversion of NOx, etc.) Must have senior standing. Consent of instructor required.

CHE 375 (CEE 375) Environmental Engineering Processes 3 Credits
Processes applied in environmental engineering for air pollution control, treatment of drinking water, municipal wastewater, industrial wastes, hazardous/toxic wastes, and environmental remediation. Kinetics, reactor theory, mass balances, application of fundamental physical, chemical and biological principles to analysis and design.
Prerequisites: CEE 170

CHE 376 (ME 376) Energy: Issues & Technology 3 Credits
Energy usage and supply, fossil fuel technologies, renewable energy alternatives and environmental impacts. The scope will be broad to give some perspective of the problems, but in-depth technical analysis of many aspects will also be developed. Must have college-level introductory courses in chemistry, physics and mathematics. Consent of instructor required.

CHE 377 Electrochemical Engineering 3 Credits
Fundamental concepts of electrochemistry, covering the thermodynamics, kinetics, and transport phenomena that occur in both liquid and solid state electrochemical systems. This course draws upon concepts from physical chemistry, chemical engineering and materials science to address the phenomena that govern the performance of electrochemical devices, and that drive important engineering phenomena such as corrosion. The course will serve as a basis for a career in electrochemistry as it applies to energy issues.
Prerequisites: Senior level in ChE or instructor approval.

CHE 380 Senior Research Project (OSI) 1-6 Credits
Independent study of a problem involving laboratory investigation, design, and theory, when possible involves one of the local communities or industries. Team work under the guidance of Faculty advisors. Experiential learning opportunity to bridge educational gap between conventional textbook learning and industrial approaches to real-world technical problem solving. Must have senior standing. Consent of department required.
Repeat Status: Course may be repeated.

CHE 383 Chemical Engineering Fundamentals III 4 Credits
Fundamentals of thermodynamics, reaction kinetics and reactor analysis, and applied mathematics. Consent of department required. Cannot apply towards a Chemical Engineering undergraduate degree.
Prerequisites: CHE 282

CHE 386 Process Control 3 Credits
Open-loop and closed-loop stability analysis using root locus and Nyquist techniques, design of feedback controllers with time and frequency domain specifications. Experimental process identification. Control of multivariable processes. Introduction to sampled-data control theory.
Prerequisites: CHE 242

CHE 387 (ECE 387, ME 387) Digital Control 3 Credits
Sampled-data systems; z-transforms; pulse transfer functions; stability in the z-plane; root locus and frequency response design methods; minimal prototype design; digital control hardware; discrete state variables; state transition matrix; Liapunov stability state feedback control (2 lectures and one laboratory per week).
Prerequisites: CHE 386 or ECE 212 or ME 343
CHE 388 (CHM 388, MAT 388) Polymer Synthesis and Characterization Laboratory 3 Credits
Techniques include: free radical and condensation polymerization; molecular weight distribution by gel chromatography; crystallinity and order by differential scanning calorimetry; pyrolysis and gas chromatography; dynamic mechanical and dielectric behavior; morphology and microscopy; surface properties. Must have senior level standing in CHE, CHM or MAT.
Prerequisites: CHM 341 and CHM 110

CHE 389 (ECE 389, ME 389) Control Systems Laboratory 2 Credits
Experiments on a variety of mechanical, electrical and chemical dynamic control systems. Exposure to state-of-the-art control instrumentation: sensors, transmitters, control valves, analog and digital controllers. Emphasis on comparison of theoretical computer simulation predictions with actual experimental data. Lab teams will be interdisciplinary.
Prerequisites: CHE 242 or ECE 212 or ME 343

CHE 391 (CHM 391) Colloid and Surface Chemistry 3 Credits
Physical chemistry of everyday phenomena. Intermolecular forces and electrostatic phenomena at interfaces, boundary tensions and films at interfaces, mass and charge transport in colloidal suspensions, electrostatic and London forces in disperse systems, gas adsorption and heterogeneous catalysis. Consent of instructor required.

CHE 392 (MAT 392) Introduction to Polymer Science 3 Credits
Introduction to concepts of polymer science. Kinetics and mechanism of polymerization, synthesis and processing of polymers, characterization. Relationship of molecular conformation, structure and morphology to physical and mechanical properties.

CHE 393 (CHM 393, MAT 393) Physical Polymer Science 3 Credits
Structural and physical aspects of polymers (organic, inorganic, natural). Molecular and atomic basis for polymer properties and behavior. Characteristics of glassy, crystalline, and paracrystal-line states (including viscoelastic and relaxation behavior) for single- and multi-component systems. Thermodynamics and kinetics of transition phenomena. Structure, morphology, and behavior. Available to graduate and undergraduate students (with senior level standing) in CHE, CHEM or MAT.

CHE 394 (CHM 394) Organic Polymer Science I 3 Credits
Organic chemistry of synthetic high polymers. Polymer nomenclature, properties, and applications. Functionality and reactivity or monomers and polymers. Mechanism and kinetics of step-growth and chain-growth polymerization in homogenous and heterogenous media. Brief description of emulsion polymerization, ionic polymerization, and copolymerization. Must have completed one year of physical chemistry and one year of organic chemistry.

CHE 400 Chemical Engineering Thermodynamics 3 Credits
Applications of thermodynamics in chemical engineering. Topics include energy and entropy, heat effects accompanying solution, flow of compressible fluids, refrigeration including solution cycles, vaporization and condensation processes, and chemical equilibria. Must have completed an introductory course in thermodynamics.

CHE 401 Chemical Engineering Thermodynamics II 3 Credits
A detailed study of the uses of thermodynamics in predicting phase equilibria in solid, liquid, and gaseous systems. Fugacities of gas mixtures, liquid mixtures, and solids. Solution theories; uses of equations of state; high-pressure equilibria.

CHE 410 Chemical Reaction Engineering 3 Credits
The application of chemical kinetics to the engineering design and operation of reactors. Non-isothermal and adiabatic reactions. Homogeneous and heterogeneous catalysis. Residence time distribution in reactors.

CHE 413 Heterogeneous Catalysis and Surface Characterization 3 Credits
History and concepts of heterogeneous catalysis. Surface characterization techniques, and atomic structure of surfaces and adsorbed monolayers. Kinetics of elementary steps (adsorption, desorption, and surface reaction) and overall reactions. Catalysis by metals, metal oxides, and sulfides. Industrial applications of catalysis: selective oxidation, pollution control, ammonia synthesis, hydrogenation of carbon monoxide to synthetic fuels and chemicals, polymerization, hydrotreating, and cracking.

CHE 415 Transport Processes 4 Credits
A combined study of the fundamentals of momentum transport, energy transport and mass transport and the analogies between them. Evaluation of transport coefficients for single and multicomponent systems. Analysis of transport phenomena through the equations of continuity, motion, and energy.
Prerequisites: CHE 461 or ENGR 452 or CHE 452

CHE 419 (MECH 419) Asymptotic Methods in the Engineering Sciences 3 Credits

CHE 421 (BIOE 421) Biomolecular & Cellular Mechanics 3 Credits
Mechanics and physics of cell components, from fundamental biomolecules to the entire cell. The mechanics of proteins and other biopolymers in 1D, 2D, and 3D structures, cell membrane structure and dynamics, and the mechanics of the whole cell. This course is a graduate version of CHE 321 (BioE/Phy 321). The lecture content will be the same as in CHE 321 (BioE/Phy 321), but students enrolled in CHE 421 (BioE 421) will have more advanced assignments. Closed to students who have completed CHE 321 (BioE/Phy 321). Must have graduate standing or consent of instructor.

CHE 428 Rheology 3 Credits
An intensive study of momentum transfer in elastic viscous liquids. Rheological behavior of solution and bulk phase polymers with emphasis on the effect of molecular weight, molecular weight distribution and branching. Derivation of constitutive equations based on both molecular theories and continuum mechanics principles. Application of the momentum equation and selected constitutive equations to geometries associated with viscometric flows. Consent of instructor required.
Prerequisites: CHE 461 or CHE 452

CHE 430 Mass Transfer 3 Credits
Theory and developments of the basic diffusion and mass transfer equations and transfer coefficients including simultaneous heat and mass transfer, chemical reaction and dispersion effects. Applications to various industrially important operations including continuous contact mass transfer, absorption, humidification, etc. Brief coverage of equilibrium stage operations as applied to absorption and to binary and multicomponent distillation.

CHE 433 (ECE 433, ME 433) Linear Systems and Control 3 Credits
A combined study of the fundamentals of momentum transport, energy transport and mass transport and the analogies between them. Evaluation of transport coefficients for single and multicomponent systems. Analysis of transport phenomena through the equations of continuity, motion, and energy.
Prerequisites: CHE 461 or ENGR 452 or CHE 452

CHE 439 (MECH 439) Asymptotic Methods in the Engineering Sciences 3 Credits

CHE 441 (MECH 441) Asymptotic Methods in the Engineering Sciences 3 Credits

CHE 443 (ECE 443, ME 443) Linear Systems and Control 3 Credits
A combined study of the fundamentals of momentum transport, energy transport and mass transport and the analogies between them. Evaluation of transport coefficients for single and multicomponent systems. Analysis of transport phenomena through the equations of continuity, motion, and energy.
Prerequisites: CHE 461 or ENGR 452 or CHE 452

CHE 450 Chemical Engineering Thermodynamics 3 Credits
Applications of thermodynamics in chemical engineering. Topics include energy and entropy, heat effects accompanying solution, flow of compressible fluids, refrigeration including solution cycles, vaporization and condensation processes, and chemical equilibria. Must have completed an introductory course in thermodynamics.

CHE 451 Chemical Engineering Thermodynamics II 3 Credits
A detailed study of the uses of thermodynamics in predicting phase equilibria in solid, liquid, and gaseous systems. Fugacities of gas mixtures, liquid mixtures, and solids. Solution theories; uses of equations of state; high-pressure equilibria.

CHE 452 Chemical Reaction Engineering 3 Credits
The application of chemical kinetics to the engineering design and operation of reactors. Non-isothermal and adiabatic reactions. Homogeneous and heterogeneous catalysis. Residence time distribution in reactors.

CHE 461 (ECE 461) Digital Control Systems 3 Credits
Digital controllers. Emphasis on comparison of theoretical computer simulation predictions with actual experimental data. Lab teams will be interdisciplinary.

CHE 468 Chemical Engineering Thermodynamics 3 Credits
Applications of thermodynamics in chemical engineering. Topics include energy and entropy, heat effects accompanying solution, flow of compressible fluids, refrigeration including solution cycles, vaporization and condensation processes, and chemical equilibria. Must have completed an introductory course in thermodynamics.

CHE 469 Chemical Engineering Thermodynamics II 3 Credits
A detailed study of the uses of thermodynamics in predicting phase equilibria in solid, liquid, and gaseous systems. Fugacities of gas mixtures, liquid mixtures, and solids. Solution theories; uses of equations of state; high-pressure equilibria.

CHE 470 Chemical Reaction Engineering 3 Credits
The application of chemical kinetics to the engineering design and operation of reactors. Non-isothermal and adiabatic reactions. Homogeneous and heterogeneous catalysis. Residence time distribution in reactors.

CHE 471 Chemical Engineering Thermodynamics 3 Credits
Applications of thermodynamics in chemical engineering. Topics include energy and entropy, heat effects accompanying solution, flow of compressible fluids, refrigeration including solution cycles, vaporization and condensation processes, and chemical equilibria. Must have completed an introductory course in thermodynamics.

CHE 472 Chemical Engineering Thermodynamics II 3 Credits
A detailed study of the uses of thermodynamics in predicting phase equilibria in solid, liquid, and gaseous systems. Fugacities of gas mixtures, liquid mixtures, and solids. Solution theories; uses of equations of state; high-pressure equilibria.

CHE 473 Chemical Reaction Engineering 3 Credits
The application of chemical kinetics to the engineering design and operation of reactors. Non-isothermal and adiabatic reactions. Homogeneous and heterogeneous catalysis. Residence time distribution in reactors.

CHE 474 Chemical Engineering Thermodynamics 3 Credits
Applications of thermodynamics in chemical engineering. Topics include energy and entropy, heat effects accompanying solution, flow of compressible fluids, refrigeration including solution cycles, vaporization and condensation processes, and chemical equilibria. Must have completed an introductory course in thermodynamics.

CHE 475 Chemical Engineering Thermodynamics II 3 Credits
A detailed study of the uses of thermodynamics in predicting phase equilibria in solid, liquid, and gaseous systems. Fugacities of gas mixtures, liquid mixtures, and solids. Solution theories; uses of equations of state; high-pressure equilibria.
CHE 434 (ECE 434, ME 434) Multivariable Process Control 3 Credits
A state-of-the-art review of multivariable methods of interest to process control applications. Design techniques examined include loop interaction analysis, frequency domain methods (Inverse Nyquist Array, Characteristic Loci and Singular Value Decomposition) feed forward control, internal model control and dynamic matrix control. Special attention is placed on the interaction of process design and process control. Most of the above methods are used to compare the relative performance of intensive and extensive variable control structures.
Prerequisites: CHE 433 or ME 433 or ECE 433

CHE 436 (ECE 436, ME 436) Systems Identification 3 Credits
The determination of model parameters from time history and frequency response data by graphical, deterministic and stochastic methods. Examples and exercises taken from process industries, communications and aerospace testing. Regression, quasilinearization and invariant-imbedding techniques for nonlinear system parameter identification included.

CHE 437 (ECE 437, ME 437) Stochastic Control 3 Credits
Prerequisites: CHE 433 or ME 433 or ECE 433

CHE 438 Process Modeling and Control Seminar 1 Credit
Presentations and discussions on current methods, approaches, and applications. Credit cannot be used for the M.S. degree.

CHE 439 (BIOE 439) Neuronal Modeling and Computation 3 Credits
This course is a graduate version of CHE 339 (BIOE 339). While the lecture content will be the same as the 300-level course, students in the 400-level class will be expected to complete an independent term project. Closed to students who have completed CHE 339 (BIOE 339). Must have graduate standing in Chemical Engineering or Bioengineering.

CHE 440 Chemical Engineering in the Life Sciences 3 Credits
Introduction of important topics in life sciences to chemical engineers. Topics include protein and biomolecule structures and characterization, recombinant DNA technology, immunoaffinity technology, combinatorial chemistry, metabolic engineering, bioinformatics. Must have Bachelor’s degree in science or engineering.

CHE 441 (BIOE 441) Biotechnology I 3 Credits
See the course description listed for CHE 341 (BIOE 341). In order to receive 400-level credits, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken CHE 341 (BIOE 341).

CHE 442 (BIOE 442) Biotechnology II 3 Credits
See the course description listed for CHE 342 (BIOE 342). In order to receive 400-level credits, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken CHE 342 (BIOE 342).

CHE 444 Bioseparations 3 Credits

CHE 446 Biochemical Engineering Laboratory 3 Credits
Laboratory and pilot-scale experiments in fermentation and enzyme technology, tissue culture, and separations techniques. Closed to students who have taken CHE 346.
Prerequisites: CHE 341 or CHE 444 or CHE 342
Can be taken Concurrently: CHE 342

CHE 447 (BIOE 447) Molecular Bioengineering 3 Credits
This course is a graduate version of CHE 344 (BIOE 344). While the lecture content will be the same as the 300-level course, students enrolled in CHE 444 will have more advanced assignments. Closed to students who have completed CHE 344 (BIOE 344).

CHE 448 Topics in Biochemical Engineering 3 Credits
Analysis, discussion, and review of current literature for a topical area of biotechnology. may be repeated for credit with the consent of the instructor. Consent of instructor required.
Repeat Status: Course may be repeated.

CHE 449 (BIOE 449) Metabolic Engineering 3 Credits
Quantitative perspective of cellular metabolism and biochemical pathways. Methods for analyzing stoichiometric and kinetic models, mass balances, flux in reaction networks, and metabolic control. Solving problems using advanced mathematics and computer programming. Closed to students who have completed BIOE 349. Must have graduate standing in Chemical Engineering or Bioengineering.

CHE 450 Special Topics 1-12 Credits
An intensive study of some field of chemical engineering not covered in the more general courses. Credit above three hours is granted only when different material is covered.

CHE 451 Problems In Research 1 Credit
Study and discussion of optimal planning of experiments and analysis of experimental data. Discussion of more common and more difficult techniques in the execution of chemical engineering research.

CHE 452 (ENGR 452) Mathematical Methods in Engineering 3 Credits
Analytical techniques relevant to the engineering sciences are described. Vector spaces; eigenvalues; eigenvectors. Linear ordinary differential equations; diagonalizable and non-diagonalizable systems. Inhomogeneous linear systems; variation of parameters. Non-linear systems; stability; phase plane. Series solutions of linear ordinary differential equations; special functions. Laplace and Fourier transforms; application to partial differential equations and integral equations. Sturm-Liouville theory. Finite Fourier transforms; planar, cylindrical, and spherical geometries.

CHE 453 Teaching Apprentice 1 Credit
Students will work under the guidance of individual Faculty instructors to participate in some of the following teaching tasks: Development of the course syllabus, preparation and grading of homework and exams, holding a recitation and/or lecture section. Must have graduate standing in CHE department.
Repeat Status: Course may be repeated.

CHE 454 Seminar 0-3 Credits
Critical discussion of recent advances in chemical engineering.

CHE 455 Seminar 1-3 Credits
Critical discussion of recent advances in chemical engineering. Credit above one hour is granted only when different material is covered.

CHE 460 Chemical Engineering Project 1-6 Credits
An intensive study of one or more areas of chemical engineering, with emphasis on engineering design and applications. A written report is required.
Repeat Status: Course may be repeated.

CHE 463 (BIOE 463) Numerical Methods for Scientists and Engineers 3 Credits
See the course description listed for CHE 363 (BIOE 363). This course is graduate version of CHE 363 (BIOE 363). The lecture content will be the same as CHE 363 (BIOE 363), but students enrolled in CHE 463 (BIOE 463) will have more advanced assignments. Closed to students who have taken CHE 363 (BIOE 363). Must have graduate standing or consent of the instructor.

CHE 464 Biochemical Engineering Laboratory 3 Credits
Laboratory and pilot-scale experiments in fermentation and enzyme technology, tissue culture, and separations techniques. Closed to students who have taken CHE 346.
Prerequisites: CHE 341 or CHE 444 or CHE 342
Can be taken Concurrently: CHE 342
CHE 473 Environmental Separation and Control 3 Credits
Theory and application of adsorption, ion exchange, reverse osmosis, air stripping and chemical oxidation in water and wastewater treatment. Modeling engineered treatment processes.
Prerequisites: CEE 470

CHE 480 Research 3 Credits
Investigation of a problem in chemical engineering.

CHE 481 Research 3 Credits
Continuation of CHE 480.

CHE 482 (CHM 482, MAT 482) Mechanical Behaviors of Polymers 3 Credits

CHE 483 (CHM 483, MAT 483) Emulsion Polymers 3 Credits
Examination of fundamental concepts important in the manufacture, characterization, and application of polymer latexes. Topics to be covered will include colloidal stability, polymerization mechanisms and kinetics, reactor design, characterization of particle surfaces, latex rheology, morphology considerations, polymerization with functional groups, film formation and various application problems.

CHE 485 (CHM 485, MAT 485) Polymer Blends and Composites 3 Credits
Synthesis, morphology, and mechanical behavior of polymer blends and composites. Mechanical blends, block and graft copolymers, interpenetrating polymer networks, polymer impregnated concrete, and fiber and particulate reinforced polymers are emphasized. Must have completed any introductory course in polymers.

CHE 486 Polymer Processing 3 Credits
Application of fundamental principles of mechanics, fluid dynamics and heat transfer to the analysis of a wide variety of polymer flow processes. A brief survey of the rheological behavior of polymers is also included. Topics include pressurization, pumping, die forming, calendering, coating, molding, fiber spinning and elastic phenomena.

CHE 490 Thesis 1-6 Credits

CHE 492 (CHM 492, MAT 492) Topics in Polymer Science 3 Credits
Intensive study of topic selected from areas of current research interest such as morphology and mechanical behavior, thermodynamics and kinetics of crystallization, new analytical techniques, molecular weight distribution, non-Newtonian flow behavior, second order transition phenomena, novel polymer structures. Credit above three hours is granted only when different material is covered.
Prerequisites: CHE 392 or CHE 392 or CHM 392 or CHM 392

CHE 499 Dissertation 1-15 Credits
Repeat Status: Course may be repeated.