Chemical and Biochemical Engineering

Interim Chair
- Jun Wang

Undergraduate major: chemical engineering (BSE)
Graduate degrees: MS in chemical and biochemical engineering; PhD in chemical and biochemical engineering
Faculty: https://engineering.uiowa.edu/cbe/cbe-people
Website: https://engineering.uiowa.edu/cbe

Chemical and biochemical engineers combine engineering principles with knowledge of mathematics and specific sciences—chemistry, the biological sciences, and physics—to develop and operate processes that convert raw materials into products that benefit society. For example, biochemical engineers might develop and operate processes to convert switchgrass into biofuels or to mass produce an antibiotic.

Chemical and biochemical engineers engage in a wide variety of activities that benefit the global community. Chemical engineering has served as a foundational discipline for many industries and applications, including the development of fuel cells, solar energy, and bio-renewable fuels (e.g., biodiesel or ethanol); pharmaceutical manufacturing, rechargeable batteries, and new materials; and green technologies for decarbonation and combating global climate change through air pollution control and precision agriculture.

Chemical engineering distinguishes itself from other engineering professions with its reliance on chemical reactions and physicochemical transformations to produce a wide variety of important materials and products. Biochemical engineers are involved in a wide variety of industrial biocatalytic, fermentation, and cell culture processes that generate products ranging from the high fructose corn syrup used in soft drinks to recombinant human insulin.

As part of their training, chemical and biochemical engineers learn ethical design and a respect for the larger issues in any design, such as community health, employee safety, and the global implications of the design. The University of Iowa’s curriculum emphasizes chemical process safety and environmentally conscious chemical engineering design.

Facilities

Undergraduate Core
Materials Science Laboratory
The Materials Science Laboratory allows students in ENGR:2720 Materials Science to further explore the concepts they learn in the classroom. It is equipped with tensiometers, hardness testers, an Izod impact tester, a contact angle goniometer, and heat treatment/sintering furnaces to characterize and examine the mechanical properties in a variety of materials. Optical microscopes, metallography specimen kits, and crystallography packages are used to facilitate understanding of structure-property relationships.

Required Undergraduate Laboratories

Chemical Engineering Laboratory
The Chemical Engineering Laboratory provides hands-on instruction for undergraduate students in CBE:3150 Thermodynamics/Transport Laboratory and CBE:3155 Chemical Reaction Engineering/Separations Laboratory. It is equipped for student experimentation in thermodynamics, fluid flow, heat transfer, mass transfer, chemical reaction engineering, and separations. All key equipment pieces in the lab, such as a distillation column, a wiped film evaporator, and multiple heat exchangers are constructed of transparent materials, allowing students to visually inspect the inner workings of this equipment. Additional equipment includes a fluid friction apparatus, a jacketed kettle, and a membrane gas separator. Students study this equipment using state-of-the-art portable analytical equipment such as densitometers, polarimeters, and refractometers.

Additionally, a wide array of small equipment is available to support laboratory projects and demonstrations in chemical engineering courses, and for use by students performing independent investigations or student groups competing in national chemical engineering contests.

Chemical Process Safety Laboratory
The Chemical Process Safety Laboratory is an integral part of CBE:3125 Chemical Process Safety. It is equipped with two MiniFlash automatic flash point testers (closed cup), an advanced reactive system screening tool (ARSSST), a minimum ignition energy (MIE) apparatus, a flammability chamber, a modified Hartmann tube, a Hartmann bomb, a liquid conductivity apparatus, a powder chargeability apparatus, a powder volume resistivity apparatus, a Van de Graaff generator, two high impedance electrometers, a field meter, a Faraday cage, and relief sizing software. This equipment is used in a series of experiments to demonstrate principles of flammability, reactivity, explosions, relief valve sizing, and electrostatics relevant to industry.

Biochemical Engineering Laboratory
The Biochemical Engineering Laboratory is an integral part of CBE:3205 Introduction to Biochemical Engineering. It is equipped with two controlled New Brunswick BioFlo/CelliGen 115 bioreactors, electrophoresis apparatus, and a thermocycler. This equipment is used for recombinant DNA experiments and to study the growth and metabolism of microorganisms.

Programs

Undergraduate Program of Study
Major
- Major in Chemical Engineering (Bachelor of Science in Engineering)

Graduate Programs of Study
Majors
- Master of Science in Chemical and Biochemical Engineering
- Doctor of Philosophy in Chemical and Biochemical Engineering
Process Control Laboratory

The Process Control Laboratory is a modern, computer-based instructional laboratory that is integral to CBE:4105 Process Dynamics and Control in Design. The lab consists of computer control of a shell-and-tube heat exchanger and a level-and-flow control process rig with state-of-the-art industrial control interfaces.

The Computer Control Laboratory offers an ensemble of learning experiences with the same equipment. Additional laboratories provide instruction in the use of process simulators that provide analogies and better insight into the control process. Topics include determination of the gain and time constants for single-capacitance systems; determination of gain, time constant, and damping factor of second-order processes; determination of open-loop and closed-loop response to step-and-ramp changes in input for single-capacitance and multipacitance processes; approximations of multipacitance systems as first- and second-order processes with dead time; analysis of instrumentation characteristics and transfer functions; tuning and optimization of feedback control parameters (P, PI, PID); system identification through frequency response methods; and determination of system stability.

Experimental arrangements in the lab are simple enough in design to be easily understood, yet complicated enough to help students appreciate system characteristics inherent in industrial processes (e.g., large time lags and error in parameter estimation).

Graduate Facilities and Laboratories

The department offers a wide variety of facilities to support and develop research activities.

Air Pollution Computational, Field, and Laboratory Studies

The department maintains extensive facilities for computational, field, and laboratory studies of air pollution, carbon cycle gases, aerosols, and nanoparticles at the Center for Global and Regional Environmental Research (CGRER). The Center occupies 5,000 square feet of research and office space on the fourth floor of the Iowa Advanced Technology Laboratories.

CGRER houses one R2 ImmersaDesk Portable Large Scale Visualization System and is linked on campus to two more R2 ImmersaDesk units.

The center’s computer laboratory for environmental and spatial data analysis provides numerous Windows and UNIX workstations, sophisticated software packages, and workstations and a file server necessary to run intensive visualization programs. The network backbone is university supported with high-speed wireless throughout. A variety of digital environmental databases and an extensive library of documentation and related references are available. There are 4 Beowulf Linux clusters on site and Linux clusters of 4, 16, 18, and 20 nodes for large computations and data assimilation. CGRER retains 15 TB of redundant storage and 50 TB of total storage; local storage space is scalable and expandable. A variety of software packages and programming languages are available for data analysis and display, including ArcInfo, ArcView, NCAR Graphics, MATLAB, S-PLUS, and Vis5D, as well as geographical information software. The Esri software suite is part of a university-wide site license.

Laboratory and field equipment includes aerosol samplers, including scanning mobility particle sizers for aerosols from 3 nanometer to 1 micron with time resolution to 30 seconds; aerosol particle sizers for aerodynamic measurements of in situ particles with time resolution to 1 second; and varied condensation particle counters for measuring total particle counts. Several hygroscopic tandem differential mobility analyzers are used, as well as varied aerosol generation devices and unique aerosol inlets for relative humidity (RH) and temperature modification and control. Cloud droplet number can be measured in the lab or in the field using a Droplet Measurement Technologies cloud condensation nuclei detector. Advanced computer control of instruments is available through LabVIEW.

Selected instruments are field deployable in a custom air-conditioned trailer. Through collaboration with the IIHR—Hydroscience and Engineering, access to micrometeorology sensors, 1D and 2D elastic and Raman lidar, and gas sensors is available, including multichannel ammonia monitors.

Biochemical Engineering

Biochemical engineering laboratories provide facilities for preparation of biological media and cultivation of organisms as well as for separation and analysis of biomolecules. This equipment includes biological incubators and floor incubator shakers, agitated and airlift bioreactors, light microscopes, autoclaves, Vi-Cell cell counter, thermocycler for polymerase chain reaction (PCR) amplification of DNA, high- and low-speed centrifuges, UV-Vis spectrophotometers, a lyophilizer, biological safety cabinets, and an anaerobic glove box. Phase-contrast and epifluorescence microscopes, gel electrophoresis systems, gas chromatography units with flame ionization and electron capture detectors, and several high performance liquid chromatography systems with refractive index and photodiode array detectors are available for characterization of microorganisms and constituent biomolecules.

Through collaborative research agreements, graduate students also have access to specialized facilities for electron microscopy, large-scale fermentation, protein structure, recombinant DNA research, and tissue culture/hybridoma; the Flow Cytometry Facility; and the High Resolution Mass Spectrometry Facility.

Biomedical Engineering

The biomedical engineering laboratories house particle technology equipment including microemulsion equipment for drug encapsulation, sonicators, benchtop scale spray dryers, laser diffraction particle sizer, zetapotentiometer; DNA preparation equipment, gel electrophoresis apparatus; interfacial stress rheometer, surface tensiometer, UV-Vis/fluorescent plate reader, high performance liquid chromatograph, luminometer, lyophilizer, custom-built simulated cough machine, microscopes, incubators, wet chemistry equipment, rotary shakers, incubated plate shakers, autoclave, centrifuges, and laboratory computers. Cell culture and bacterial culture facilities are housed adjacent to the laboratories.

Graduate students also have access to core research facilities including the Central Microscopy Research Facility, Flow Cytometry Facility, Iowa Institute of Human Genetics, Electron Spin Resonance Facility, Nuclear Magnetic Resonance Facility, High Resolution Mass Spectrometry Facility, and the Center for Gene Therapy.
Computer Facilities
The departmental computer facilities contain a variety of laptops, desktop workstations, and printers. The department is supported by the college’s Engineering Technology Center, which maintains a large network of high performance Linux and Windows workstations along with extensive commercial and public domain software. The department also has access to the university’s central high performance research computing facility through ITS–Research Services. The University of Iowa also has access to the ACCESS and Blue Waters national supercomputing resources and is a founding member of the Great Lakes Consortium for Petascale Computing. Locally-hosted long-term data storage services are available.

Fundamentals and Applications of Photopolymerization
The Photopolymerization Center was established to advance fundamental understanding of the kinetics and mechanisms of photopolymerizations. To this end, the center provides unique opportunities for collaborations by industrial and academic investigators to explore photopolymerization processes and develop novel applications based on photopolymerizations.

The center provides equipment and instrumentation for the characterization of photopolymerization systems on the molecular, microscopic, and macroscopic levels. Center researchers pursue understanding of fundamental photophysical and photochemical processes involved in the photoinitiation reaction, characterization of high-speed propagation and termination kinetics that lead to the polymer structure, and evaluation of material properties through the course of the photopolymerization reaction. Both radical and cationic photopolymerizations are studied with state-of-the-art experimental techniques to elucidate the complex chemical and physical mechanisms that control the initiation, propagation, and termination of the active centers.

Courses

Chemical and Biochemical Engineering Courses

CBE:0000 Chemical Engineering Internship/Co-op 0 s.h.
Chemical engineering students participating in the Cooperative Education Program register for this course during work assignment periods; registration provides a record of participation in the program on the student's permanent record. Requirements: admission to Cooperative Education Program.

CBE:1000 CBE Departmental Seminar 1 s.h.
Introduction to the profession and the department; presentations by guest speakers, visits to laboratories and industries.

CBE:1180 First-Year Seminar 1 s.h.
Small discussion class taught by a faculty member; topics chosen by instructor; may include outside activities (e.g., films, lectures, performances, readings, visits to research facilities, field trips). Requirements: first- or second-semester standing.

CBE:2030 Energy and Society 3 s.h.
History of energy development and use throughout the world; how energy has affected the development of human societies; societal impact of engineering advances; current state of energy consumption worldwide, including distribution of energy sources, global variations in consumption, advantages and disadvantages of current energy sources; role of fossil fuel consumption in global climate change, potential scenarios for the future of energy.

CBE:2040 Environment, Energy, and Climate Change 3 s.h.
Traditional concerns (e.g., pollution and conservation of energy resources) with clear, scientific explanations; Earth's dynamic processes and response to natural and human-induced stresses; link between energy and climate; reasons why we need to support reducing emissions and build a clean and sustainable environment.

CBE:2050 Severe and Unusual Weather 3 s.h.
Basic weather concepts behind severe weather phenomena and essential safety information; how weather events cause billions of dollars in damage and thousands of casualties; winter storms can impact half of the nation, paralyzing the transportation network with icy roads and wind driven snow; tornadoes can strike within minutes tearing apart homes; hurricanes can destroy entire communities with strong winds, heavy rain, and deadly storm surge; how understanding severe weather and knowing what to do before, during, and after an event can significantly reduce injury, deaths, and property damage. Same as CEE:2050.

CBE:2105 Process Calculations 3 s.h.
Fundamental principles of chemical process analysis, including material and energy balances for single-unit and multiple-unit processes, analysis of reactive and nonreactive systems, introduction to equations of state, thermodynamics of multiphase systems. Prerequisites: MATH:1550.

CBE:2110 Computational Tools for Chemical Engineers 2 s.h.

CBE:3000 Professional Seminar: Chemical Engineering 1 s.h.
Professional aspects of chemical engineering presented through lectures and discussions by guest speakers, field trips, films, panel discussions. Prerequisites: CBE:2105. Requirements: sophomore standing.

CBE:3020 Applied Statistics for Chemical and Natural Resources Engineering 3 s.h.
Statistical and computational (Python programming) analysis of weather and climate data, univariate and multivariate statistics, hypothesis testing, statistical forecasting, forecast verification, time-series analysis, trend analysis, and principal component analysis.

CBE:3105 Chemical Engineering Thermodynamics 3 s.h.
Applications of thermodynamic principles to chemical and physical processes; prediction of material properties; phase and chemical equilibria applied to mixtures and reacting systems. Prerequisites: ENGR:2130. Corequisites: CBE:2105.
CBE:3109 Fluid Flow  
Fundamentals of fluid flow, including fluid statics, fluid rheology, laminar and turbulent flow in pipes, external flow, flow through packed beds, fluidized beds, pumps and compressors, boundary layer theory, potential flow, dimensional analysis, and Navier Stokes Equations. Corequisites: CBE:2105.

CBE:3113 Heat and Mass Transfer  
Fundamentals of heat and mass transfer including heat exchanger design; conductive, convective, and radiative heat transfer; mechanisms of diffusional and convective mass transfer. Prerequisites: MATH:2560 and CBE:2105. Recommendations: CBE:3109.

CBE:3117 Separations  
Solution of industrial problems including design of distillation, extraction, absorption, adsorption, drying, membrane processes, and mechanical separations. Prerequisites: CBE:2105 and CBE:3105. Corequisites: CBE:3113.

CBE:3120 Chemical Reaction Engineering  
Application of chemical reaction kinetics to design of chemical reactors: batch reactors, mixed flow reactors, plug flow reactors; reversible and irreversible single reactions; parallel, series, and mixed reactions; temperature and pressure effects on reactor design; heterogeneous catalysis; transport in porous catalysts. Prerequisites: MATH:2560. Corequisites: CBE:3105. Recommendations: CBE:3113.

CBE:3125 Chemical Process Safety  
Application of transport phenomena, thermodynamics, chemical kinetics to study of safety, health, loss prevention; government regulations, toxicology/industrial hygiene, relief sizing, runaway reactions, toxic release and dispersion models, source models, fires and explosions, risk assessment, hazard identification, case studies and accident investigation, incorporation of safety into design; laboratory experiments. Prerequisites: CBE:3105 and CBE:3109. Corequisites: CBE:3113.

CBE:3150 Thermodynamics/Transport Laboratory  

CBE:3155 Chemical Reaction Engineering/Separations Laboratory  

CBE:3205 Introduction to Biochemical Engineering  

CBE:3415 Statistical and Computational Analysis of Weather and Climate Data  
Statistical and computational (Python programming) analysis of weather and climate data, univariate and multivariate statistics, hypothesis testing, statistical forecasting, forecast verification, time-series analysis, principal component analysis, trend analysis, and cluster analysis. Requirements: senior or graduate standing.

CBE:3998 Individual Investigations: Chemical Engineering  
Individual projects for chemical engineering undergraduate students, such as laboratory study, engineering design project, analysis and simulation of an engineering system, computer software development, research.

CBE:4105 Process Dynamics and Control in Design  
Theory and application of process dynamics to the design of chemical process control systems; mathematical models of unit operations, transfer functions, feedback and feed-forward control, stability, instrumentation, digital control systems; computer methods, including simulation and commercial software use; laboratory focus on process analysis and design. Prerequisites: MATH:2560 and CBE:2105 and CBE:3109. Corequisites: CBE:3120.

CBE:4109 Chemical Engineering Process Design I  
Engineering economics of process evaluation, including time value of money and bases for cost estimation; preliminary design of chemical process plants using computer-aided engineering. Prerequisites: CBE:3109 and CBE:3113 and CBE:3117. Corequisites: CBE:3120 and CBE:3125.

CBE:4110 Chemical Engineering Process Design II  
Capstone chemical engineering course; design and optimization of chemical process plants; application of process calculations, thermodynamics, kinetics, process synthesis, energy efficiency in separations, heat-exchanger network synthesis, physical property estimation, safety, computer-aided design, unit operations theory, process control, and economics. Prerequisites: CBE:4109. Recommendations: CBE:4105 and CBE:3205.

CBE:4125 Advanced Chemical Process Safety  
Chemical process safety including qualitative and quantitative hazard analysis, risk and consequence analysis, human factors and operator error, incident investigation, management of change procedures, interlocks and safety instrumented systems, layer of protection analysis, dust hazard analysis, and process safety management. Prerequisites: CBE:3125.

CBE:4195 Senior Enriching Activities Seminar  
Aspects of chemical engineering education, including multidisciplinary team skills, understanding the impact of engineering practice locally and globally. Corequisites: CBE:4110. Requirements: completion of enriching activity.

CBE:4410 Sustainable Systems  
New and emerging concepts in sustainable systems design and assessment. Same as CEE:4107.

CBE:4420 Environmental Chemistry  
Principles of general, physical, organic chemistry applied in water and air systems; emphasis on qualitative and quantitative understanding of chemical kinetics and equilibrium; acid-base reactions, complex formation, precipitation, dissolution, and oxidation-reduction reactions; organic nomenclature. Prerequisites: CHEM:1120. Same as CEE:4150.
CBE:4459 Air Pollution Control Technology 3 s.h. Sources, environmental and health impacts, regulations, modeling of air pollution; processes and alternative strategies for control; global climate considerations. Same as CEE:4159, IGPI:4159.

CBE:4460 Process and Design for Satellites and Environmental Sensors 3 s.h. Exploration of how to design, develop, and implement science instruments, sensor networks, and satellite mission; emphasis on atmospheric sensors for planetary atmospheres; disciplines required, how to build a team, developing science requirements, developing instrument requirements, development and management of interface controls, workflow tracking, quality assurance verification, and resolving hardware/design problems; considerations needed by a principal investigator, instrument manager, instrument scientist, plan manager, or systems engineer to pursue a major instrument, mission development, industrial plan development, or expansion.

CBE:5000 Seminar in Chemical and Biochemical Engineering 1 s.h. Presentation and discussion of recent advances and research in chemical and biochemical engineering by guest lecturers, faculty, students. Requirements: graduate standing.

CBE:5100 Graduate Professional Development Seminar 1 s.h. Seminar participants work with a faculty member to select and attend eight hours of approved seminars and professional development trainings at the University of Iowa; final meeting of participants is held to share notable seminars; typical seminar series include College of Engineering lectures, departmental and research center graduate seminars, chemical and biochemical engineering professional seminar series, and Center for Teaching and Learning offerings. Requirements: master's standing in chemical and biochemical engineering.

CBE:5104 Introduction to Literature Review and Technical Writing 3 s.h. Review of technical literature, how to contribute to it; produce and present orally a peer-reviewed-journal-quality review article; brainstorming, group writing, research ethics, plagiarism. Recommendations: nonthesis track graduate standing.

CBE:5105 Introduction to Literature Review and Proposal Writing 3 s.h. Tools for reviewing literature, skills for critical reading of publications, training in successful proposal writing; experience drafting a proposal that can be used as a starting point for the PhD comprehensive.

CBE:5110 Intermediate Thermodynamics 3 s.h. Fundamental principles of thermodynamics as applied to phase equilibrium; properties of fluids, first and second law, variable composition systems, behavior of real fluids, mathematical techniques for solution thermodynamics. Requirements: CBE:3105 or ME:3040 or graduate standing. Same as ME:5210.

CBE:5115 Transport Phenomena I 3 s.h. Unified treatment of momentum, mass, energy transport in chemical engineering problems; use of vector and tensor notations in expressing equations of continuity, motion, energy.

CBE:5120 Data Science in Chemical and Engineering Systems 3 s.h. Theory and application of numerical methods and data driven algorithms towards understanding chemical processes; scientific computing in Python programming language; numerical solutions to differential equations; nonlinear and constrained optimization; data preprocessing and visualization; dimensionality reduction and clustering; supervised machine learning.


CBE:5199 Contemporary Topics: Chemical and Biochemical Engineering arr. Research techniques for graduate students in chemical and biochemical engineering.

CBE:5210 Bioseparations 3 s.h. Unit operations used to isolate and purify biologically derived chemicals, including flocculation, filtration, centrifugation, extraction, adsorption, chromatography, precipitation, crystallization, electrophoresis and cell disruption for intracellular product recovery.

CBE:5300 Drug Delivery Devices 3 s.h. Why drug delivery devices are needed and how they are regulated; review of several clinical device categories (inhalation, transdermal, implantable) and preclinical technologies on the horizon.

CBE:5310 Polymer Science and Technology 3 s.h. Uses and properties of industrially important polymeric materials; polymer chemistry, polymer structure, characterization, and polymer processing. Prerequisites: CHEM:2210 or CHEM:2230.

CBE:5315 Polymer Chemistry 3 s.h. Monomer reactivity and polymerization reactions; step, radical, ionic, and ring-opening polymerizations. Prerequisites: CHEM:2220.

CBE:5390 Photopolymerization Topics 1 s.h. Seminars presented by faculty members, research assistants, students.

CBE:5405 Green Chemical and Energy Technologies 3 s.h. Strategies for pollution prevention for chemical processes studied at macroscale (industrial sector), mesoscale (unit operations), and microscale (molecular level); case studies. Prerequisites: CBE:2105.

CBE:5410 Electrochemical Engineering 3 s.h. Fundamentals of electrochemical engineering; various applications; focus on processes and systems that transform chemical energy into electrical energy (e.g., batteries, fuel cells) and vice versa (e.g., electrolyzers, oxygen generators for medical applications); electrochemical engineering in an increasingly important role in energy, chemical, environmental, and biomedical sectors.

CBE:5412 Atmospheric Modeling 3 s.h. Model equations and approaches for atmospheric dynamics and chemistry; numerical methods for radiative, chemical, and aerosol rates; parameterization of subgrid-scale processes; model evaluation and inverse modeling.
CBE:5415 Satellite Image Processing and Remote Sensing of Atmosphere  3 s.h.
Introduction to principles of atmospheric radiation and techniques for satellite image processing; hands-on experience with data calibration, image registration and enhancement, noise filtering and (supervised and unsupervised) multi-spectral classification of satellite imageries; various satellite sensors used for monitoring of different atmospheric processes and constituents. Same as IGPI:5415.

CBE:5417 Physical Meteorology and Atmospheric Radiative Transfer  3 s.h.
Physical processes for weather and climate including radiative transfer, cloud and precipitation formation, and atmospheric electricity; theory of scattering by atmospheric particles (e.g., clouds, aerosols, molecules), atmospheric radiative transfer equations, and numerical techniques and tools to solve these equations. Requirements: senior or graduate standing. Same as IGPI:5417.

CBE:5425 Atmospheric Chemistry and Physics  3 s.h.
Principal chemical and physical processes affecting atmospheric trace gas and pollutant cycles; emphasis on atmospheric photochemistry, aerosol science, major sources, and removal processes. Corequisites: CBE:3120. Same as CEE:5115.

CBE:5466 Optical Components, Alignment, and Instrumentation for Remote Sensing  3 s.h.
Explore optical components including lenses, mirrors, beam splitters, fiber optics, and filters, and optical assemblies including beam expanders, interferometers, and laser cavities; assess and align optical assemblies using metrology equipment including collimators, autocollimators, and wavemeters; hands-on laboratory work. Work with optics, optical devices, and metrology equipment; learn how to handle, work with, and assess optics and optical components and how to align complex assemblages of components in a sensor. Recommendations: basic or introductory physics course with applications to atmospheric chemistry.

CBE:5740 Engineering Principles of Drug Delivery  3 s.h.
Fundamental concepts in drug delivery from an engineering perspective: delivery mechanisms; materials and formulations for drug delivery; drug modifications (prodrugs, PEGylation); engineering principles of controlled release and targeted delivery (nanoparticles, microparticles, polymer and lipid based systems); quantitative understanding of drug transport; significance of biodistributions and pharmacokinetic models; toxicity issues; immune responses.

CBE:5745 Alternatives in Biotechnology  1 s.h.
Topics related to careers in biotechnology with an emphasis on preparing graduate students for careers outside of academia; discussions led by a series of guest speakers from leading biotech industries; understanding the societal impact of basic research; participation in round-table discussions; and presentation of student research findings. Requirements: graduate standing and good academic standing in a participating department supported by the Predoctoral Training Program in Biotechnology. Same as BMB:5875, CEE:5875, CHEM:5875, MICR:5875, PHAR:5875.

CBE:5998 Individual Investigations: Chemical and Biochemical Engineering  arr.
Individual projects for chemical and biochemical engineering graduate students; may include laboratory study, engineering design project, analysis and simulation of an engineering system, computer software development, research. Requirements: graduate standing.

CBE:5999 MS Thesis Research: Chemical and Biochemical Engineering  arr.
Experimental and/or analytical investigation of an approved topic for partial fulfillment of requirements for MS with thesis in chemical and biochemical engineering. Requirements: graduate standing.

CBE:6145 Diffusive Transport  3 s.h.
Diffusive transport of heat, mass, and momentum; phenomenological laws and analogies; analytical and numerical solution techniques; inverse heat conduction; multiphase and multicomponent systems. Prerequisites: ME:5145. Same as ME:6245.

CBE:6415 Advanced Satellite and Remote Sensing of Atmosphere  3 s.h.
Cloud masking and retrieval of cloud properties from satellites, aerosol detection and retrievals, Earth radiation energy budget, land and/or ocean remote sensing, microwave remote sensing, wind retrieval, multi-sensor intercomparison and validation, optimization and inversion theory; hands-on projects.

CBE:6435 Advanced Atmospheric Radiative Transfer  3 s.h.
Theory of scattering by atmospheric particles (e.g., clouds, aerosols, molecules), atmospheric radiative transfer equations, and techniques to solve these equations for solar and terrestrial radiation; numerical experiments with Mie scattering, T-matrix calculation, and radiative transfer models.

CBE:7999 Research: Chemical and Biochemical Engineering PhD Dissertation  arr.
Experimental and/or analytical investigation of an approved topic for PhD in chemical and biochemical engineering.