Chemical and Biological Engineering

Degrees Offered

- Master of Science (Chemical Engineering)
- Doctor of Philosophy (Chemical Engineering)
- Online Graduate Certificate in Chemical Engineering Processes in Energy Transitions

Program Description

The Chemical and Biological Engineering Department of Colorado School of Mines is a dynamic, exciting environment for research and higher education. Mines provides a rigorous educational experience where faculty and top-notch students work together on meaningful research with far-reaching societal applications. Departmental research areas include bioengineering, catalysis, colloids and complex fluids, computational science, fuel cells, gas hydrates, membranes, polymers, and solar and electronic materials. Visit our webpage for additional information about our graduate program. https://chemeng.mines.edu/

Program Requirements

Prerequisites

The program outlined here assumes that the candidate for an advanced degree has a background in chemistry, mathematics, and physics equivalent to that required for the bachelor's degree in Chemical Engineering at Colorado School of Mines. Undergraduate course deficiencies must be removed prior to enrollment in graduate coursework.

The essential undergraduate courses include:

CBEN201	MATERIAL AND ENERGY BALANCES	3.0
CBEN307	FLUID MECHANICS	3.0
CBEN314	CHEMICAL ENGINEERING HEAT AND MASS TRANSFER	4.0
CBEN357	CHEMICAL ENGINEERING THERMODYNAMICS	3.0
CBEN375	CHEMICAL ENGINEERING SEPARATIONS	3.0
CBEN418	KINETICS AND REACTION ENGINEERING	3.0
Total Semester Hrs		**19.0**

Required Curriculum

Master of Science Program

Master of Science (with Thesis)

Students entering the master of science (with thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 18 credits of coursework. All students must complete:

Chemical Engineering core graduate courses		
CBEN507	APPLIED MATHEMATICS IN CHEMICAL ENGINEERING	3.0
or CBEN505	NUMERICAL METHODS IN CHEMICAL ENGINEERING	
CBEN509	ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS	3.0
CBEN516	ADVANCED TRANSPORT PHENOMENA	3.0
or CBEN530	TRANSPORT PHENOMENA	
CBEN518	REACTION KINETICS AND CATALYSIS	3.0
or CBEN519	ADVANCED TOPICS IN HETEROGENEOUS CATALYSIS	
CBEN568	INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING	3.0
CBEN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT	6.0
ELECT	Approved Coursework Electives	6.0
RESEARCH	Research Credits or Coursework	3.0
Total Semester Hrs		**30.0**

Students must take a minimum of 6 research credits, complete, and defend an acceptable master's dissertation. Between coursework and research credits a student must earn a minimum of 30 total credits. Full-time master's students must enroll in graduate colloquium (CBEN605) each semester. A maximum of 3 credits of CBEN605 can be counted towards the degree requirements.

Master of Science (Non-Thesis)

Students entering the master of science (non-thesis) program with an acceptable undergraduate degree in chemical engineering are required to take a minimum of 30 credits of coursework. All students must complete:

Chemical Engineering core graduate courses		
CBEN507	APPLIED MATHEMATICS IN CHEMICAL ENGINEERING	3.0
or CBEN505	NUMERICAL METHODS IN CHEMICAL ENGINEERING	
CBEN509	ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS	3.0
CBEN516	ADVANCED TRANSPORT PHENOMENA	3.0
or CBEN530	TRANSPORT PHENOMENA	
CBEN518	REACTION KINETICS AND CATALYSIS	3.0
or CBEN519	ADVANCED TOPICS IN HETEROGENEOUS CATALYSIS	
ELECT	Approved Electives	18.0
Total Semester Hrs		**30.0**

Students may complete an acceptable engineering report for up to 6 credits. Full-time master's students must enroll in graduate colloquium (CBEN605) each semester. A maximum of 3 credits of CBEN605 can be counted toward the degree requirements.

Mines Combined Undergraduate/graduate degree program

Students enrolled in Mines' combined undergraduate/graduate program may double count up to 6 credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with B- or better, not be substitutes for required coursework, and meet all other university, department, and program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

Doctor of Philosophy Program

The course of study for the PhD degree consists of a minimum of 30 credits of coursework. All PhD students must complete:

Core courses		
CBEN507	APPLIED MATHEMATICS IN CHEMICAL ENGINEERING	3.0
CBEN509	ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS	3.0
CBEN516	ADVANCED TRANSPORT PHENOMENA	3.0
CBEN518	REACTION KINETICS AND CATALYSIS	3.0
CBEN568	INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING	3.0
CBEN630	PROPOSAL PREPARATION	1.0
CBEN	600-Level Coursework Electives	3.0
ELECT	Approved Coursework Electives	12.0
CBEN707	Graduate Research Credit (up to 12 hours per semester)	42.0
Total Semester Hrs		**73.0**

In addition, students must complete and defend an acceptable doctoral dissertation. Full-time PhD students must enroll in graduate colloquium (CBEN605) each semester. A maximum of 3 credits of CBEN605 can be counted toward the degree requirements.

Students in the PhD program are required to pass both a qualifying exam and the PhD proposal defense. After successful completion of 30 credits of coursework and completion of the PhD proposal defense, PhD candidates will be awarded a non-thesis master of science Degree. The additional requirements for the PhD program are described below.

PhD Qualifying Examination

The PhD qualifying examination will be offered twice each year, at the start and end of the spring semester. All students who have entered the PhD program must take the qualifying examination at the first possible opportunity. However, a student must be in good academic standing (above 3.0 GPA) to take the qualifying exam. A student may retake the examination once if he/she fails the first time; however, the examination must be retaken at the next regularly scheduled examination time. Failure of the PhD qualifying examination does not disqualify a student for the master's degree, although failure may affect the student's financial aid status.

The qualifying examination will cover the traditional areas of Chemical Engineering and will consist of two parts: GPA from core graduate classes (CBEN507, CBEN509, CBEN516, and CBEN518) and an oral examination. The oral examination will consist of a presentation by the student on a technical paper from chemical engineering literature. Students will choose a paper from a list determined by the faculty. Papers for the oral examination will be distributed well in advance of the oral portion of the exam so students have sufficient time to prepare their presentations. The student is required to relate the paper to the core chemical engineering classes and present a research plan, followed by questions from the faculty. A one- to two-page paper on the research plan is due the Friday prior to the oral examination.

If a student fails the first attempt at the qualifying exam, his/her grade from a 600-level Chemical Engineering elective can replace the lowest grade from the core graduate classes for, and only for, the GPA calculation defined above.

PhD Proposal Defense

After passing the qualifying exam, all PhD candidates are required to prepare a detailed written proposal on the subject of their PhD research topic. An oral examination consisting of a defense of the thesis proposal must be completed prior to their fifth semester. Written proposals must be submitted to the student's thesis committee no later than one week prior to the scheduled oral examination.

Two negative votes from the doctoral committee members are required for failure of the PhD proposal defense. In the case of failure, one re-examination will be allowed upon petition to the department head. Failure to complete the PhD proposal defense within the allotted time without an approved postponement will result in failure. Under extenuating circumstances, a student may postpone the exam with approval of the graduate affairs committee, based on the recommendation of the student's thesis committee. In such cases, a student must submit a written request for postponement that describes the circumstances and proposes a new date. Requests for postponement must be presented to the thesis committee no later than two weeks before the end of the semester in which the exam would normally have been taken.

Online graduate certificate in Chemical engineering processes in energy transitions

The Mines graduate certificate in Chemical Engineering Processes in Energy Transitions is a three-course online program that provides engaging learning experiences in understanding current challenges and existing technologies in the safe production of energy, development of efficient energy storage systems, and associated environmental remediation methods related to carbon capture and utilization. Courses in the program focus on real-world challenges and state-of-the-art technologies. By bringing salient aspects of energy and environment under one umbrella, students develop the expertise necessary to address technological problems, make economic decisions, or formulate government policies. This program is designed for professionals and recent graduates who want to acquire new skills for career advancement or get a head start on an advanced graduate degree. The certificate program requires three 3-credit graduate courses identified below.

CBEN522	CHEMICAL ENGINEERING FLOW ASSURANCE	3.0
CBEN598B	ADVANCED ELECTROCHEMICAL ENGINEERING	3.0
SYGN598A	NON-GEOLOGIC CCUS: CAPTURE & UTILIZATION	3.0

Courses

CBEN504. ADVANCED PROCESS ENGINEERING ECONOMICS. 3.0 Semester Hrs.
Advanced engineering economic principles applied to original and alternate investments. Analysis of chemical and petroleum processes relative to marketing and return on investments. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN505. NUMERICAL METHODS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.
Engineering applications of numerical methods. Numerical integration, solution of algebraic equations, matrix 54 Colorado School of Mines Graduate Bulletin 2011 2012 algebra, ordinary differential equations, and special emphasis on partial differential equations. Emphasis on application of numerical methods to chemical engineering problems

which cannot be solved by analytical methods. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN506. ADVANCED FUNCTIONAL POROUS MATERIALS. 3.0 Semester Hrs.

Foundation on basic chemical strategies for making nanomaterials. Integration of fundamentals and functional applications of ordered porous materials at different length scales: from micro to macroporous regime. Chemical engineering concepts in nanochemistry. Existing and emerging functional applications of these porous materials in gas separations, heterogeneous catalysis, and adsorption.

Course Learning Outcomes

CBEN507. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.

(I, II) This course stresses the application of mathematics to problems drawn from chemical and biological engineering fundamentals such as thermodynamics, transport phenomena, and kinetics. Formulation and solution of ordinary and partial differential equations arising in chemical engineering or related processes or operations are discussed. Prerequisite: Undergraduate differential equations course; undergraduate chemical engineering courses covering reaction kinetics, and heat, mass and momentum transfer. 3 hours lecture; 3 semester hours.

Course Learning Outcomes

- n/a

CBEN508. NATURAL GAS PROCESSING. 3.0 Semester Hrs.

Application of chemical engineering principles to the processing of natural gas. Emphasis on using thermodynamics and mass transfer operations to design and analyze the process for natural gas production, processing, and use. Relevant aspects of computer aided process simulation will be applied to facilitate the learning and understand the many components associated with natural gas as an energy resource.

Course Learning Outcomes

- 1. Demonstrate a basic understanding of the industry “from wellhead to burner tip”
- 2. Develop a basic understanding of gas chemistry and resulting physical properties
- 3. Develop an understanding of the processing steps needed to abide by transportation & usage requirements and specifications
- 4. Demonstrate the ability to use simulation software for natural gas characterization, fractionation, and related operations.

CBEN509. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS. 3.0 Semester Hrs.

Extension and amplification of under graduate chemical engineering thermodynamics. Topics will include the laws of thermodynamics, thermodynamic properties of pure fluids and fluid mixtures, phase equilibria, and chemical reaction equilibria. Prerequisite: CBEN357 or equivalent. 3 hours lecture; 3 semester hours.

CBEN511. NEUROSCIENCE, MEMORY, AND LEARNING. 3.0 Semester Hrs.

Equivalent with CBEN411,

(II) This course relates the hard sciences of the brain and neuroscience to memory encoding and current learning theories. Successful students in the course should be able to read, understand, and critique current, scholarly literature on the topic of Neuroscience, Memory, and Learning. When this course is cross-listed and concurrent with CBEN411, students that enroll in CBEN511 will complete additional and/or more complex assignments. Pre-requisites: CBEN110, CBEN120, CHGN221, CHGN222, PHGN100, and PHGN200. 3 hours lecture, 3 semester hours.

Course Learning Outcomes

- Define memory types and how they relate to different types of learning and list the biochemistry of memory generation, stabilization, and maintenance.
- State how brain systems relate to episodic and semantic memory and list neuroscience bases for actions, habits, and fear
- Generate and test hypotheses to improve learning, based on biochemistry

CBEN513. SELECTED TOPICS IN CHEMICAL ENGINEERING. 1-3 Semester Hr.

Selected topics chosen from special interests of instructor and students. Course may be repeated for credit on different topics. Prerequisite: none. 1 to 3 semester hours lecture/discussion; 1 to 3 semester hours.

CBEN516. ADVANCED TRANSPORT PHENOMENA. 3.0 Semester Hrs.

Principles of momentum, heat, and mass transport with applications to chemical and biological processes. Analytical methods for solving ordinary and partial differential equations in chemical engineering with an emphasis on scaling and approximation techniques. Convective transport in the context of boundary layer theory and development of heat and mass transfer coefficients. Introduction to computational methods for solving coupled transport problems in irregular geometries.

Course Learning Outcomes

- n/a

CBEN518. REACTION KINETICS AND CATALYSIS. 3.0 Semester Hrs.

(I) This course applies the fundamentals of kinetics, transport and thermodynamics to the analysis of gas-phase and catalytic reactions. A focus is placed on a molecular description of chemical kinetics with applications to the design and analysis chemical and biological reactors, complex reaction networks, and catalysis. Prerequisite: CBEN418 or equivalent. 3 hours lecture; 3 semester hours.

Course Learning Outcomes

- n/a

CBEN519. ADVANCED TOPICS IN HETEROGENEOUS CATALYSIS. 3.0 Semester Hrs.

Heterogenous catalysts are the workhorse of the chemical industry and are responsible for many of the critical chemical transformations tied to the technological progress of our society. From enabling the development of processes to produce gasoline for transportation and fertilizers for food security, passing through the development of car catalytic converters to eliminate toxic emissions, to now being called to play a central role in many technological challenges such as transforming CO2 to useful compounds, biomass to useful fuels, water to hydrogen fuels, powering cars using fuel cells, among many others. This grad/undergrad course will take the student on a learning journey through the state-of-the-art of catalyst development. The journey will be made through the fundamental basics of both computational/theoretical and experimental/practical aspects of catalyst development, with Special Topic sessions discussing the most up to date examples of synergistic integration of these aspects in industry and research. Not only will the student gain an understanding of what kind of critical societal problems are tried to be solved by developing new catalysts, but also will gain an understanding of how that development is taking place and what entails.

Course Learning Outcomes

- 1. Demonstrate an understanding of the crystal structures of solids and the origin of catalyst functions.
- 2. Demonstrate an understanding of adsorptions and reactions on surfaces.
- 3. Be able to use density functional theory (DFT) methods to calculate adsorption and activation energies and to estimate rate parameters from DFT-derived energies.
- 4. Be able to construct microkinetic modeling using theory-derived rate parameters and to predict rates and selectivities at catalytic conditions.
- 5. Be able to interpret experimental kinetic rate data and compare them to theory-derived values.
- 6. Demonstrate an understanding of diffusion phenomena in porous materials and its consequences on rates and selectivities.
- 7. Be able to analyze experimental and theoretical data to characterize diffusion in porous materials and to determine their textural properties.
- 8. Be able to explain different synthesis techniques to prepare catalytic materials.
- 9. Demonstrate an understanding of appropriate research tools that can be applied to characterize catalytic materials.
- 10. Demonstrate an understanding of the key physical chemistry concepts of spectroscopic methods.
- 11. Demonstrate an understanding of the applications of spectroscopic methods to answer specific research questions.

CBEN522. CHEMICAL ENGINEERING FLOW ASSURANCE. 3.0 Semester Hrs.

Chemical Engineering Flow Assurance will include the principles of the application of thermodynamics and mesoscopic and microscopic tools that can be applied to the production of oil field fluids, including mitigation strategies for solids, including gas hydrates, waxes, and asphaltenes.

Course Learning Outcomes

- 1. Demonstrate an understanding of the chemistry and physical properties of oil field production fluids and solids.
- 2. Demonstrate an understanding of the thermodynamics of oil field fluids and solids, including gas hydrates, waxes, and asphaltenes phase equilibria.
- 3. Be able to apply phase equilibrium models to predict the phase equilibria behavior of complex fluids, as well as gas solubility in water/oil systems.
- 4. Be able to apply multiphase flow transport models to predict pressure drop and slurry viscosity in oil and gas flowlines.
- 5. Demonstrate an understanding of the macroscopic, mesoscopic, and microscopic tools that can be applied to study oil field processing methods, including the control of hydrates, waxes, asphaltenes, scale.
- 6. Demonstrate an understanding of the appropriate chemical treatments and compatibility of the treatment processes for flow assurance.
- 7. Demonstrate an understanding of the key physical chemistry concepts of flow assurance.
- 8. Demonstrate an understanding of the key concepts of industrial gas transportation and storage.

CBEN524. COMPUTER-AIDED PROCESS SIMULATION. 3.0 Semester Hrs.

Advanced concepts in computer-aided process simulation are covered. Topics include optimization, heat exchanger networks, data regression analysis, and separations systems. Use of industry-standard process simulation software (Aspen Plus) is stressed. 3 hours lecture; 3 semester hours. Prerequisite: none.

CBEN530. TRANSPORT PHENOMENA. 3.0 Semester Hrs.

This course covers theory and applications of momentum, energy, and mass transfer based on microscopic control volumes. Analytical and numerical solution methods are employed in this course. Students registered for the 500-level version of this course will complete an additional project using finite element analysis software and present an oral or written report. Prerequisite: MATH225 or equivalent.

Course Learning Outcomes

- 1. Write Newton’s law of viscosity, Fourier’s law of heat conduction, and Fick’s law of diffusion. Define flux, gradient, averages, and velocity averages (i.e., bulk quantities).
- 2. Derive microscopic shell balances for the conservation of mass, momentum, energy, and chemical species, including energy sources and chemical reaction. Describe the similarities between conservation equations for momentum, energy and chemical species.
- 3. Apply the generalized equations of change for mass, energy and momentum transport in rectangular, cylindrical and spherical coordinates to describe transport problems.
- 4. Derive boundary conditions for physical problems involving transport of momentum, energy or chemical species. Distinguish between processes that occur at the interface and those that occur within the bulk fluid or material.
- 5. Choose and justify simplifying assumptions to facilitate the solution of a problem describing a physical process. State restrictions that will apply to the solution due to simplifying assumptions.
- 6. Solve limited cases of mass, momentum or energy transport, including unsteady-state and two-dimensional problems that require solutions by ordinary differential equations, separation of variables, and similarity transforms.
- 7. Describe boundary layer development in flow past a flat plate for transport of momentum, and heat or chemical species.
- 8. Define mass average and molar average velocities.
- 9. Describe moving reference frames. Interrelate various forms of Fick’s law based on mass average velocity, molar average velocity and stationary reference frames.
- 10. Describe and use analogies between momentum, heat and mass transport to obtain values for friction factors, heat transfer coefficients and mass transfer coefficients.
- 11. Define common dimensionless groups arising in transport problems (Reynolds, Prandtl, Schmidt, Sherwood, and Nusselt numbers) and relate analogous groups.
- 12. Demonstrate the ability to simulate coupled momentum, heat, and mass transfer phenomena in a technologically relevant problem using a finite element analysis solver. Further, demonstrate the ability to analyze the data and present in a written or oral report.

CBEN531. IMMUNOLOGY FOR SCIENTISTS AND ENGINEERS. 3.0 Semester Hrs.

(II) This course introduces the basic concepts of immunology and their applications in engineering and science. We will discuss the molecular, biochemical and cellular aspects of the immune system including structure and function of the innate and acquired immune systems. Building on this, we will discuss the immune response to infectious agents and the material science of introduced implants and materials such as heart valves, artificial joints, organ transplants and lenses. We will also discuss the role of the immune system in cancer, allergies, immune deficiencies, vaccination and other applications such as immunoassay and flow cytometry. Prerequisites: Biology BIOL110 or equivalent or graduate standing.

CBEN532. TRANSPORT PHENOMENA IN BIOLOGICAL SYSTEMS. 3.0 Semester Hrs.

The goal of this course is to develop and analyze models of biological transport and reaction processes. We will apply the principles of mass, momentum, and energy conservation to describe mechanisms of physiology and pathology. We will explore the applications of transport phenomena in the design of drug delivery systems, engineered tissues, and biomedical diagnostics with an emphasis on the barriers to molecular transport in cardiovascular disease and cancer.

Course Learning Outcomes

- 1. Explain the barriers of momentum and mass transfer at the organism, organ, and cellular length scales.
- 2. Explain and interpret the primary literature on biotransport phenomena.
- 3. Apply the conservation of momentum equation and constitutive relationships to biologically relevant flows on different length scales and in different media.
- 4. Apply the conservation of species equation and constitutive relationships to biologically relevant mass transfer phenomena on different length scales and in different media.
- 5. Predict the relative importance of different forces and rate processes (diffusion, convection, and reaction) using dimensional analysis.
- 6. Use the Generate Ideas Method to formulate models of physiologic and pathologic processes.
- 7. Use the Generate Ideas Method to design therapeutic and diagnostic strategies.

CBEN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.

Equivalent with MLGN535,PHGN435,PHGN535,

Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. 1 hour lecture, 4 hours lab; 3 semester hours.

CBEN550. MEMBRANE SEPARATION TECHNOLOGY. 3.0 Semester Hrs.

This course is an introduction to the fabrication, characterization, and application of synthetic membranes for gas and liquid separations. Industrial membrane processes such as reverse osmosis, filtration, pervaporation, and gas separations will be covered as well as new applications from the research literature. The course will include lecture, experimental, and computational (molecular simulation) laboratory components. Prerequisites: CBEN375, CBEN430. 3 hours lecture; 3 semester hours.

CBEN554. APPLIED BIOINFORMATICS. 3.0 Semester Hrs.

(II) In this course we will discuss the concepts and tools of bioinformatics. The molecular biology of genomics and proteomics will be presented and the techniques for collecting, storing, retrieving and processing such data will be discussed. Topics include analyzing DNA, RNA and protein sequences, gene recognition, gene expression, protein structure prediction, modeling evolution, utilizing BLAST and other online tools for the exploration of genome, proteome and other available databases. In parallel, there will be an introduction to the PERL programming language. Practical applications to biological research and disease will be presented and students given opportunities to use the tools discussed. General Biology BIOL110 or Graduate standing.

CBEN555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM. 1.0 Semester Hr.

Equivalent with CHGN555,MLGN555,

The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: none. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

CBEN568. INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING. 3.0 Semester Hrs.

(I) Students will be expected to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature, and interact effectively with students in classroom. Skills to be developed and discussed include oral presentations, technical writing, proposal writing, principles of hypothesis driven research, critical review of the literature, research ethics, research documentation (the laboratory notebook), research funding, types of research, pedagogical methods, and assessment tools. Prerequisites: graduate student in Chemical and Biological Engineering in good standing. 3 semester hours.

Course Learning Outcomes

- Students will be able to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature, and interact effectively with students in classroom

CBEN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.

Equivalent with MEGN569,MLGN569,MTGN569,

(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials- science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

CBEN570. INTRODUCTION TO MICROFLUIDICS. 3.0 Semester Hrs.

This course introduces the basic principles and applications of microfluidics systems. Concepts related to microscale fluid mechanics, transport, physics, and biology are presented. To gain familiarity with small-scale systems, students are provided with the opportunity to design, fabricate, and test a simple microfluidic device. Students will critically analyze the literature in this emerging field. Prerequisites: CBEN307 or equivalent. 3 hours lecture, 3 semester hours.

CBEN580. NATURAL GAS HYDRATES. 3.0 Semester Hrs.

The purpose of this class is to learn about clathrate hydrates, using two of the instructor's books, (1) Clathrate Hydrates of Natural Gases, Third Edition (2008) co authored by C.A.Koh, and (2) Hydrate Engineering, (2000). Using a basis of these books, and accompanying programs, we have abundant resources to act as professionals who are always learning. 3 hours lecture; 3 semester hours.

CBEN584. FUNDAMENTALS OF CATALYSIS. 3.0 Semester Hrs.
The basic principles involved in the preparation, charac terization, testing and theory of heterogeneous and homo geneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN598. SPECIAL TOPICS. 0-6 Semester Hr.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

CBEN598. SPECIAL TOPICS. 0-6 Semester Hr.

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CBEN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: "Independent Study" form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

CBEN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.

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CBEN604. TOPICAL RESEARCH SEMINARS. 1.0 Semester Hr.
Lectures, reports, and discussions on current research in chemical engineering, usually related to the student's thesis topic. Sections are operated independently and are directed toward different research topics. Course may be repeated for credit. Prerequisite: none. 1 hour lecture-discussion; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

CBEN605. COLLOQUIUM. 1.0 Semester Hr.
Students will attend a series of lectures by speakers from industry, academia, and government. Primary emphasis will be on current research in chemical engineering and related disciplines, with secondary emphasis on ethical, philosophical, and career-related issues of importance to the chemical engineering profession. Prerequisite: Graduate status.

CBEN608. ADVANCED TOPICS IN FLUID MECHANICS. 1-3 Semester Hr.
Indepth analysis of selected topics in fluid mechanics with special emphasis on chemical engineering applications. Prerequisite: CBEN508. 1 to 3 hours lecture discussion; 1 to 3 semester hours.

CBEN609. ADVANCED TOPICS IN THERMODYNAMICS. 1-3 Semester Hr.
Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: none. 1 to 3 semester hours.

CBEN610. APPLIED STATISTICAL THERMODYNAMICS. 3.0 Semester Hrs.
Principles of relating behavior to microscopic properties. Topics include element of probability, ensemble theory, application to gases and solids, distribution theories of fluids, and transport properties. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN617. GRADUATE TRANSPORT PHENOMENA II. 3.0 Semester Hrs.
(II) Analysis of momentum, heat, and mass transfer problems using advanced analytical and numerical methods with an emphasis on coupled transport problems and irregular geometries. Advanced analytical techniques may include regular and singular perturbation analysis, eigenvalue problems, finite Fourier transforms, and Laplace transforms. Numerical methods for solving differential equations include finite differences, finite elements, Monte Carlo methods, and computational fluid dynamics. Prerequisite: CBEN516. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- Be able to solve transport problems analytically using regular and singular perturbation analysis, eigenvalue methods, finite Fourier transforms, and Laplace transforms.
- Be able to solve transport problems numerically using finite differences, finite elements, Monte Carlo methods, and commercial software

CBEN620. ENGINEERING OF SOFT MATTER. 3.0 Semester Hrs.
(II) Soft matter is a field of inquiry involving physical systems having low moduli and which are structured on length scales ranging from about 10 nanometers up to 100 microns. This graduate level class provides a survey of relevant material systems including polymers, colloids, surfactants, liquid crystals, and biological materials. The course emphasis is on the chemical physics of soft materials and therefore requires a high level of mathematical sophistication; students should have the equivalent of one semester of graduate level applied mathematics as a prerequisite. A term paper in the form of a short publishable review of a relevant topic is a major component of the class. Prerequisites: the equivalent of one semester of graduate level applied mathematics. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- Be able to solve problems involving elastic materials including polymers, rubbers, and hydrogels through the calculation of molecular dimensions, moduli, swelling ratios, and other relevant quantities.
- Complete a publishable review article in on a topic in soft matter physics.
- Be capable of qualitatively describing different liquid crystalline phases and their technical applications. Perform calculations of free energies and other relevant thermodynamic quantities in order to predict the phase behavior of liquid crystals as a function of concentration, temperature, and pressure

CBEN624. APPLIED STATISTICAL MECHANICS. 3.0 Semester Hrs.
This course will introduce the both rigorous and approximate theories to estimate the macroscopic thermodynamic properties of systems based on laws that control the behavior of molecules. Course contents include classical dynamics and phase space, different types of ensembles, ideal and interacting gases, modern theory of liquids, ideal solids, as well

as molecular simulation techniques. Prerequisite: Undergraduate-level classical thermodynamics.
Course Learning Outcomes

- be able to calculate macroscopic theromodynamic properties based on both rigorous and approxiamte microscopic models

CBEN625. MOLECULAR SIMULATION. 3.0 Semester Hrs.
Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. The quantum mechanical and statistical foundation of thermodynamics and kinetics will be discussed. In-depth discussion of Quantum Mechanics, Molecular Dynamics, and Monte Carlo simulation techniques will follow. Modern molecular interaction models, extended ensemble approaches, hybrid multiscale techniques, and mathematical algorithms used in molecular simulations will be included. Prerequisites: CBEN509, CBEN610.

CBEN630. PROPOSAL PREPARATION. 1.0 Semester Hr.
(I) This course is designed to guide students through the steps in writing a proposal. The Proposal writing process is divided into logical steps each of which when completed will lead to the graduate student having a draft proposal that could be successfully defended. Topics include: how to conduct a literature search and maintain an up to date database of relevant sources; Writing of a literature review in the context of a proposal; how to write a testable scientific hypothesis; the format and writing of a scientific paper; how best to present data and errors; an understanding of ethics and plagiarism issues; writing of a work plan with tasks related to objectives and time budget, Gantt charts; creation of a project budget; presentation techniques and oral defense of the proposal.

1 hour lecture; 1 semester. hour. Repeatable.
Course Learning Outcomes

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CBEN690. SUPERVISED TEACHING OF CHEMICAL ENGINEERING. 3.0 Semester Hrs.
(I) Individual participation in teaching, outreach, and/or pedagogical research activities. Discussion, problem review and development, guidance of laboratory experiments, course development, supervised practice teaching. 6 to 10 hours supervised teaching; 3 semester hours. Prerequisite: Good academic standing, CBEN 507, CBEN 509, CBEN 516, CBEN 518.
Course Learning Outcomes

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CBEN698. SPECIAL TOPICS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.
Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles. Prerequisite: none.

CBEN698. SPECIAL TOPICS. 0-6 Semester Hr.

CBEN698. SPECIAL TOPICS. 0-6 Semester Hr.

CBEN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: “Independent Study” form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

CBEN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.

CBEN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

Professors

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Timothy A. Barbari

Anuj Chauhan

Andrew M. Herring

Carolyn A. Koh, William K. Coors Distinguished Chair of Chemical and Biological Engineering

David W.M. Marr, Gaylord & Phyllis Weaver Distinguished Professor, Chemical and Biological Engineering

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