Chemical and Biological Engineering Program

Aims and Scope of the Graduate Program

The Chemical and Biological Engineering Program (CBE) offers its students opportunities to develop real-world solutions to global challenges by leveraging basic discoveries in chemical and biological sciences. These include the development of new processes for gas and liquid separations, water desalination, as well as the development of new materials for reducing greenhouse gases and remediating chemical and biological threats.

Students in CBE may choose between two tracks: (1) Advanced Chemical Engineering and (2) Advanced Biological Engineering.

Master's Degree

CBE offers students two options to earn a Master's Degree: a thesis option and a non-thesis option. Both options require that students complete a minimum of 36 credits in three semesters plus one summer session. Of these 36 credits, 24 credits are earned from coursework, including four core courses and four elective courses. The remaining 12 credits may be earned from directed research, summer internship, and additional broadening experience courses.

1. Core Curriculum: (12 credits)
    - Advanced Chemical Engineering Track: Applied Engineering Thermodynamics (CBE 201), Transport Phenomena (CBE 202), Reaction Engineering (CBE 203), Membrane Science and Membrane Separation Processes (CBE 336)
    - Advanced Biological Engineering Track: Biophysics (CBE 221), Bioprocess fundamentals (CBE 222), Fundamentals of Cell Biology (CBE 224), Membrane Science and Membrane Separation Processes (CBE 336)
2. Elective Curriculum: (12 credits)
   Four additional courses are to be selected with the approval of the student's advisor.

CBE offers the following elective courses. The description of each course is shown in the appendix.

CBE 206, CBE 207, CBE 208, CBE 209, CBE 210, CBE 213, CBE 215, CBE 219, CBE 225, CBE 230, CBE 239, CBE 240, CBE 301, CBE 304, CBE 317, CBE 326

Seminar

Registration in the CBE graduate seminar (CBE 298) is required during each semester of enrollment. Students do not earn program credit for the graduate seminar, but attendance in at least 80% of the seminars is required.

Thesis Option

A minimum of 6 credits of thesis research (CBE 297) is required although it is expected that a student will enroll in 12 credits of M.S. thesis work. With permission of the M.S. thesis advisor, a student who enrolls in only 6 credits of thesis research may use one of the following options to earn the six remaining credits of degree requirements:

- **Internship:** 6 credits of research-based summer internship (administered as directed research, CBE 299)
- **Non-Technical Broadening Experience Courses:** 3 to 6 credits of courses that broaden a student's M.S. experience.
- **Ph.D.-Level Courses:** 6 credits of CBE courses numbered 300 or greater. Any course in the PhD core requirements that is passed with a minimum grade of B– may be used towards meeting the core PhD requirements of the CBE program if the student chooses to continue for a PhD degree in CBE at KAUST.

Students are permitted to register for more than 12 credits of M.S. thesis research as necessary and with the permission of the thesis advisor.

Evaluation of satisfactory completion of M.S. thesis work is performed by a committee comprising the M.S. thesis advisor and two other faculty members. The chair of the committee must be a faculty member within the CBE program. The evaluation of M.S. thesis credits is through a pass or a fail grade. The requirement of a public CBE seminar based on the student's work is left to the discretion of the MS thesis advisor. For additional details on thesis requirements and committee formation, see General Degree Program Guidelines.

The student is responsible for scheduling the thesis defense date with his/her supervisor and committee members. It is advisable that the student submits a written copy of the thesis to the thesis committee members at least two weeks prior the defense date.

Non-Thesis Option

Research requirement: A minimum of 6 credits of directed research credits (CBE 299) is required. Summer internship credits may be used to fulfil the research requirement provided that the summer internship is research-based. Summer internships are subject to approval by the student's academic advisor.

Students must complete the remaining credits through one or a combination of the options listed below:

- **Two Courses:** Any two 3-credit courses in any program at KAUST.
- **Non-technical Broadening Experience Courses:** 6 credits of courses that broaden a student's M.S. experience.
- **Ph.D.-Level Courses:** 6 credits of CBE courses numbered 300 or greater. Any course in the PhD core requirements that is passed with a minimum

grade of B– may be used towards meeting the core PhD requirements of the CBE program if the student chooses to continue for a PhD degree in CBE at KAUST.
- **Internship:** 6 credits of research-based summer internship (administered as directed research, CBE 299)

It should be noted that a student may also mix and match courses to satisfy the six-credit requirement. For example, a student could take one Ph.D.-level course and one graduate-level course in another program. A student may not enroll in two summer internships.

Degree of Doctor of Philosophy

Students holding B.S. degrees, M.S. degrees from universities other than KAUST, and students enrolled in the M.S. program at KAUST may be considered for admission to the Ph.D. program in CBE.

Coursework Requirements
For students with an M.S. or equivalent degree, a minimum of 6 credits of coursework on the 300-level is required. If the M.S. degree is in a field other than CBE, there may be additional courses required. Such courses will be identified by the research advisor. Students who enter with a B.S. degree must complete 24 credits, equivalent to the M.S. degree coursework, in addition to the 6 credits of coursework at the 300-level. Courses should be selected after consultation with the research advisor and should be relevant to the student's dissertation topic or general area of the proposed research.

In addition to the required coursework, 60 credits of dissertation research (CBE 397) are required. A full-time workload for PhD students is considered to be 12 credits per semester (courses and CBE 397) and 6 credits during the summer (CBE 397). There is a minimum residency requirement (enrollment period at KAUST) of 2.5 years for students entering with a M.S. degree and 3.5 years for those entering with a B.S. degree.

Designation of a Research Advisor
Students in the PhD degree program in CBE must identify and select a KAUST faculty member as their research advisor within 6 months after first enrollment in the Ph.D. program. If the research advisor is not a CBE faculty member, it is recommended that the student select a co-supervisor from CBE.

Comprehensive Examination
There is no comprehensive written examination required in CBE.

Research Proposal Defense Upon successful completion of all coursework and designation of a research advisor, students must take and pass a research proposal examination. The research proposal examination must be taken within 18 months of the first enrollment in the program if the student enters the program with an M.S. degree and within 24 months if the student enters the program with a B.S. degree.

The research proposal examination is an oral exam administered by the student's research proposal examination committee. This committee includes the research advisor(s) and at least three other KAUST faculty members, one of whom must be external to the CBE program. The proposal examination will begin with a 30- to 45-minute presentation by the student on the student's proposed research topic, followed by a 15- to 30-minute question and answer session to answer any questions that might be raised from the committee.

The result of the exam will be made based on the recommendation of the examination committee. There are four possible results: (1) Pass: the student passes the exam and may proceed to independent study and research for the doctoral dissertation; (2) Conditional pass: the student may be required to provide additional information about the proposal. If the student provides satisfactory addition information, the exam is then passed without sitting another oral exam; (3) Failure with retake: the student must prepare a new research proposal and be orally examined again within six weeks from the date of the first exam; (4) Failure: the student is deemed unqualified to pursue further Ph.D. studies and must leave the program.

Dissertation Defense
The dissertation examination committee consists of a minimum of four members, one of whom should be a KAUST faculty member external to the CBE degree program. A committee member who is external to KAUST (holding a faculty position or equivalent position at another institution) can be included with the approval of the faculty research advisor and division Dean. Passing the dissertation examination is achieved by acceptance of a written dissertation and a public oral defense of the dissertation. The oral defense will begin with a 45-minute presentation followed by a 10- to 15-minute open question and answer session for the student to answer any questions that may arise from the audience, followed by another 15- to 30-minute closed question session during which the student should clarify or defend any questions related to the dissertation or other academic related matters raised by the committee.

The result of the defense will be made based on the recommendation of the committee. There are four possible results: (1) Pass: the student passes the exam and the dissertation is accepted as submitted; (2) Pass with revisions: the student passes the exam and the student is advised of the revisions that must be made to the text of the dissertation; (3) Failure with retake: normally this means the student must do more research to complete the dissertation. The student must revise the dissertation and give another oral examination within six months from the date of the first defense; and (4) Failure: the student does not pass the exam, the dissertation is not accepted, and the degree is not awarded.

Appendix: Chemical and Biological Engineering Course Descriptions

CBE 201: Applied Engineering Thermodynamics (3-0-3)
The main objective of this course is the application of thermodynamics and molecular theory in chemical engineering. Topics include thermodynamics of phase equilibria, Gibbs phase rule, solutions of non-electrolytes and strong electrolytes (activity and osmotic coefficients), entropy and information. Part of the course will deal with applications, such as systems for power production, heating and cooling and pumps and compressors.
Prerequisites: An undergraduate thermodynamics course

CBE 202: Advanced Transport Phenomena (3-0-3)
The aim of this course is to enable students to i) derive appropriate differential balances for specific material properties, including momentum, thermal energy, and mass species, accounting appropriately for property flux by convective and diffusive (molecular-scale) processes, along with property generation or loss in the material continua; ii) write the Thermal Energy Equation, the Species Continuity Equation, and the Navier-Stokes Equations and pose (simplify) them appropriately for specific transport problems; iii) know appropriate boundary conditions that can be applied to specific transport problems; iv) conduct scale or dimensional analyses of transport problems, using the analyses to help simplify or enhance understanding of underlying transport processes; v) solve and physically interpret one-dimensional steady-state conduction and species diffusion problems in rectangular, cylindrical, and spherical geometries, with and without zero-order and first-order generation/loss; vi) use the separation of variables technique to solve and physically interpret two-dimensional steady-state conduction and species diffusion problems; vii) use similarity methods to solve and physically interpret unsteady state conduction and diffusion problems in unbounded material regions; viii) use the finite Fourier transform method to solve and interpret unsteady state conduction and diffusion problems in bounded material regions; ix) solve and physically interpret unidirectional steady and unsteady viscous flows in unbounded regions and in bounded regions (i.e. flow conduits or ducts); and x) solve and physically interpret simultaneous convection and diffusion (conduction) problems involving the interaction of thermal or concentration boundary layers with developing or developed velocity profiles.
Prerequisites: Basic knowledge of fluid mechanics, heat & mass transfer, vector analysis, and differential equations.

CBE 203: Advanced Reaction Engineering (3-0-3)
The objective of this course is to impart and to continue the rigorous study of reaction engineering. In this course, particular emphasis will be given to chemical kinetics and transport phenomena, review of elements of reaction kinetics, rate processes in heterogeneous reacting systems, design of fluid-fluid and fluid-solid reactors, scale-up and stability of chemical reactors and residence time analysis of heterogeneous chemical reactors

Prerequisite: An undergraduate reaction engineering course or consent of instructor

CBE 206: Synthetic Biology and Biotechnology (2-1-3)
Introduction to genetic circuits in natural systems; engineering principles in biology; BioBricks and standardization of biological components; numerical methods for systems analysis and design; fabrication of genetic systems in theory and practice; transformation and characterization; examples of engineered systems; hands-on experiments.
Prerequisite: A degree in biological sciences or engineering or consent of instructor.

CBE 207: Physiology and Metabolic Engineering (2-1-3)
The course will provide a growth and development explanation of plant physiology that includes physical, chemical and biochemical functions of higher seed plants (angiosperms). Topics will focus on mechanisms and processes that are fundamental for cell, tissue and organ composition, differentiation and development. How plant growth and development are regulated and modulated by genetic, chemical and environmental cues will be emphasized. Basic physical, chemical and biochemical mechanisms and processes will be presented in the context of the plant growth and development beginning with seed germination, then vegetative growth and development, and followed by reproduction (flowering and fruit maturation). Mechanisms and processes will be dissected at the molecular genetics, physical, and biochemical levels. Basic plant metabolism such as photosynthesis (primary metabolism) and secondary products (secondary metabolism), signaling and signal responses to chemical (hormonal) and environmental metabolic stimuli, water and nutrient transport and utilization and plant defense will be discussed. Distinguished experts will present lectures that translate plant physiology into agriculture and other anthropogenic uses.

CBE 208: Plant Biology (2-1-3)
Review of cellular structure function, diffusion and active transport limitations and benefits on plant cell systems. Membrane structures translocation and transport. Energy and primary metabolism, secondary metabolism in microbes and plants.
Prerequisite: A degree in biological sciences or engineering or consent of instructor.

CBE 209: Genomics (2-1-3)
Prokaryotic versus eukaryotic genome structure, conservation (gene order/sequence/structure, regulatory sequences), approaches to mapping/sequencing genomes, DNA sequencing, DNA sequencing technologies, approaches to genome annotation, SNPs, microarray technology, gene expression microarrays, antibodies, chromatin immuno-purification, high throughput perturbation studies. Problem-solving/data-handling/critical thinking/journal-club sessions. Possible interactions with Genomics Research Core facility.

Prerequisite: A degree in biological sciences or engineering or consent of instructor.

CBE 210: Materials Chemistry (3-0-3)
This course will present fundamental concepts in materials chemistry. The main topics to be covered include structure and characterization, macroscopic properties and synthesis and processing

CBE 213: Interface Science, Engineering and Technology (3-0-3)
Surface tension and surface free energy (theory and measurement methods); Surface films on liquid substrates (surface potential, monomolecular films, Langmuir-Blodgett layers); Electrical aspects of surface chemistry (electrical double layer, zeta potential, DLVO theory); Solid-liquid interface, stability of dispersions, stabilization of suspensions; Contact angle (theory and measurement methods); Emulsions, foams and aerosols; Wetting of surfaces by liquids, Lotus effect; Flotation, aggregation and flocculation; Detergency, surfactants, self-assembly, micelles and vesicles; Friction, lubrication and adhesion; Adsorption; Characterization of colloidal particles; Applications of colloid and surface science in petroleum recovery, coating and painting, food, pharmaceutical and cosmetic industry

CBE 215: Polymers and Polymerization Processes (3-0-3)
Cornerstones of polymer science: synthesis, characterization, processing and properties. Monomer synthesis, polymerization chemistry, reactors and scale-up, polymer structure (solution and solid state), morphology and “processability”.

CBE 219: Bioinorganic Chemistry (3-0-3)
This course is designed for students on the Master’s or PhD level in chemistry, biochemistry and biotechnology. The more advanced chemical and biochemical aspects and methods are all developed during the course. The course will provide students with a general overview of the many very fundamental tasks performed by inorganic elements in living organisms as well as the related methods and theories with particular emphasis on enzymatic conversions and electron transfer. Tthe elucidation of model systems and technical applications of both, concepts learned from nature as well as biological systems is also covered.
Prerequisite: A basic understanding of chemistry and inorganic chemistry as taught in any undergraduate chemistry, biochemistry, biotechnology or chemical engineering degree program.

CBE 221: Biophysics (3-0-3)
Conservation of mass and momentum, physiological mass transport, membrane structure, carrier proteins and active membrane transport, ion channels, intracellular vesicular transport, diffusion in reacting systems, heat and mass transfer in bioreactors, culture aeration. Lectures and laboratory.

CBE 222: Bioprocess Fundamentals (3-0-3)

Genetic recombination, expression systems, principles of fermentation processes, bioreactor types and operation modes, process scale-up, separation and recovery of biological products. Industrially relevant applications, such as microbial systems, mammalian systems, stem cell systems. Lectures, case studies and laboratory

CBE 224: Fundamentals of Cell Biology (3-0-3)
Types of microorganisms (e.g., viruses, microbes, yeast, mammalian and stem cells); cell physiology, structure and function; gene expression and protein synthesis; protein folding; post-translational modification; cell cycle; molecular biology techniques.

CBE 225: Materials Chemistry II
This course will introduce electron microscopy based techniques: Scanning electron microscopy (SEM), Transmission electron microscopy (TEM), Electron diffraction (ED), Scanning transmission electron microscopy (STEM), Energy-filtered TEM (EFTEM), Energy dispersive X-ray analysis (EDX), and Electron energy loss spectroscopy (EELS). On-site demonstration of the electron microscope will be given. Nanoporous materials including zeolites and mesoporous materials will be another topic of this course.

CBE 230: Physical Chemistry Of Macromolecules (3-0-3)
Conformation and configuration; Solution Thermodynamics; Phase separation (theory and experimental aspects), polymer fractionation; Mechanisms and kinetics of phase separation; Miscibility of polymer blends and compatibilization; Microphase separation and self-assembly; Rheology of polymer solutions; Viscosity of diluted and concentrated solutions, polymer gels; Rheology of polymer melts and composites, relevance for polymer processing; Amorphous state, glass-rubber transition, plasticizers; Elasticity and Viscoelasticity; Thermal analysis, dynamic mechanical analysis; Crystalline state, liquid-crystalline state; Mechanical properties.

CBE 239: Stem Cells (3-0-3)
This course covers stem cell biology and therapeutics. It is intended to provide a comprehensive overview of current understanding of embryonic and adult stem cells, including their basic properties and interactions within organisms. Stem cell isolation methods, experimental models and potential biomedical therapeutic applications will be encountered through research of literature. This course requires a basic background in biology.

CBE 240: Genomics II (3-0-3)
This course provides an introduction to the field of genomics. It covers genome sequencing techniques (shotgun, massive parallel sequencing etc.), genome assembly and annotation (gene finding, conserved protein domain, promoter identification and TFBS analysis). It also includes an introduction to using

comparative genomics, computational genomics, and population genomics to solve biological problems of interest.

CBE 297: Master's Thesis Research (1 ~ 12 credits)

CBE 298: Graduate Seminar
Master's-level seminar focuses on special topics in the field.

CBE 299: Directed Research (3 credit)
Master's-level supervised research. Formulating and solution of problems in process synthesis, design and operations using advanced optimization methods. Mathematical modeling via mixed integer and continuous optimization formulations, principles of continuous optimization, principles of modeling with integer variables, principles of mixed-integer linear and nonlinear optimization, principles of optimization under uncertainty, applications to interactions of design and control and model-based control.

CBE 304: Advanced Topics in Sequencing Technology (3-0-3)
Next-generation sequencing technology has emerged as a major transformative tool in the genomics field. This course consists of advanced topics, focusing on detailed description of sequencing technologies and several sequencers (for example, 454, SOLiD, Solexa), sequencing motivation and fundamental concepts, practical work in analysis of data, data quality control (how to determine if a run has performed well), alignment to a reference, de-novo assembly, data management, storage and sharing, and applications of sequencing technology to cancer genomics, human variation analysis, etc.

B301/CBE301: Computational Biology
Computational Biology is an advanced and practical course, taking a hands-on approach to the field of computational biology. The course is recommended for both molecular biologists and computer scientists desiring to understand the major issues concerning analysis of genomes, sequences and learn large-scale modeling of complex systems. Various existing methods will be critically described and the strengths and limitations of each will be discussed. There will be practical assignments utilizing the tools described. A final paper will be required for the course that critically and constructively analyzes any area of computational molecular biology, bioinformatics or genomics. The final project may also present a novel application of existing tools or the development of some new or improved method
Prerequisites: Genomics I (B204/CBE209) and Genomics II (B204).

CBE 317: Clean Fossil Fuels and Biofuels (3-0-3)
The different types of biofuels will be presented and discussed in this course. Topics include biomass feedstocks, first-, second- and third-generation biofuels, fuel from cellulose, catalytic conversion of biomass to liquid, energy balance of biofuels, biological production of hydrogen, biodiesel, microbial fuel cells. The

Clean Fossil Fuel part of this course deals with gasification processes including ICCG power plants, Fischer Tropsch synthesis, clean coal technologies, desulfurization and carbon dioxide capture and storage.
Prerequisites: Undergraduate chemical engineering and chemistry courses

CBE 326: Biocatalysis (3-0-3)
Application of Biocatalysis has a long tradition. Starting from basic food-processing fermentation, e.g., related to bread baking or cheese making, today the results emerging from this discipline influence all areas of modern daily life. Developments in pharmacy, medicine, nutrition, analytics, environmental technology, fine chemical synthesis and others are based on the progress in Biocatalysis research. Enzymes as nature's catalysts set the benchmarks for artificial systems in terms of activity and selectivity. Correspondingly, Biocatalysis has evolved into one of the pillars of biotechnology and chemical industry. This course aims to provide an understanding of fundamental aspects of biocatalysis, while the general focus is set on current applications of biocatalytic systems. It targets students enrolled in chemical sciences, chemical engineering and biological engineering.

CBE 336: Membrane Science and Membrane Separation Processes (3-0-3)
Formulation and solution of engineering problems involving design of membrane systems for gas separation, reverse osmosis, filtration, dialysis, pervaporation and gas absorption/stripping processes. Membrane selection, fabrication and preparation. Membrane transport: gas permeation and reverse osmosis. Polarization and fouling, membrane module design. Lectures and laboratory.

CBE 397: Dissertation Research (1~12 credits)

CBE 398: Graduate Seminar
Doctoral-level seminar focuses on special topics within the field.

CBE 399: Directed Research (3 credits)
Doctoral-level supervised research.