

# CHEMICAL ENGINEERING

**Director of undergraduate studies:** Michael Loewenberg, 303 ML, 432-4334, michael.loewenberg@yale.edu; seas.yale.edu/departments/chemical-and-environmental-engineering

Energy, the environment, and health care are key challenges facing humanity in the twenty-first century. Chemical engineering is a discipline well placed to confront these challenges. Chemical engineering is rooted in the basic sciences of mathematics, chemistry, physics, and biology; a traditional engineering science core of thermodynamics, transport phenomena, and chemical kinetics; a rigorous design component; and an expanding focus on emerging topics in materials, nanotechnology, and life sciences. The discipline has grown from its petrochemical origins to become central to state-of-the-art technologies in microelectronics, alternative energy, biomedicine, and pharmaceuticals.

The Chemical Engineering program is principally focused on basic and engineering sciences and on problem solving. Additional emphasis is on communication, analysis of experiments, and chemical process design. A special feature of the program is the accessibility of laboratory research – most Chemical Engineering majors participate in faculty-led research projects, often resulting in publication and/or presentation at national meetings.

Chemical Engineering graduates find a wide range of professional opportunities in academia, industry, government, business, and the nonprofit sector. Many majors go on to graduate programs in chemical, biomedical, or environmental engineering, or to medical, law, or business schools.

The educational objectives of the Chemical Engineering program are the following. Graduating students will achieve positions of leadership within academia, industry, and government; excel in top graduate programs in chemical, biomedical, environmental, and related engineering fields; excel in top professional schools in fields such as law, medicine, or management; join and rise in the ranks of large and small corporations; become successful entrepreneurs; practice engineering toward the benefit of humankind.

## PREREQUISITES

Students considering a Chemical Engineering major are encouraged to take two terms of chemistry and mathematics during the first year, and to contact the DUS.

Students in both degree programs (see below) take the following prerequisite courses: MATH 112, 115, and ENAS 151 or MATH 120; CHEM 161 and 165, or CHEM 163 and 167; CHEM 134L and 136L; ENAS 130; PHYS 180, 181. Students with advanced high school preparation may reduce the number of prerequisites by placing out of certain courses.

## REQUIREMENTS OF THE MAJOR

**The major for the Class of 2019** With DUS approval, the following changes to the requirements of the major may be fulfilled by students who declared their major under previous requirements.

**The major for the Class of 2020 and subsequent classes** All students majoring in Chemical Engineering and Engineering Sciences (Chemical) must follow the requirements listed below as approved by the program's faculty. Two degree programs are offered: a B.S. in Chemical Engineering accredited by the Engineering Accreditation Commission of ABET, Inc., and a B.S. in Engineering Sciences (Chemical).

**B.S. degree program in Chemical Engineering** The curriculum for the ABET-accredited B.S. degree in Chemical Engineering requires eighteen term courses, including the senior requirement, CENG 416, and the following courses beyond the prerequisites:

1. Mathematics: ENAS 194
2. Chemistry: CHEM 174 and 175 or CHEM 220 and 221; CHEM 222L and 223L; CHEM 332 and 333
3. Engineering science: MENG 361 and three term courses chosen from engineering electives
4. Chemical engineering: CENG 150 or CENG 210; 300, 301, 315, 411, 412L, 480

**B.S. degree program in Engineering Sciences (Chemical)** The B.S. degree in Engineering Sciences (Chemical) requires eleven term courses, including the senior requirement, CENG 416, and the following courses beyond the prerequisites, chosen in consultation with the DUS:

1. Mathematics: ENAS 194
2. Chemistry: 3 advanced chemistry courses: *option 1*: CHEM 174 and 175 or CHEM 220 and 221; and CHEM 332; or *option 2*: CHEM 174 or 220; CHEM 332 and 333
3. Engineering science: MENG 361
4. Chemical engineering: CENG 150 or CENG 210; 300, 301, 315, 411

## SENIOR REQUIREMENT

**B.S. degree program in Chemical Engineering** In their senior year students must complete a senior research project in CENG 416.

**B.S. degree program in Engineering Sciences (Chemical)** In their senior year students must complete a senior research project in CENG 416.

## REQUIREMENTS OF THE MAJOR

### CHEMICAL ENGINEERING, B.S.

**Prerequisites** MATH 112, 115, ENAS 151 or MATH 120; CHEM 161 and 165, or CHEM 163 and 167; CHEM 134L and 136L; PHYS 180, 181; ENAS 130

**Number of courses** 18 term courses beyond prereqs (incl senior req)

**Specific courses required** ENAS 194 or equivalent; CHEM 174 and 175 or CHEM 220 and 221; CHEM 222L and 223L; CHEM 332, 333; MENG 361; CENG 150 or CENG 210; 300, 301, 315, 411, 412L, 480

**Distribution of courses** 3 addtl electives in engineering

**Senior requirement** CENG 416

### ENGINEERING SCIENCES (CHEMICAL), B.S.

**Prerequisites** MATH 112, 115, ENAS 151 or MATH 120; CHEM 161 and 165 or CHEM 163 and 167; CHEM 134L and 136L; PHYS 180, 181; ENAS 130

**Number of courses** 11 term courses beyond prereqs (incl senior req)

**Specific courses required** ENAS 194 or equivalent; 3 adv chem courses, as specified; MENG 361; CENG 150 or CENG 210; 300, 301, 315, 411

**Senior requirement** CENG 416

## FACULTY OF THE DEPARTMENT OF CHEMICAL AND ENVIRONMENTAL ENGINEERING

**Professors** Eric Altman, †Paul Anastas, †Michelle Bell, †Ruth Blake, Menachem Elimelech, Gary Haller (*Emeritus*), †Edgar Hertwich, †Edward Kaplan, Jaehong Kim, Michael Loewenberg, †Andrew Miranker, Jordan Peccia, Lisa Pfefferle, Daniel Rosner (*Emeritus*), †Mark Saltzman, †Udo Schwarz, T. Kyle Vanderlick, Paul Van Tassel, Julie Zimmerman

### Associate Professors

**Assistant Professors** Drew Gentner, Amir Haji-Akbari, †Shu Hu, Desirée Plata, Mingjiang Zhong

**Lecturers** †Anikò Bezur, †Paul Whitmore

†A joint appointment with primary affiliation in another department or school.

## Courses

\* **CENG 120b / ENAS 120b / ENVE 120b, Introduction to Environmental Engineering** Jordan Peccia

Introduction to engineering principles related to the environment, with emphasis on causes of problems and technologies for abatement. Topics include air and water pollution, global climate change, hazardous chemical and emerging environmental technologies.

Prerequisites: high school calculus and chemistry or CHEM 161, 165 or CHEM 163, 167 (may be taken concurrently) or permission of instructor. QR, SC

**CENG 150b, Engineering Improv: An Introduction to Engineering Analysis** Michael Loewenberg

Mathematical modeling is not a scripted procedure. Models are constrained by physical principles, including conservation laws and experimental observations but this does not provide a closed description. There is a lot more art in mathematical modeling than is commonly acknowledged and improvisation plays a significant role. The artistic aspects are important and intellectually engaging because they often lead to a deeper understanding. This course provides a general introduction to engineering analysis and to chemical engineering principles. Material includes the derivation of governing equations from first principles and the analysis of these equations, including underlying assumptions, degrees of freedom, dimensional analysis, scaling arguments, and approximation techniques. The goal of this course is to obtain the necessary skills for improvising mathematical models for a broad range of problems that arise in engineering, science and everyday life. Students from all majors are encouraged to take this course. Prerequisite: MATH 112. QR, SC

**CENG 300a, Chemical Engineering Thermodynamics** Shu Hu

Analysis of equilibrium systems. Topics include energy conservation, entropy, heat engines, Legendre transforms, derived thermodynamic potentials and equilibrium criteria, multicomponent systems, chemical reaction and phase equilibria, systematic derivation of thermodynamic identities, criteria for thermodynamic stability, and introduction to statistical thermodynamics. Prerequisite: MATH 120 or ENAS 151 or permission of instructor. QR, SC RP

**CENG 301b, Chemical Kinetics and Chemical Reactors** Mingjiang Zhong

Physical-chemical principles and mathematical modeling of chemical reactors. Topics include homogeneous and heterogeneous reaction kinetics, catalytic reactions, systems of coupled reactions, selectivity and yield, chemical reactions with coupled mass transport, nonisothermal systems, and reactor design. Applications from problems in environmental, biomedical, and materials engineering.

Prerequisite: ENAS 194 or permission of instructor. QR, SC RP

**CENG 315b / ENVE 315b, Transport Phenomena** Amir Haji Akbari Balou

Unified treatment of momentum, energy, and chemical species transport including conservation laws, flux relations, and boundary conditions. Topics include convective and diffusive transport, transport with homogeneous and heterogeneous chemical reactions and/

or phase change, and interfacial transport phenomena. Emphasis on problem analysis and mathematical modeling, including problem formulation, scaling arguments, analytical methods, approximation techniques, and numerical solutions. Prerequisite: ENAS 194 or permission of instructor. QR, SC RP

**CENG 351b / BENG 351b, Biotransport and Kinetics** Kathryn Miller-Jensen

Creation and critical analysis of models of biological transport and reaction processes. Topics include mass and heat transport, biochemical interactions and reactions, and thermodynamics. Examples from diverse applications, including drug delivery, biomedical imaging, and tissue engineering. Prerequisites: MATH 115, ENAS 194; BIOL 101 and 102; CHEM 161, 163, or 167; BENG 249. QR

**CENG 373a / ENVE 373a, Air Pollution Control** Drew Gentner

An overview of air quality problems worldwide with a focus on emissions, chemistry, transport, and other processes that govern dynamic behavior in the atmosphere. Quantitative assessment of the determining factors of air pollution (e.g., transportation and other combustion-related sources, chemical transformations), climate change, photochemical "smog," pollutant measurement techniques, and air quality management strategies. Prerequisite: ENVE 120. QR, SC RP

\* **CENG 377a / ENVE 377a, Water Quality Control** Jaehong Kim

Study of the preparation of water for domestic and other uses and treatment of wastewater for recycling or discharge to the environment. Topics include processes for removal of organics and inorganics, regulation of dissolved oxygen, and techniques such as ion exchange, electrodialysis, reverse osmosis, activated carbon adsorption, and biological methods. Prerequisite: ENVE 120 or permission of instructor. SC RP

**CENG 411a, Separation and Purification Processes** Paul Van Tassel

Theory and design of separation processes for multicomponent and/or multiphase mixtures via equilibrium and rate phenomena. Topics include single-stage and cascaded absorption, adsorption, extraction, distillation, partial condensation, filtration, and crystallization processes. Applications to environmental engineering (air and water pollution control), biomedical-chemical engineering (artificial organs, drug purification), food processing, and semiconductor processing. Prerequisite: CENG 300 or 315 or permission of instructor. QR, SC RP

**CENG 412Lb / CENG 412, Chemical Engineering Laboratory and Design** Paul Van Tassel

An introduction to design as practiced by chemical and environmental engineers. Engineering fundamentals, laboratory experiments, and design principles are applied toward a contemporary chemical process challenge. Sustainability and economic considerations are emphasized. SC

**CENG 416b / ENVE 416b, Chemical Engineering Process Design** Eric Altman

Study of the techniques for and the design of chemical processes and plants, applying the principles of chemical engineering and economics. Emphasis on flowsheet development and equipment selection, cost estimation and economic analysis, design strategy and optimization, safety and hazards analysis, and environmental and ethical considerations. Enrollment limited to seniors majoring in Chemical Engineering or Environmental Engineering. QR, SC RP

**CENG 471a or b, Independent Research** Michael Loewenberg

Faculty-supervised individual student research and design projects. Emphasis on the integration of mathematics with basic and engineering sciences in the solution of a theoretical, experimental, and/or design problem. May be taken more than once for credit.

**CENG 480a, Chemical Engineering Process Control** Eric Altman

Transient regime modeling and simulations of chemical processes. Conventional and state-space methods of analysis and control design. Applications of modern control methods in chemical engineering. Course work includes a design project. Prerequisite: ENAS 194 or permission of instructor. QR, SC RP

\* **CENG 490a or b, Senior Research Project** Michael Loewenberg

Individual research and/or design project supervised by a faculty member in Chemical Engineering, or in a related field with permission of the director of undergraduate studies.

**RELATED COURSE THAT COUNTS TOWARD THE MAJOR**

**MENG 361a, Mechanical Engineering II: Fluid Mechanics** Alessandro Gomez

Mechanical properties of fluids, kinematics, Navier-Stokes equations, boundary conditions, hydrostatics, Euler's equations, Bernoulli's equation and applications, momentum theorems and control volume analysis, dimensional analysis and similitude, pipe flow, turbulence, concepts from boundary layer theory, elements of potential flow. Prerequisites: ENAS 194 or equivalent, and physics at least at the level of PHYS 180. QR, SC RP