The Department of Chemical and Biomolecular Engineering offers Bachelor of Science in Engineering, Master of Science, and Doctor of Philosophy degree programs. The department has twelve full-time faculty members, all of whom lead active research programs in advanced and emerging areas of chemical and biomolecular engineering.

Mission
The Department of Chemical and Biomolecular Engineering inspires learning and the pursuit of scholarly activities in chemical and biological engineering and related science and engineering disciplines. The Department offers educational programs and a research environment that enable our graduates to succeed in an evolving workplace, provides opportunities for students and faculty to advance knowledge at the highest levels of the profession, and addresses technological and personnel needs of industry, governments, and society.

Background
The profession of chemical engineering involves the analysis, design, operation and control of processes that convert matter and energy to more useful forms, encompassing processes at all scales from the molecular to the megascale. Traditionally, chemical engineers are responsible for the production of basic chemicals, plastics, and fibers. However, today's chemical engineers are also involved in food and fertilizer production, synthesis of electronic materials, waste recycling, and power generation. Chemical engineers also develop new materials (ceramic composites and electronic chips, for example) as well as biochemicals and pharmaceuticals. The breadth of training in engineering and the sciences gives chemical engineers a particularly wide spectrum of career opportunities. Chemical engineers work in the chemical and materials related industries, in government, and are accepted by graduate schools in engineering, chemistry, medicine, and law.

Research
Research in the department is sponsored by a variety of state and federal agencies, by private industry, and by foundations. Current active research topics include:

Energy
- Novel energy storage systems for transportation, grid storage applications, and portable devices
- Energy efficient extraction and processing of materials
- Fuel cells and batteries
- Novel catalysts, electrocatalysts, and plasmas for conversion of gases to fuels
- Simulation, modeling, and fundamental characterization of transport and interfacial processes in electrochemical energy storage and conversion systems

Materials
- Advanced materials for electronic and electrochemical device applications
- Novel synthesis and deposition methods and reactor designs, including electrochemical and plasma reactors
- Novel characterization of materials and in situ reactor diagnostics
- Simulation and theory of materials properties
- Surface properties and interfacial phenomena
- Materials processing and engineering at molecular through macro scales
- Novel separations processes

Biomolecular Engineering
- Biosensors
- Cell and tissue engineering
- Biocatalysis and protein engineering

Undergraduate Programs
The Bachelor of Science degree program in Chemical Engineering is accredited by the Engineering Accreditation Commission of ABET, www.abet.org.

Program Educational Objectives
The undergraduate program in chemical engineering seeks to produce graduates who will:
1. be able to excel in professional careers across a broad range of industries
2. apply the knowledge and skills acquired through the chemical engineering curriculum to positively contribute to their profession and society
3. assume positions of responsibility and/or leadership in academia, industry, government, and business
4. succeed in post-graduate and professional degree programs

Student Outcomes
In preparation for achieving the above educational objectives, the BS degree program in Chemical Engineering is designed so that students attain:
- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multidisciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
Department of Chemical and Biomolecular Engineering

- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Bachelor of Science in Engineering

Required Courses: Major in Chemical Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

Major Required Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECHE 151</td>
<td>Introduction to Chemical Engineering at Case</td>
<td></td>
</tr>
<tr>
<td>ECHE 260</td>
<td>Introduction to Chemical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 360</td>
<td>Transport Phenomena for Chemical Systems</td>
<td>4</td>
</tr>
<tr>
<td>ECHE 361</td>
<td>Separation Processes</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 362</td>
<td>Chemical Engineering Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>ECHE 363</td>
<td>Thermodynamics of Chemical Systems</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 364</td>
<td>Chemical Reaction Processes</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 365</td>
<td>Measurements Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 367</td>
<td>Process Control</td>
<td>4</td>
</tr>
<tr>
<td>ECHE 398</td>
<td>Process Analysis and Design</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 399</td>
<td>Chemical Engineering Design Project</td>
<td>3</td>
</tr>
</tbody>
</table>

Related Required Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 223</td>
<td>Introductory Organic Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>or CHEM 323</td>
<td>Organic Chemistry I</td>
<td></td>
</tr>
<tr>
<td>CHEM 290</td>
<td>Chemical Laboratory Methods for Engineers</td>
<td>3</td>
</tr>
</tbody>
</table>

or all of the following three courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 113</td>
<td>Principles of Chemistry Laboratory</td>
<td></td>
</tr>
<tr>
<td>CHEM 233</td>
<td>Introductory Organic Chemistry Laboratory I</td>
<td></td>
</tr>
<tr>
<td>CHEM 234</td>
<td>Introductory Organic Chemistry Laboratory II</td>
<td></td>
</tr>
<tr>
<td>STAT 313</td>
<td>Statistics for Experimenters</td>
<td>3</td>
</tr>
<tr>
<td>or STAT 312</td>
<td>Basic Statistics for Engineering and Science</td>
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</tbody>
</table>

Science Elective: One of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 221</td>
<td>Introduction to Modern Physics</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 224</td>
<td>Introductory Organic Chemistry II</td>
<td></td>
</tr>
<tr>
<td>or any 300 level or higher lecture-based course in Chemistry, Physics, Biology, or Biochemistry</td>
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<td></td>
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</tbody>
</table>

Materials Elective: One of the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 270</td>
<td>Introduction to Polymer Science and Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 276</td>
<td>Polymer Properties and Design</td>
<td></td>
</tr>
<tr>
<td>EMSE 276</td>
<td>Materials Properties and Design</td>
<td></td>
</tr>
<tr>
<td>BIOL 307</td>
<td>Introduction to Biochemistry From Molecules To Medical Science</td>
<td></td>
</tr>
<tr>
<td>PHYS 313</td>
<td>Thermodynamics and Statistical Mechanics</td>
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</tr>
<tr>
<td>PHYS 331</td>
<td>Introduction to Quantum Mechanics I</td>
<td></td>
</tr>
<tr>
<td>BIOL 334</td>
<td>Structural Biology</td>
<td></td>
</tr>
<tr>
<td>EMSE 343</td>
<td>Materials for Electronics and Photonics</td>
<td></td>
</tr>
<tr>
<td>EECS 321</td>
<td>Semiconductor Electronic Devices</td>
<td></td>
</tr>
</tbody>
</table>

Total Units 61-63

A single course can only satisfy one of the Science, Materials, and Physical Chemistry electives; it cannot double count to satisfy two of these electives.

Breadth Elective Sequences

A distinctive feature of the chemical engineering program is the three-course breadth elective sequence that enables a student to specialize in a technical or professional area that complements the chemical engineering core.

Breadth elective sequences that have standing departmental approval are described below. Alternatively, students may design their own breadth elective sequence, which must be approved by the department.

Biochemical Engineering (Advisor: Dr. Baskaran)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 301</td>
<td>Biotechnology Laboratory: Genes and Genetic Engineering</td>
<td>3</td>
</tr>
<tr>
<td>BIOL 343</td>
<td>Microbiology (Spring)</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 340</td>
<td>Biochemical Engineering (Spring)</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Units 9

Computing (Advisor: Dr. Lacks)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EECS 281</td>
<td>Logic Design and Computer Organization</td>
<td>4</td>
</tr>
<tr>
<td>EECS 346</td>
<td>Engineering Optimization (Spring)</td>
<td>3</td>
</tr>
</tbody>
</table>

One additional EECS course at 200 level or above 3-4

Total Units 10-11

Electrochemical Engineering (Advisor: Dr. Landau)

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECHE 381</td>
<td>Electrochemical Engineering (Spring)</td>
<td>3</td>
</tr>
<tr>
<td>ECHE 383</td>
<td>Chemical Engineering Applied to Microfabrication and Devices (Fall)</td>
<td>3</td>
</tr>
</tbody>
</table>

One additional course selected from:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMSE 343</td>
<td>Materials for Electronics and Photonics</td>
<td></td>
</tr>
</tbody>
</table>
EECS 309  Electromagnetic Fields I (Fall)
EECS 321  Semiconductor Electronic Devices (Spring)
ECHE 481  Corrosion Fundamentals

Total Units: 9

Electronic Materials (Advisor: Dr. Liu)
ECHE 383  Chemical Engineering Applied to Microfabrication and Devices (Fall) 3

Total Units: 3

EECS 309  Electromagnetic Fields I (Fall) 3

One additional course selected from:
EMSE 343  Materials for Electronics and Photonics
EECS 321  Semiconductor Electronic Devices (Spring)

Total Units: 3

Total Units: 9

Energy (Advisor: Dr. Savinell)
ECHE 381  Electrochemical Engineering (Fall) 3

Two additional courses selected from approved energy course in Engineering, Physics, Chemistry, Management, or Law: 6-7

Total Units: 9

Environmental Engineering (Advisor: Dr. Feke)
ECIV 368  Environmental Engineering (Spring) 3

Two additional courses selected from:
ECIV 351  Engineering Hydraulics and Hydrology
ECIV 361  Water Resources Engineering (Fall)
ECIV 362  Solid and Hazardous Waste Management (Spring)
ESTD 398  Seminar in Environmental Studies (Fall)
EEPS 220  Environmental Geology
EEPS 303  Environmental Law
EEPS 321  Hydrogeology
EECS 342  Introduction to Global Issues (Fall)

Total Units: 9

Management/Entrepreneurship (Advisor: Dr. Savinell)
ACCT 203  Survey of Accounting 3

Two additional courses selected from:
BAFI 355  Corporate Finance (Fall)
or BAFI 341  Money and Banking
BLAW 331  Legal Environment of Management
ENTP 301  Entrepreneurial Strategy
or ENTP 311  Entrepreneurship and Wealth Creation
OPRE 301  Operations Research and Supply Chain Management
MGMT 315  International Management Institute

Total Units: 9

Polymer Science (Advisor: Dr. Akolkar)
EMAC 270  Introduction to Polymer Science and Engineering (Fall) 3

Two additional courses selected from:
EMAC 276  Polymer Properties and Design (Spring)
EMAC 376  Polymer Engineering (Spring)
EMAC 377  Polymer Processing (Spring)
EMAC 378  Polymer Engineer Design Product (Spring)
EMAC 303  Structure of Biological Materials

Total Units: 9

Pre-Medical (Advisor: Dr. Baskaran)
CHEM 113  Principles of Chemistry Laboratory 2
BIOL 214  Genes, Evolution and Ecology 3
BIOL 214L  Genes, Evolution and Ecology Lab 1
BIOL 215  Cells and Proteins 3
BIOL 215L  Cells and Proteins Laboratory 1

Total Units: 10

Research (Advisor: Dr. Martin)
ECHE 350  Undergraduate Research Project I (Fall) 3
ECHE 351  Undergraduate Research Project II 3
An elective course approved by sequence advisor 3

Total Units: 9

Systems and Control (Advisor: Dr. Lacks)
EECS 346  Engineering Optimization (Spring) 3
EECS 281  Logic Design and Computer Organization (Fall) 4
EECS 304  Control Engineering I with Laboratory (Spring) 3

Total Units: 10

BS/MS Advanced Study Sequence (Advisor: Dr. Martin)
Three 400-level 3-credit ECHE courses 9

Total Units: 9

Custom-Designed Sequence (Advisor: Dr. Lacks)
Students can design a custom breadth elective sequence, consisting of three courses (9 credits) that fit in one coherent technical or professional theme. The courses must be technical or professional courses (see footnote b) that are 200-level or higher, with at least one of the courses being 300-level or higher. These courses cannot be research or independent study courses. Students interested in this option should submit a petition to their advisor naming and explaining the coherent theme, why this theme complements the chemical engineering core for him/her, and how the three courses fit into this theme. The petition must be approved by the faculty of the Department of Chemical and Biomolecular Engineering.
At most one course in this sequence may double count to satisfy the Materials, Science, or Physical Chemistry elective requirement. This double counting does not reduce the total credit hour requirement for the degree; there are no restrictions on the additional course(s) used to meet the total credit requirement.

For the purpose of the sequences, “technical and professional courses” are defined as courses that would not satisfy the humanities and social sciences requirement of the Case School of Engineering; also excluded are courses in American Studies (AMST), Asian Studies (ASIA), Childhood studies (CHST), ethics (ETHS), Judaic studies (JDST), music (MUAP), education (EDUC), women’s and gender studies (WGST), Washington study program (WASH), and other courses deemed by the department to be of this genre.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Chemical Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

First Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>17</td>
<td>18</td>
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</tbody>
</table>

- General Physics I - Mechanics (PHYS 121)**,c or Physics and Frontiers I - Mechanics (PHYS 123)
- Principles of Chemistry for Engineers (CHEM 111)**
- Calculus for Science and Engineering I (MATH 121)**,c or Calculus I (MATH 123)
- FSxx SAGES First Seminar*
- Introduction to Chemical Engineering at Case (ECHE 151)
- PHED (2 half semester courses)*
- General Physics II - Electricity and Magnetism (PHYS 122)**,c or Physics and Frontiers II - Electricity and Magnetism (PHYS 124)
- Chemistry of Materials (ENGR 145)**
- Calculus for Science and Engineering II (MATH 122)**,c or Calculus II (MATH 124)
- Elementary Computer Programming (ENGR 131)**
- USxx SAGES University Seminar I*
- Year Total: 17

Second Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>15</td>
<td>18</td>
<td></td>
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</tbody>
</table>

- Introductory Organic Chemistry I (CHEM 223)c or Organic Chemistry I (CHEM 323)
- Calculus for Science and Engineering III (MATH 223)**,c or Calculus III (MATH 227)
- Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)**
- Year Total: 15

Third Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>16</td>
<td>15</td>
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</tbody>
</table>

- Transport Phenomena for Chemical Systems (ECHE 360)
- Process Control (ECHE 367)
- Introduction to Circuits and Instrumentation (ENGR 210)**
- Chemical Laboratory Methods for Engineers (CHEM 290)
- Breadth elective sequence I e
- Separation Processes (ECHE 361)
- Chemical Reaction Processes (ECHE 364)
- Measurements Laboratory (ECHE 365)
- Professional Communication for Engineers (ENGR 398)**
- Professional Communication for Engineers (ENGL 398)**
- Humanities/Social Science elective II **
- Year Total: 16

Fourth Year

<table>
<thead>
<tr>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
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<tbody>
<tr>
<td>15</td>
<td>16</td>
<td></td>
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</tbody>
</table>

- Chemical Engineering Laboratory (ECHE 362)
- Process Analysis and Design (ECHE 398)
- Materials elective h
- Breadth Elective Sequence II e
- Humanities/Social Science elective III **
- Chemical Engineering Design Project (ECHE 399) j
- Statics and Strength of Materials (ENGR 200)**
- Physical Chemistry elective l
- Breadth elective sequence III e
- Humanities/Social Science elective IV **
- Year Total: 16

Total Units in Sequence: 130

Hours required for graduation: 129-131 (depending on breadth elective sequence)

* University general education requirement
** Engineering general education requirement
c Higher number (advanced or honors) courses are available to students by invitation only.
Biochemical Engineering Concentration

Biochemical engineering can be defined as the field of application of chemical engineering principles to systems that utilize biomolecules or bio-organisms to bring forth biotransformation. Biochemical engineering applications are versatile, ranging from waste-water treatment to bio-organisms. Biochemical engineering can be defined as the field of application of chemical engineering principles to systems that utilize biomolecules or bio-organisms to bring forth biotransformation.

For the biochemical engineering concentration, students select the elective courses as described below, and take two additional courses:

**Materials Elective**: BIOC 307

**Science Elective**: BIOL 300

**Physical Chemistry Elective**: BIOL 334

**Breadth Elective Sequence**: Biochemical Engineering sequence (described above)

**Must also take**

- BIOL 308 Molecular Biology
- BIOL 382 Drugs, Brain, and Behavior
- PHRM 309 Principles of Pharmacology

Pre-Medical Concentration

By using the flexibility provided by science and technical electives in the curriculum, students are able to pursue courses that provide the background needed for medical school. Students choose the following electives to meet the course requirements of most medical schools.

**Materials Elective**: BIOC 307

**Science Elective**: CHEM 224 or CHEM 324

**Chemistry Labs**: CHEM 113 and CHEM 233 and CHEM 234 instead of CHEM 290

**Breadth Elective Sequence**: Pre-Medical sequence (described above)

Co-op and Internship Programs

Outstanding undergraduate students have the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree. This opportunity enables students to gain valuable handson experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition, but maintain their full-time status while earning a salary.

Five-Year Combined BS/MS Program

Outstanding undergraduate students have the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree. Normally, it takes two years beyond the BS to earn an MS degree. In this program, an undergraduate student can take up to nine hours of graduate credit that simultaneously satisfies undergraduate degree requirements. Typically, students in this program start their research leading to the MS thesis in the fall semester of the senior year. The BS degree is awarded at the completion of the senior year. The BS degree requirements are a 3.2 grade point average and the recommendation of the department. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatesudies/gradprofessional/#accelerationtowardgraduatedegreetext).

Five-and-a Half Year Cooperative BS/MS Program

The cooperative bachelor’s/master’s program enables outstanding students who are enrolled in the cooperative education program to earn an MS in one semester beyond the BS degree. Students complete six credits of a graduate project (ECHE 660) during the second co-op period and follow an Advanced Study elective sequence. Up to nine credits of graduate coursework can be used to satisfy both graduate and undergraduate requirements. At the end of the fifth year, the student receives the BS degree. Upon completion of an additional 12 credits of graduate work the following semester, the student receives the MS degree (non-thesis). Application for admission to the five-and-a-half year co-op BS/MS program is made during the second semester of the junior year (this semester is taken in the fall of the fourth year). Minimum requirements are a 3.2 grade point average, satisfactory performance.
in the previous co-op assignment, and the recommendation of the department.

**Minor in Chemical Engineering**

The minor in chemical engineering is for students majoring in other disciplines. A minimum of 17 hours in chemical engineering courses are required for the minor. The required courses are:

- ENGR 225 Thermodynamics, Fluid Dynamics, Heat and Mass Transfer 4
- ECHE 260 Introduction to Chemical Systems 3
- ECHE 360 Transport Phenomena for Chemical Systems 4

Plus two courses selected from the following: 6-7
- ECHE 361 Separation Processes
- ECHE 363 Thermodynamics of Chemical Systems
- ECHE 364 Chemical Reaction Processes
- ECHE 365 Measurements Laboratory
- ECHE 367 Process Control

Total Units 17-18

**Graduate Programs**

**Master of Science Program**

Each MS candidate must complete a minimum of 27 hours of graduate-level credits. These credits can be distributed in one of two ways, Plan A or Plan B.

**Plan A**

- ECHE 401 Chemical Engineering Communications 1

Six graduate-level courses 18
- MS thesis research 9

Total Units 28

or

**Plan B**

- Eight graduate-level courses 24
- Project and/or Special Problems 3

Total Units 27

Some of the graduate-level courses must be taken from a list of recommended courses that satisfy the Chemical Engineering core ‘units’ requirement. The list is maintained by the department. For the MS program, students should demonstrate that they have acquired a minimum of three core ‘units’ in each of the categories of Chemical Engineering Transport, Thermodynamics, Reactions and Applied Mathematics.

In special cases, a student may be permitted to complete a 6 credit project. In this case, only seven graduate courses will be required.

Full-time MS students are expected to serve as a teaching assistant as part of their education. Also, at various points during their thesis research, students will be required to present seminars and reports on their progress.

**Doctor of Philosophy Program**

The degree of Doctor of Philosophy is awarded in recognition of deep and detailed knowledge of chemical engineering and a comprehensive understanding of related subjects together with a demonstration of the ability to perform independent research, to suggest new areas for research, and to communicate results in an acceptable manner. For students entering the PhD program with a BS degree, a total of 12 courses (36 credit hours) is required. Course requirements for students entering with MS degrees are adjusted to account for work done at other universities, but a minimum of 6 courses (18 credit hours) must be taken at CWRU. The course requirements for students entering with a BS degree are as follows:

| Core and Elective courses  a | 30 |
| Professional Development courses  b | 6 |
| PhD thesis research  c | 18 |
| **Total Units** | **54** |

Some of the graduate-level courses should be taken from a list of recommended courses that satisfy the Chemical Engineering core ‘units’ requirement. This list will be provided to the students upon admission to the program. For the PhD program, students should demonstrate that they have acquired a minimum of three core ‘units’ in each of the categories of Chemical Engineering Transport, Thermodynamics, Reactions and Applied Mathematics.

Professional development is an integral part of the PhD program of study. The 6 professional development credits are acquired through courses in Chemical Engineering Communications (3 total credits), and by attending the Chemical Engineering Colloquium (3 total credits). All PhD students are required to assist in three teaching experiences as part of their degree requirements.

Students in the PhD program are required to complete 18 credits of thesis research. Also, students who enter the PhD program must pass a First Proposition Oral Examination (with an accompanying written report) that tests a student's ability to think creatively, grasp new research concepts, and discuss such concepts critically and comprehensively. The First Proposition Exam, typically taken in the Fall semester of the second year, serves as the qualifying examination for the PhD degree. A Second Proposition Exam focusing on the student's own research topic is required by the end of the second year in the PhD program. All PhD students must satisfy the residency requirements of the university and the Case School of Engineering. In addition, at various points in the course of the dissertation research, students will be required to prepare reports and seminars on their work, and defend their dissertation. The Chemical and Biomolecular Engineering Graduate Student Handbook contains a more detailed description of the department's PhD requirements and a time schedule for their completion.

The department anticipates that from time to time, special cases will arise which are exceptions to the above guidelines, e.g., a student may have taken a graduate-level course at another school. In these cases, the student must submit a statement with the Planned Program of Study
justifying the departure from the guidelines and have it approved by the department.

Facilities
The department is housed in the Albert W. Smith Building and portions of the Bingham Building on the Case Quadrangle. Professor Smith was chair of industrial chemistry at Case from 1911 to 1927. Under his leadership a separate course of study in chemical engineering was introduced at Case in 1913. Professor Smith was also a close associate of Herbert Dow, the Case alumnus who founded Dow Chemical in 1890 with the help and support of Professor Smith. The Albert W. Smith Chemical Engineering Building contains one technology enhanced classroom; the undergraduate Unit Operations Laboratory; an undergraduate reading room, named after Prof. Robert V. Edwards; and the normal complement of offices and research laboratories. The lobby of the A.W. Smith Building, renovated by contributions from the James family, often serves as a formal and informal gathering place for students and faculty. The department has exceptionally strong facilities for electrochemical and energy research, for microfabrication, and for chemical vapor deposition and thin film synthesis. In addition, a full range of biochemical, analytical and materials characterization instrumentation is available in the Case School of Engineering. Analytical instrumentation is available within the Department of Chemical and Biomolecular Engineering, the Department of Chemistry, and the Materials Research Laboratory.

Faculty
Daniel Lacks, PhD
(Harvard University)
C. Benson Branch Professor of Chemical Engineering, Department Chair
Molecular simulation, statistical mechanics, triboelectric charging

Rohan N. Akolkar, PhD
(Case Western Reserve University)
Associate Professor and F. Alex Nason Chair
Electrochemical phenomena in next-generation batteries, photovoltaics and semiconductor devices

John C. Angus, PhD
(University of Michigan)
Emeritus Professor
Chemical vapor deposition of diamond, electrochemistry of diamond, gallium nitride synthesis

Harirha Baskaran, PhD
(The Pennsylvania State University)
Professor
Transport phenomena in biology and medicine

Donald L. Feke, PhD
(Princeton University)
Distinguished University Professor and Vice Provost for Undergraduate Education
Colloidal and transport phenomena, dispersive mixing, particle science and processing

Burcu Gurkan, PhD
(University of Notre Dame)
Assistant Professor
Energy storage, nonflammable electrolytes, electrode fabrication, electrochemical separation processes

Uziel Landau, PhD
(University of California, Berkeley)
Professor
Electrochemical engineering, modeling of electrochemical systems, electrodeposition, batteries, fuel cells, electrolyzers, corrosion

Chung-Chiu Liu, PhD
(Case Institute of Technology)
Distinguished University Professor and Wallace R. Persons Professor of Sensor Technology and Control
Electrochemical sensors, electrochemical synthesis, electrochemistry related to electronic materials

J. Adin Mann Jr., PhD
(Iowa State University)
Emeritus Professor
Surface phenomena, interfacial dynamics, colloid science, light scattering, biomembranes, molecular electronics, Casimir force (effects)

Heidi B. Martin, PhD
(Case Western Reserve University)
Associate Professor
Conductive diamond films; electrochemical sensors; chemical modification of surfaces for electrochemical and biomedical applications; biomaterials; microfabrication of sensors and devices

Syed Qutubuddin, PhD
(Carnegie Mellon University)
Professor
Surfactant and polymer solutions, separations, nanoparticles, novel polymeric materials, nanocomposites

Julie Renner, PhD
(Purdue University)
Assistant Professor
Electrochemical engineering, protein engineering, biomimetic materials, regenerative medicine

Robert F. Savinell, PhD
(University of Pittsburgh)
Distinguished University Professor and George S. Dively Professor
Electrochemical engineering, electrochemical reactor design and simulation, electrode processes, batteries and fuel cells

R. Mohan Sankaran, PhD
(California Institute of Technology)
Leonard Case Professor
Microplasmas, nanoparticle synthesis

Jesse S. Wainright, PhD
(Case Western Reserve University)
Research Professor
Electrochemical power sources: fuel cells, batteries, supercapacitors; biomedical applications
Courses

ECHE 151. Introduction to Chemical Engineering at Case. 1 Unit.
An introduction to the profession of chemical engineering, its practice in industry, and review of the challenges and opportunities for the profession. The academic programs and curricular enhancements available to students majoring in chemical engineering at CWRU, including breadth sequence sequences and concentrations, undergraduate research, international study opportunities, cooperative education and internships, are presented. In addition to introducing the chemical engineering faculty and their research, a number of guest speakers representing the broad professional opportunities discuss career options with the students. Through lectures and discussions, students are also introduced to topics such as professionalism and ethics. Upperclassmen students conduct their co-op debriefing in the class, sharing experiences and initiating networking. In the lab/recitation section, students in smaller groups conduct experiments on chemical processes, spanning different aspects of the profession, and run computer-based simulations of those experiments. Analysis and discussion of the results will follow. Chemical engineering upperclassmen serve as teaching assistants.

ECHE 250. Honors Research I. 1 - 3 Units.
A special program which affords a limited number of students the opportunity to conduct research under the guidance of one of the faculty. At the end of the first semester of the sophomore year, students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. Subject to the availability of funds, the faculty employs students throughout the summers of their sophomore and junior years, as members of their research teams.

ECHE 251. Honors Research II. 1 - 3 Units.
(See ECHE 250.) Recommended preparation: ECHE 250.

ECHE 260. Introduction to Chemical Systems. 3 Units.
Material and energy balances. Conservation principles and the elementary laws of physical chemistry applied to chemical processes. Developing skills in quantitative formulation and solution of word problems. Prereq: CHEM 111, ENGR 145 and MATH 122.

ECHE 305. Topics in Chemical Engineering. 0 Unit.
Topics in chemical engineering will be covered in an independent study mode. Readings and homework assignments will be assigned. Students are graded on the basis of homework assignments and a final exam.

ECHE 340. Biochemical Engineering. 3 Units.
Chemical engineering principles applied to biological and biochemical systems and related processes. Microbiology and biochemistry linked with transport phenomena, kinetics, reactor design and analysis, and separations. Specific examples of microbial and enzyme processes of industrial significance. Recommended preparation: BIOL 307, BIOL 343 and ECHE 364, or permission of instructor.

ECHE 350. Undergraduate Research Project I. 3 Units.
This course affords a student the opportunity to conduct research under the guidance of one of the faculty, as part of the Chemical Engineering Research breadth elective sequence. Students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. ECHE 351. Undergraduate Research Project II. 3 Units.
This course affords a student the opportunity to conduct research under the guidance of one of the faculty, as part of the Chemical Engineering Research breadth elective sequence. Students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. Prereq: ECHE 350.

ECHE 355. Quantitative Molecular, Cellular and Tissue Bioengineering. 3 Units.
Physical and chemical principles associated with kinetics and mass transport. Molecular-cellular components incorporated in quantitative analysis of cellular, tissue, and organ systems. Mathematical and computational modeling developed for diagnostic and therapeutic applications. Offered as EBME 350 and ECHE 355.

ECHE 360. Transport Phenomena for Chemical Systems. 4 Units.
Fundamentals of fluid flow, heat and mass transport from the microscopic and macroscopic perspectives. Applications to chemical systems, including steady and transient operations, convective and molecular (conduction and diffusion) effects, and interfacial transport. Design of unit operations (e.g., heat exchangers). Heat and mass transfer analogies. Vector/tensor analysis and dimensional analysis used throughout. Prereq: ENGR 225 and MATH 223.

ECHE 361. Separation Processes. 3 Units.
Analysis and design of separation processes involving distillation, extraction, absorption, adsorption, and membrane processes. Design problems and the physical and chemical processes involved in separation. Equilibrium stage, degrees of freedom in design, graphical and analytical design techniques, efficiency and capacity of separation processes. Prereq: ECHE 260. Prereq or Coreq: ECHE 363.

ECHE 362. Chemical Engineering Laboratory. 4 Units.
Experiments in the operation of separation and reaction equipment, including design of experiments, technical analysis, and economic analysis. Experiments cover distillation, liquid-liquid extraction, heat transfer, fluidized beds, control, membrane separations, and chemical and electrochemical reactors. Prereq: ECHE 260, ECHE 360, ECHE 361, ECHE 363 and ECHE 364.

ECHE 362D. Chemical Engineering Laboratory in Denmark. 4 Units.
Chemical Engineering Laboratory in Denmark. A version of ECHE 362 taught during the summer at DTU in Lyngby. Prereq: ECHE 260 and ECHE 360 and ECHE 361 and ECHE 363 and ECHE 364.

ECHE 363. Thermodynamics of Chemical Systems. 3 Units.
First law, second law, phase equilibria, phase rule, chemical reaction equilibria, and applications to engineering problems. Thermodynamic properties of real substances, with emphasis on solutions. Thermodynamic analysis of processes including chemical reactions. Prereq: ECHE 260 and Prereq or Coreq: ENGR 225.

ECHE 364. Chemical Reaction Processes. 3 Units.
ECHE 365. Measurements Laboratory. 3 Units.
Laboratory introduction to the measurement process in engineering. Matching measurements to approximate and exact physical models is stressed. Extraction of physical parameters and estimation of the errors in the parameter estimates is an important part of the course. Example projects cover steady and unsteady state heat transfer, momentum transfer, and the first law of thermodynamics. Recommended preparation: ECHE 360. Prereq: ECHE 260 and ENGR 225. Prereq or Coreq: ECHE 363.

ECHE 367. Process Control. 4 Units.
Theoretical and practical aspects of feedback control of chemical processes. The course involves extensive use of computer software with some exams taken using the computer. Short laboratories and LabVIEW training are integrated into the course. Topics include: analysis of linear dynamical systems using Laplace transforms, derivation of unsteady state mathematical models of simple chemical processes, dynamic simulation of linear and nonlinear models, design of PID controllers by model inverse methods, tuning of controller to accommodate process model uncertainty, two degrees of freedom controllers, feed-forward and cascade control. The LabVIEW training covers programming basics, interfacing to a data acquisition system, and incorporating control algorithms. Prereq: MATH 224. Prereq or Coreq: ECHE 260.

ECHE 377. Data Acquisition and LabVIEW Bootcamp. 1 Unit.
This course will introduce and implement basic data acquisition concepts and LabVIEW virtual instrumentation programming, providing hands-on experience with hardware and software. It is intended to help those with little or no data acquisition experience to get started on setting up data acquisition for their application. No prior experience with LabVIEW is required. Consult with the instructor for additional details. Offered as ECHE 377 and ECHE 477.

ECHE 381. Electrochemical Engineering. 3 Units.
Engineering aspects of electrochemical processes including current and potential distribution, mass transport and fluid mechanical effects. Examples from industrial processes including electroplating, industrial electrolysis, corrosion, and batteries. Recommended preparation: ECHE 260 or permission of instructor. Offered as ECHE 381 and ECHE 480.

ECHE 383. Chemical Engineering Applied to Microfabrication and Devices. 3 Units.
Silicon based microfabrication and micromachining require many chemical engineering technologies. Microfabricated devices such as sensors are also directly related to chemical engineering. The applications of chemical engineering principles to microfabrication and micromachining are introduced. Oxidation processing, chemical vapor deposition, etching and patterning techniques, electroplating and other technologies are discussed. Graduate students will submit an additional final project on some technical aspect of microfabrication technology or devices. Recommended preparation: ECHE 363 and ECHE 371. Offered as ECHE 383 and ECHE 483.

ECHE 397. Special Topics in Chemical Engineering. 3 Units.
Special topics within an area of chemical engineering.

ECHE 398. Process Analysis and Design. 3 Units.

ECHE 399. Chemical Engineering Design Project. 3 Units.
This is a course that uses the small teams approach to solve chemical process design problems. Numerous exercises involving process design are used to integrate material taught in previous and concurrent courses. This includes application of computer based design tools, economics, scheduling, decision making with uncertainty, and proposal and report preparation. This work leads to one comprehensive process design project done by the class, which includes a written and oral report. Recommended preparation: ECHE 362 and ECHE 398. Counts as SAGES Senior Capstone. Prereq: ECHE 360, ECHE 361, ECHE 364, ECHE 365, and ECHE 367.

ECHE 400T. Graduate Teaching I. 0 Unit.
All Ph.D. students are required to take this course. The experience includes elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Recommended preparation: Entering Ph.D. student in Chemical Engineering.

ECHE 401. Chemical Engineering Communications. 1 Unit.
Introductory course in communication for Chemical Engineering graduate students: preparation of first proposal for thesis, preparation of technical reports and scientific papers, literature sources, reviewing proposals, and manuscripts for professional journals, and making effective technical presentations.

ECHE 402. Chemical Engineering Communications II. 2 Units.
This course is a continuation of ECHE 401 and is designed to develop skills in writing proposals for funding research projects. The federal requirements are reviewed for submitting proposals to the major granting agents including NSF, NIH and DoD. We will study strategies for developing fundable projects. Each student will submit a research proposal for a thesis project and do an oral presentation of the project.

ECHE 460. Thermodynamics of Chemical Systems. 3 Units.
Phase equilibria, phase rule, chemical reaction equilibria in homogeneous and heterogeneous systems, ideal and non-ideal behavior of fluids and solutions, thermodynamic analysis of closed and open chemical systems with applications. Recommended preparation: ECHE 363.

ECHE 461. Transport Phenomena. 3 Units.

ECHE 462. Chemical Reaction Engineering. 3 Units.

ECHE 464. Surfaces and Adsorption. 3 Units.
Thermodynamics of interfaces, nature of interactions across phase boundaries, capillary wetting properties of adsorbed films, friction and lubrication, flotation, detergency, the surface of solids, relation of bulk to surface properties of materials, non-catalytic surface reactions. Recommended preparation: CHEM 335 or equivalent.
ECHE 466. Colloid Science. 3 Units.

ECHE 469. Chemical Engineering Seminar. 0 Unit.
Distinguished outside speakers present current research in various topics of chemical engineering science. Graduate students also present technical papers based on thesis research.

ECHE 470. Graduate Research Colloquium. 5 Unit.
Outside speakers present lectures on their current research. Various topics in the areas of chemical engineering science, bioengineering, material science, and applied mathematics are covered in the lectures. Graduate students also present technical papers based on their own research. Students are graded on the submission of one-page summary reports on any two lectures.

ECHE 472. Electrochemical Energy Storage. 3 Units.
Batteries and supercapacitors as part of renewable energy systems are introduced. Related fundamental electrochemistry concepts, materials and techniques are described. Challenges, current literature and future opportunities in energy storage will be discussed. Prereq: Graduate standing or requisites not met permission.

ECHE 474. Biotransport Processes. 3 Units.
Biomedical mass transport and chemical reaction processes. Basic mechanisms and mathematical models based on thermodynamics, mass and momentum conservation. Analytical and numerical methods to simulate in vivo processes as well as to develop diagnostic and therapeutic methods. Applications include transport across membranes, transport in blood, tumor processes, bioreactors, cell differentiation, chemotaxis, drug delivery systems, tissue engineering processes. Recommended preparation: EBME 350 or equivalent. Offered as EBME 474 and ECHE 474.

ECHE 475. Chemical Engineering Analysis. 3 Units.

ECHE 477. Data Acquisition and LabVIEW Bootcamp. 1 Unit.
This course will introduce and implement basic data acquisition concepts and LabVIEW virtual instrumentation programming, providing hands-on experience with hardware and software. It is intended to help those with little or no data acquisition experience to get started on setting up data acquisition for their application. No prior experience with LabVIEW is required. Consult with the instructor for additional details. Offered as ECHE 377 and ECHE 477.

ECHE 480. Electrochemical Engineering. 3 Units.
Engineering aspects of electrochemical processes including current and potential distribution, mass transport and fluid mechanical effects. Examples from industrial processes including electroplating, industrial electrolysis, corrosion, and batteries. Recommended preparation: ECHE 260 or permission of instructor. Offered as ECHE 381 and ECHE 480.

ECHE 481. Corrosion Fundamentals. 3 Units.
This course will cover fundamentals of corrosion, including thermodynamic and kinetic aspects of the electrochemical reactions leading to corrosion. Salient features of the various types of corrosion will be reviewed, with an emphasis on fundamental mechanisms. Electrochemical testing, corrosion monitoring and techniques to stifle corrosion will be discussed. After completion of this course, students will be able to classify corrosion systems, understand the mechanisms underlying corrosion, and outline strategies to design corrosion-resistant systems.

ECHE 483. Chemical Engineering Applied to Microfabrication and Devices. 3 Units.
Silicon-based microfabrication and micromachining require many chemical engineering technologies. Microfabricated devices such as sensors are also directly related to chemical engineering. The applications of chemical engineering principles to microfabrication and micromachining are introduced. Oxidation processing, chemical vapor deposition, etching and patterning techniques, electroplating and other technologies are discussed. Graduate students will submit an additional final project on some technical aspect of microfabrication technology or devices. Recommended preparation: ECHE 363 and ECHE 371. Offered as ECHE 383 and ECHE 483.

ECHE 486. Protein Engineering. 3 Units.
This course will provide an in-depth examination of protein engineering topics and their applications. In particular, this class will cover the design and expression of recombinant proteins, purification strategies, and the incorporation of non-natural amino acids using a bacterial system. Specifically, amino acid sequences that dictate well-defined secondary structures such as beta-sheets, alpha-helices, and leucine zippers will be studied. We will examine recent tissue engineering examples from the literature such as incorporation of bioactive sequences to promote specific cell response (e.g., cell adhesion sites and protease degradation sequences). In addition, this course will explore the application of protein engineering in drug delivery, electrochemical technology, sensors, and nanoparticle assembly. Current computational techniques for protein design and directed evolution methods will also be explored. This class will emphasize primary literature papers and will expose students to the newest technologies being developed in these fields. Recommended preparation: ECHE 363. Prereq: Graduate standing or requisites not met permission.

ECHE 500T. Graduate Teaching II. 0 Unit.
All Ph.D. students are required to take this course. The experience will include elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Recommended preparation: Ph.D. student in Chemical Engineering.
ECHE 508. Seminar on Review of Literature on Research Topic. 3 Units.
Impactful research requires a deep and comprehensive understanding of the current state of research on the topic. A critical review of relevant background literature will help determine what is already known on the topic, how extensively the topic has already been studied, who are the experts active in the field, and the relevant key questions that deserve further exploration. A review of the literature that describes methodologies (both experimental and theoretical) used in prior studies or new approaches that could be adapted from other research areas can also lead to the effective pursuit of the research topic. Through this course, students will learn how to develop a plan for a literature review, conduct the literature review and monitor continuing developments in the field, and create an annotated bibliography appropriate to the research project.

ECHE 509. Seminar on Preparation of Articles for Publication in Journals. 3 Units.
This course is intended for advanced graduate students who have generated results at the stage of being ready to be written up for a journal article. The course will cover: understanding what findings warrant publication, factors affecting journal selection, formatting requirements of journals, publication-quality figures, appropriate material for each of the sections of the paper. During the course students will be putting together a manuscript based on their research that would eventually be submitted to a journal.

ECHE 580. Special Topics. 3 Units.
Special topics in chemical engineering. Prereq: Consent of instructor.

ECHE 590. Topics in Materials Engineering. 3 Units.
Seminar course focusing on topics related to materials engineering. Typical subjects include processing and properties of electronic and nanomaterials, composites and dispersions; mixing of particles and agglomerates; electrodeposition of alloys; molecular level simulations. Students will be assigned readings from book chapters, classical articles and state of the art publications. A discussion leader (pre-assigned) will be responsible for introducing the papers and leading a critical discussion. Active student participation in the discussions is expected.

ECHE 600T. Graduate Teaching III. 0 Unit.
All Ph.D. students are required to take this course. The experience will include elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Recommended preparation: Ph.D. student in Chemical Engineering.

ECHE 601. Independent Study. 1 - 18 Units.

ECHE 651. Thesis M.S.. 1 - 18 Units.
Research course taken by Plan B M.S. students.

ECHE 660. Special Problems. 1 - 18 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in ECHE Plan B Program.

ECHE 695. Project M.S.. 1 - 9 Units.
Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

ECHE 701. Dissertation Ph.D.. 1 - 9 Units.