Energy, Environmental & Chemical Engineering

The Department of Energy, Environmental & Chemical Engineering (EECE) provides integrated and multidisciplinary programs of scientific education in cutting-edge areas, including the PhD in Energy, Environmental & Chemical Engineering. Research and educational activities of the department are organized into four clusters: aerosol science & engineering; engineered aquatic processes; multiscale engineering; metabolic engineering & systems biology. These overlapping clusters address education and research in four thematic areas: energy; environmental engineering science; advanced materials; and sustainable technology for public health and international development. In addition to the core faculty in the department, faculty in the schools of Medicine, Arts & Sciences, Business, Law, and Social Work collaborate to provide students with a holistic education and to address topical problems of interest.

Two master's programs are offered through the department: Master of Engineering in Energy, Environmental & Chemical Engineering (MEng) and Master of Engineering in Energy, Environmental & Chemical Engineering/Master of Business Administration (MEng/MBA). The MEng degree provides students with critical scientific and engineering skill sets; leadership training for management, economics, and policy decision; and the opportunity to specialize in one of five pathways. The MEng/MBA is a dual degree between the School of Engineering & Applied Science and the Olin Business School which provides engineering and business approaches to issues of sustainability, energy, the environment, and corporate social responsibility. Interested students must apply and be accepted to both programs before admission is provided to the MEng/MBA dual degree program.

The department is a key participant in the university's Energy, Environment & Sustainability (http://sustainability.wustl.edu) initiative and supports both the International Center for Advanced Renewable Energy and Sustainability (I-CARES (http://icares.wustl.edu)) and the McDonnell Academy Global Energy and Environment Partnership (MAGEEP (http://mageep.wustl.edu)). Major externally funded research centers in the department include the Consortium for Clean Coal Utilization (http://cleancoal.wustl.edu), the National Nanotechnology Infrastructure Node (http://nano.wustl.edu), and the Solar Energy Research Institute for India and the United States (SERIIUS (http://www.seriius.org)).

Phone: 314-935-5548
Website: https://eece.wustl.edu/graduate/programs

Faculty

Chair and Endowed Professor

Pratim Biswas (https://engineering.wustl.edu/Profiles/Pages/Pratim-Biswas.aspx)
Lucy and Stanley Lopata Professor
PhD, California Institute of Technology
Aerosol science and engineering, air quality and pollution control, nanotechnology, environmentally benign energy production

Endowed Professors

Richard L. Axelbaum (https://engineering.wustl.edu/Profiles/Pages/Richard-Axelbaum.aspx)
Stifel and Quinette Jens Professor
PhD, University of California, Davis
Combustion, advanced energy systems, clean coal, aerosols, nanoparticle synthesis, rechargeable battery materials, thermal science

Milorad P. Dudukovic (https://engineering.wustl.edu/Profiles/Pages/Milorad-Dudukovic.aspx)
Laura and William Jens Professor
PhD, Illinois Institute of Technology
Chemical reaction engineering, multiphase reactors, visualization of multiphase flows, tracer methods, environmentally benign processing

Daniel E. Giammar (https://engineering.wustl.edu/Profiles/Pages/Daniel-Giammar.aspx)
Walter E. Browne Professor of Environmental Engineering
PhD, California Institute of Technology
Aquatic chemistry, environmental engineering, water quality, water treatment

Vijay Ramani (https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=108)
Roma B. and Raymond H. Witcoff Distinguished University Professor of Environment Engineering
PhD, University of Connecticut, Storrs
Electrochemical engineering, energy conversion

Professors

Young-Shin Jun (https://engineering.wustl.edu/Profiles/Pages/Young-Shin-Jun.aspx)
Director of Graduate Studies
PhD, Harvard University
Aquatic processes, molecular issues in chemical kinetics, environmental chemistry, surface/physical chemistry, environmental engineering, biogeochemistry, nanotechnology
Palghat A. Ramachandran (https://engineering.wustl.edu/Profiles/Pages/Palghat-Ramachandran.aspx)
PhD, University of Bombay
Chemical reaction engineering, applied mathematics, process modeling, waste minimization, environmentally benign processing

Associate Professors

John Fortner (https://engineering.wustl.edu/Profiles/Pages/John-Fortner.aspx)
InCEES Career Development Associate Professor
PhD, Rice University
Environmental engineering, aquatic processes, water treatment, remediation, and environmental implications and applications of nanomaterials

John T. Gleaves (https://engineering.wustl.edu/Profiles/Pages/John-Gleaves.aspx)
PhD, University of Illinois
Heterogeneous catalysis, particle chemistry

Yinjie Tang (https://engineering.wustl.edu/Profiles/Pages/Yinjie-Tang.aspx)
Francis Ahmann Career Development Associate Professor and Director of Undergraduate Studies
PhD, University of Washington, Seattle
Metabolic engineering, bioremediation

Jay R. Turner (https://engineering.wustl.edu/Profiles/Pages/Jay-Turner.aspx)
Vice Dean for Education
DSc, Washington University
Air quality planning and management; aerosol science and engineering, green engineering

Rajan Chakrabarty (https://engineering.wustl.edu/Profiles/Pages/Rajan-Chakrabarty.aspx)
PhD, University of Nevada, Reno
Characterizing the radiative properties of carbonaceous aerosols in the atmosphere; and researching gas phase aggregation of aerosols in cluster-dense conditions

Marcus Foston (https://engineering.wustl.edu/Profiles/Pages/Marcus-Foston.aspx)
PhD, Georgia Institute of Technology
Utilization of biomass resources for fuel and chemical production, renewable synthetic polymers

Tae Seok Moon (https://engineering.wustl.edu/Profiles/Pages/Tae-Seok-Moon.aspx)
PhD, Massachusetts Institute of Technology
Metabolic engineering and synthetic biology

Kimberly M. Parker (https://engineering.wustl.edu/Profiles/Pages/Kimberly-Parker.aspx)
PhD, Stanford University
Investigation of environmental organic chemistry in natural and engineered systems

Elijah Thimsen (https://engineering.wustl.edu/Profiles/Pages/Elijah-Thimsen.aspx)
PhD, Washington University
Gas-phase synthesis of inorganic nanomaterials for energy applications, and novel plasma synthesis approaches

Research Associate Professor

Tianxiang Li
PhD, University of Kentucky
Combustion and applications in energy, pollutant control, biofuel synthesis, flame synthesis of nanomaterials

Research Assistant Professors

Su Huang
PhD, University of Washington, Seattle
Photovoltaic materials and devices, nonlinear optical materials for photonic devices

Benjamin Kumfer
DSc, Washington University
Advanced coal technologies, biomass combustion, aerosol processes and health effects of combustion-generated particles

Lecturers

Janie Brennan
PhD, Purdue University
Biomaterials, synthetic biology, engineering education

Trent Silbaugh
PhD, University of Washington
Chemical engineering
Joint Faculty

Himadri Pakrasi (http://wubio.wustl.edu/pakrasi)
PhD, University of Missouri-Columbia
Systems biology, photosynthesis, metal homeostasis

Nathan Ravi (http://ophthalmology.wustl.edu/Faculty/Ravi_N.aspx)
PhD, Virginia Polytechnic Institute
Cataract, ocular biomaterials

Adjunct Faculty

Robert Heider
MME, Washington University
Process control and process design

Timothy Michels
MA, Washington University
Energy economics, building construction and equipment sciences

Gary Moore
MS, Missouri University of Science and Technology
Environmental management

Nicholas J. Nissing
BS, Washington University
Product development and process design

Research Associate

Raymond Ehrhard
BS, Missouri University of Science and Technology
Water and wastewater treatment technologies, process energy management

Senior Professor

Rudolf B. Husar
PhD, University of Minnesota
Environmental informatics, aerosol science and engineering

Degree Requirements

Please refer to the following sections for information about the:

- Doctor of Philosophy (p. 3)
- Master of Engineering (p. 3)
- Combined MEng/MBA (p. 4)

Doctor of Philosophy (PhD) in Energy, Environmental & Chemical Engineering (EECE)

The doctoral degree requires a total of 72 credits beyond the bachelor's degree. Of these, a minimum of 36 must be graduate courses and a minimum of 30 must be doctoral thesis research units. To be admitted to candidacy, students must have completed at least 18 credits at Washington University, have an overall GPA equal to or greater than 3.25, and pass the qualifying examination. All students are required to enroll in the department seminar every semester to receive passing grades. The first year students must complete the core curriculum, perform two research rotations, and find a permanent research adviser. Then, within 18 months after the qualifying exam (generally in their third year), students should defend their thesis proposal.

After the successful proposal defense, students should provide the research updates through annual meetings or reports with their thesis committee until their graduation. While conducting doctoral research, students should perform professionally in a research lab including compliance with safety and regulatory requirements for their research project. During the doctoral program, students must satisfy their fundamental and advanced teaching requirements by participating in mentored teaching experiences in the department for two or three semesters, by attending professional development workshops from the Teaching Center, and by presenting at least two formal presentations at the local level or at a national or international conference. Upon completion of the thesis, students must present the thesis in a public forum and successfully defend the thesis before their thesis committee.

For more detailed guidelines, please refer to the EECE doctoral studies handbook available on the EECE Graduate Degree Programs (https://eece.wustl.edu/graduate/programs/Pages/PhD-Energy-Environmental-Chemical-Eng.aspx) webpage.

Master of Engineering (MEng) in Energy, Environmental & Chemical Engineering

This 12-month professional graduate degree is a master's program based in course work for students interested in state-of-the-art practice in environmental engineering, energy systems, and chemical engineering. The master's degree provides students with critical scientific and engineering skill sets; leadership training for management, economics, and policy decision; and the opportunity to specialize in specific pathways. The curriculum is geared to enhance skill sets for practice in industry.

The program consists of 30 units, with a total of five required core courses in four areas:

- Technical Core (6 units)
- Mathematics (3 units)
- Project Management (3 units)
- Social, Legal, and Policy Aspects (3 units)

Elective courses (400- or 500-level) are selected with the approval of the academic adviser. All courses comprising the required 30 credits must be taken for a grade (i.e., cannot be
taken pass/fail), and a minimum GPA of 2.70 is required for graduation.

Pathways composed of specific elective courses can be completed to result in a certificate of specialization. Available pathways follow:

- Advanced Energy Technologies
- Bioengineering and Biotechnology
- Environmental Engineering Science
- Energy and Environmental Nanotechnology
- Energy and Environmental Management

For more detailed information, please visit the MEng in EECE (https://eece.wustl.edu/graduate/programs/Pages/MEng-Energy-Environmental-Chemical-Eng.aspx) webpage.

**Combined MEng/MBA (given jointly with Olin Business School)**

In recent years, student interest has grown rapidly in the intersection between engineering and business approaches to issues of sustainability, energy, the environment, and corporate social responsibility. An interdisciplinary approach is necessary to address these issues with innovative, critical thinking, leading to practical, effective solutions. This combined program, the Master of Engineering in Energy, Environmental & Chemical Engineering/Master of Business Administration (MEng/MBA), between the School of Engineering & Applied Science and Olin Business School is well positioned to address this critical intersection.

The Olin MBA curriculum offers a comprehensive set of required and elective courses built upon a foundation of critical-thinking and leadership skills. Olin MBAs are able to shape the curriculum to meet their unique personal objectives, incorporating the MEng degree requirements.

Both MEng and MBA degrees will be awarded simultaneously at the completion of the program.

Please visit the Olin Combined Programs (http://www.olin.wustl.edu/EN-US/academic-programs/full-time-MBA/academics/joint-degrees/Pages/wash-u-graduate-programs.aspx) webpage for details.

**Courses**

Visit online course listings to view semester offerings for E44 EECE (https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E44&crslvl=5:8).

**E44 EECE 500 Independent Study**

Independent investigation on topic of special interest. Interested students are encouraged to approach and engage faculty to develop a topic of interest. A form declaring the agreement must be filed in the departmental office. Petitions are generally considered in the semester preceding the independent study experience. Prerequisite: graduate-level standing.

Credit variable, maximum 9 units.

**E44 EECE 501 Transport Phenomena in EECE**

The aim of the course is for students to develop skills in applying principles of momentum, heat and mass transport in an unified manner to problems encountered in the areas of energy, environmental and chemical processes. A systems approach is followed so that the general principles can be grasped, and the skills to develop mathematical models of seemingly different processes are emphasized. This provides the students with a general tool which they can apply later in their chosen field of research. (Prior to FL2015, this course was numbered: E33 501.)

Credit 3 units.

**E44 EECE 502 Advanced Thermodynamics in EECE**

The objective of this course is to understand classical thermodynamics at a deeper level than is reached during typical undergraduate work. Emphasis is placed on solving problems relevant to chemical engineering materials science. Prerequisite: E63 ChE 320 or E44 203 or equivalent. (Prior to FL2015, this course was numbered: E33 511.)

Credit 3 units.

**E44 EECE 503 Mathematical Methods in EECE**

The course introduces students to mathematical principles essential for graduate study in any engineering discipline. Applied mathematical concepts are demonstrated by applications to various areas in energy, environmental, biomedical, chemical, mechanical, aerospace, electrical and civil engineering. (Prior to FL2015, this course was numbered: E33 502.)

Credit 3 units.

**E44 EECE 504 Aerosol Science and Technology**

Fundamental properties of particulate systems — physics of aerosols, size distributions, mechanics and transport of particles: diffusion, inertia, external force fields. Visibility and light scattering. Aerosol dynamics — coagulation, nucleation, condensation. Applications to engineered systems: nanoparticle synthesis, atmospheric aerosols, combustion aerosols, pharmaceutical aerosols. Prerequisites: EEEC 301, ESE 318 and 319. (Prior to FL2015, this course was numbered: E63 518.)

Credit 3 units. EN: TU

**E44 EECE 505 Aquatic Chemistry**

Aquatic chemistry governs aspects of the biogeochemical cycling of trace metals and nutrients, contaminant fate and transport, and the performance of water and wastewater treatment processes. This course examines chemical reactions relevant to natural and engineered aquatic systems. A quantitative approach emphasizes the solution of chemical equilibrium and kinetics problems. Topics covered include chemical equilibrium and kinetics, acid-base equilibria and alkalinity, dissolution and precipitation of solids, complexation of metals, oxidation-reduction processes, and reactions on solid surfaces. A primary objective of the course is to be able to formulate and solve chemical equilibrium problems for complex environmental systems. In addition to solving problems manually to develop chemical intuition regarding aquatic systems, software applications for solving chemical equilibrium problems are also introduced. Prerequisite: Chem 112A. (Prior to FL2015, this course was numbered: E33 443/543.)

Credit 3 units. EN: TU
E44 EECE 506 Bioprocess Engineering I: Fundamentals & Applications
The course covers the fundamentals and provides the basic knowledge needed to understand and analyze processes in biotechnology in order to design, develop and operate them efficiently and economically. This knowledge is applied to understand various applications and bioprocesses, such as formation of desirable bio and chemical materials and products, production of bioenergy, food processing and waste treatment. The main objective of the course is to introduce the essential concepts and applications of bioprocessing to students of diverse backgrounds. An additional project is required to obtain graduate credit. Prerequisites: L41 Biol 2960 or equivalent or permission of instructor. (Prior to FL2015, this course was numbered: E63 453/553.) Credit 3 units. EN: TU

E44 EECE 507 Kinetics and Reaction Engineering Principles
The course is aimed at a modern multiscale treatment of kinetics of chemical and biochemical reactions and application of these fundamentals to analyze and design reactors. Application of reaction engineering principles in the areas related to energy generation, pollution prevention, chemical and biochemical processes are studied and illustrated with case studies and computer models. Description of the role of mass and heat transport in reacting systems is also provided with numerous examples. (Prior to FL2015, this course was numbered: E33 503.) Credit 3 units.

E44 EECE 508 Research Rotation
First-year doctoral students in EECE should undertake research rotation as a requirement prior to choosing a permanent research adviser. The rotation requires the student to work under the guidance of a faculty member. (Prior to FL2015, this course was numbered: E33 508.)

E44 EECE 509 Seminar in Energy, Environmental, and Chemical Engineering
All graduate students in EECE should attend the Departmental Seminar Series to gain exposure in various diverse fields of research. Students are also expected to participate in journal clubs and other discussion formats to discuss topical research areas. The course is required of all graduate students every semester of residency in the program. (Prior to FL2015, this course was numbered: E33 509.) Credit 1 unit.

E44 EECE 510 Advanced Topics in Aerosol Science & Engineering
This course is focused on discussion of advanced topics in aerosol science and engineering and its applications in a variety of fields — materials science, chemical engineering, mechanical engineering, and environmental engineering. Prerequisite: EECE 504. (Prior to FL2015, this course was numbered: E63 592A.) Credit 3 units. EN: TU

E44 EECE 512 Combustion Phenomena
Introduction to fundamental aspects of combustion phenomena including relevant thermochemistry, fluid mechanics, and transport processes. Emphasis is on elucidation of the physico-chemical processes, problem formulation, and analytical techniques. Topics covered include ignition, extinction, diffusion flames, particle combustion, deflagrations, and detonations. Prerequisites: graduate standing or permission of instructor. (Prior to FL2015, this course was numbered: E33 5404.) Credit 3 units. EN: TU

E44 EECE 513 Topics in Nanotechnology
This course is focused on the discussion of topics in nanotechnology — with a focus on nanoparticles and their applications in a variety of fields — materials science, chemical engineering, mechanical engineering, environmental engineering, medicine. (Prior to FL2015, this course was numbered: E63 526.) Credit 3 units. EN: TU

E44 EECE 514 Atmospheric Science and Climate
This course covers current research topics in atmospheric chemistry and climate change. Topics include atmospheric composition, chemistry, transport, dynamics, radiation, greenhouse gases, natural and anthropogenic primary pollution sources and secondary aerosol production, and measurement techniques. Focus is placed on how our atmosphere and climate are altered in a world of changing energy production and land use. Prerequisites: Chemistry 112A, Physics 118 or 198, and junior or higher standing. (Prior to FL2015, this course was numbered: E33 547.) Credit 3 units. EN: TU

E44 EECE 515 Dynamics of Air Pollution
Physicochemical processes governing the dynamics of pollutants from point and non-point sources: generation, transport and decay. Application of fundamental thermodynamics, mass/heat transfer and fluid mechanics principles to environmental systems. Prerequisites: EECE 203, ESE 317 or ESE 318 and 319, and EECE 505, or equivalent, or permission of instructor. (Prior to FL2015, this course was numbered: E63 510.) Credit 3 units. EN: TU

E44 EECE 516 Measurement Techniques for Particle Characterization
The purpose of this course is to introduce students to the principles and techniques of particle measurement and characterization. Practical applications of particle technology include air pollution measurement, clean manufacturing of semiconductors, air filtration, indoor air quality, particulate emission from combustion sources and so on. The course focuses on (1) integral moment measurement techniques, (2) particle sizing and size distribution measuring techniques, and (3) particle composition measurement techniques. The related issues such as particle sampling and transportation, the instrument calibration, and particle standards also are covered. (Prior to FL2015, this course was numbered: E63 563.) Credit 3 units. EN: TU

E44 EECE 518 Sustainable Air Quality
Students are encouraged to apply the methods discussed in materials and aqueous/biological systems found in engineering. MD simulations is explained and applied in the context of functional theory (DFT) calculations and molecular dynamics computational chemistry tools. The science behind density of molecular and nanoscale systems in engineering using This course explores the structure, properties and reactivity specifically how nanoscience could potentially lead to better and environmental kinetic analysis at larger scales. This course explores connections between environmental nanochemistry form of environmental pollutants at the molecular scale; (4) nanoparticles and thin films, and the speciation or chemical mechanisms of important thermochemical, hydrolytic, redox, and biochemical transformation reactions are also investigated, leading to the development of techniques (such as structure-reactivity relationships) for assessing environmental fate or human exposure potential. Prerequisite: Chem 112A. (Prior to FL2015, this course was numbered: E33 448/548.) Credit 3 units. EN: TU

E44 EECE 534 Physical and Chemical Processes for Water Treatment
Water treatment is examined from the perspective of the physical and chemical unit processes used in treatment. The theory and fundamental principles of treatment processes are covered and are followed by the operation of treatment processes. Processes covered include gas transfer, adsorption, precipitation, oxidation-reduction, flocculation, sedimentation, filtration, and membrane processes. (Prior to FL2015, this course was numbered: E33 588.) Credit 3 units. EN: TU

E44 EECE 534 Environmental Nanochemistry
This course involves the study of nanochemistry at various environmental interfaces, focusing on colloid, nanoparticle, and surface reactions. The course also (1) examines the thermodynamics and kinetics of nanoscale reactions at solid-water interfaces in the presence of inorganic or organic compounds and microorganisms; (2) investigates how nanoscale interfacial reactions affect the fate and transport of contaminants; (3) introduces multidisciplinary techniques for obtaining fundamental information about the structure and reactivity of nanoparticles and thin films, and the speciation or chemical form of environmental pollutants at the molecular scale; (4) explores connections between environmental nanochemistry and environmental kinetic analysis at larger scales. This course helps students attain a better understanding of the relationship between nanoscience/technology and the environment — specifically how nanoscience could potentially lead to better water treatments, more effective contaminated-site remediation, or new energy alternatives. (Prior to FL2015, this course was numbered: E33 534.) Credit 3 units. EN: TU

E44 EECE 536 Computational Chemistry of Molecular and Nanoscale Systems
This course explores the structure, properties and reactivity of molecular and nanoscale systems in engineering using computational chemistry tools. The science behind density functional theory (DFT) calculations and molecular dynamics (MD) simulations is explained and applied in the context of multiscale modeling. Special emphasis is placed on solid-state materials and aqueous/biological systems found in engineering. Students are encouraged to apply the methods discussed in class to their own research topics. Prerequisites: EECE 203 and 204, or permission of the instructor. (Prior to FL2015, this course was numbered: E33 591.) Credit 3 units. EN: TU

E44 EECE 551 Metabolic Engineering and Synthetic Biology
Synthetic Biology is a transformative view of biology from "observation approach" to "synthesis approach." It is a new "engineering" discipline and aims to make the engineering of new biological function predictable, safe and quick. It will pave a wide range of applications to transform our views on production of sustainable energy and renewable chemicals, environmental problems, and human disease treatments. The field intersects with Metabolic Engineering in areas such as the design of novel pathways and genetic circuits for product generation and toxic chemical degradation. In this course, the field and its basis are introduced. First, relevant topics in biology, chemistry, physics and engineering are covered. Second, students will participate in brainstorming and discussion on new biology-based systems. Last, students will design and present new synthetic biology systems to solve real-world problems. (Prior to FL2015, this course was numbered: E33 596A.) No prerequisite. Both undergrad and graduate students can take this course. Credit 3 units. EN: TU

E44 EECE 552 Biomass Energy Systems and Engineering
This course offers background in the organic chemistry, biology and thermodynamics related to understanding the conversion of biomass. In addition, it includes relevant topics relating to biomass feedstock origin, harvest, transportation, storage, processing and pretreatment along with matters concerning thermo- and biochemical conversion technologies required to produce fuels, energy, chemicals and materials. Also, various issues with respect to biomass characterization, economic, and environmental impact are discussed. The main objective of the course is to introduce concepts central to a large-scale integrated biomass conversion system. (Prior to FL2015, this course was numbered: E33 495D/595D.) Credit 3 units. EN: TU

E44 EECE 554 Molecular Biochemical Engineering
This course is set for junior-level graduate students to bridge the gap between biochemical engineering theory and academic research in bioengineering. It covers common molecular biotechnologies (molecular biology, microbiology, recombinant DNA technology, protein expression, etc.), biochemical models (enzyme catalysis, microbial growth, bioreactor, etc.) and bioengineering methodologies (protein engineering, expression control systems, etc.). These theories and technologies are introduced in a manner closely related to daily academic research or biochemical industry. Areas of application include biofuel and chemical production, drug discovery and biosynthesis, bioremediation, and environmental applications. This course also contains a lab section (20–30%) that requires students to apply the knowledge learned to design experiments, learn basic experimental skills and solve current research problems. Prerequisites: EECE 101, Biol 2960, Biol 4810. (Prior to FL2015, this course was numbered: E33 595C.) Credit 3 units. EN: TU

E44 EECE 556 Bioenergy
A broad overview of the flow of energy, captured from sunlight during photosynthesis, in biological systems, and current approaches to utilize the metabolic potentials of microbes
and plants to produce biofuels and other valuable chemical products. An overall emphasis is placed on the use of large-scale genomic, transcriptomic and metabolomic datasets in biochemistry. The topics covered include photosynthesis, central metabolism, structure and degradation of plant lignocellulose, and microbial production of liquid alcohol, biodiesel, hydrogen & other advanced fuels. Course meets during the second half of the spring semester. Prerequisites: Biol 4810 or permission of instructor. (Prior to FL2015, this course was numbered: E33 4830/5830.) Credit 2 units.

E44 EECE 571 Industrial and Environmental Catalysis
Major industrial and environmental catalytic processes. Principal theories of heterogeneous catalysis. Experimental methods and techniques used to develop modern catalytic systems. Examples from the petrochemical industry, automotive exhaust systems and industrial emissions abatement. Prerequisites: Chem 112, 262. (Prior to FL2015, this course was numbered: E63 525.) Credit 3 units. EN: TU

E44 EECE 572 Advanced Transport Phenomena
Analytical tools in transport phenomena: Scaling, perturbation and stability analysis. Numerical computations of common transport problem with MATLAB tools. Low Reynolds number flows and applications to microhydrodynamics. Turbulent flow analysis and review of recent advances in numerical modeling of turbulent flows. Convective heat and mass transfer in laminar and turbulent flow systems. Introduction to two phase flow and multiphase reactors. Pressure-driven transport and transport in membranes, electrochemical systems, double layer effects and flow in microfluid devices. Prerequisites: EECE 501 (Transport phenomena) or equivalent senior level courses in fluid mechanics and heat transfer. (Prior to FL2015, this course was numbered: E63 514.) Credit 3 units. EN: TU

E44 EECE 574 Electrochemical Engineering
This course will teach the fundamentals of electrochemistry and the application of the same for analyzing various electrochemical energy sources/devices. The theoretical frameworks of current-potential distributions, electrode kinetics, porous electrode and concentrated solution theory will be presented in the context of modeling, simulation and analysis of electrochemical systems. Applications to batteries, fuel cells, capacitors, copper deposition will be explored. Pre/corequisites: EECE 501-502 (or equivalent), or permission of instructor. (Prior to FL2015, this course was numbered: E33 589.) Credit 3 units.

E44 EECE 576 Chemical Kinetics and Catalysis
This course reflects the fast, contemporary progress being made in decoding kinetic complexity of chemical reactions, in particular heterogeneous catalytic reactions. New approaches to understanding relationships between observed kinetic behavior and reaction mechanism are explained. Present theoretical and methodological knowledge are illustrated by many examples taken from heterogeneous catalysis (complete and partial oxidation), combustion and enzyme processes. Prerequisite: senior or graduate student standing. (Prior to FL2015, this course was numbered: E33 598.) Credit 3 units. EN: TU

E44 EECE 591 Energy and Buildings
There is a $2 trillion U.S. market in energy efficiency with paybacks of 4-5 years. This course is an introduction to energy use in the built environment and means and methods for evaluating and harvesting these financial benefits. It is based on fundamentals of energy usage in building systems. Building sciences for architectural envelope, heating and cooling systems, lighting and controls. Building/weather interaction and utility weather regression analyses. Building dynamics and rates of change in energy usage. Students work in groups to perform an energy audit for a building on campus. Prerequisite: senior or graduate student standing, or permission of instructor. (Prior to FL2015, this course was numbered: E33 495/595.) Credit 3 units.

E44 EECE 593 Energy and Environment
This course sets out to instruct the student on how to understand decision-making regarding energy and the environment, and provides a unique educational experience, wherein the challenges and potential solutions to meeting future energy needs are clearly elucidated via lectures and experiential learning. Topics include: overview of energy and the environment and associated challenges; description of power generation from coal, natural gas, biomass, wind, solar, hydro, geothermal and nuclear; political, environmental and social considerations; regulations, economics, decision-making; students gain experience with software capable of analyzing renewable energy projects worldwide, from backyard to power-plant scale systems. (Prior to FL2015, this course was numbered: E33 500A.) Credit 3 units.

E44 EECE 595 Principles of Methods of Micro and Nanofabrication
A hands-on introduction to the fundamentals of micro- and nanofabrication processes with emphasis on cleanroom practices. The physical principles of oxidation, optical lithography, thin film deposition, etching and metrology methods will be discussed, demonstrated and practiced. Students will be trained in cleanroom concepts and safety protocols. Sequential microfabrication processes involved in the manufacture of microelectronic and photonic devices will be shown. Training in imaging and characterization of micro- and nanostructures will be provided. Prerequisite: graduate or senior standing or permission of the instructor. Same as E37 MEMS 5611 Credit 3 units. EN: TU

E44 EECE 597 EECE Project Management
An introduction to the theory and practice of engineering project management, with an emphasis on projects related to environmental protection and occupational health and safety. Topics include: project definition and justification; project evaluation and selection; financial analysis and cost estimation; project planning, including scheduling, resourcing and budgeting; project oversight, auditing and reporting; and effective project closure. Students will be introduced to commonly used project management tools and systems, such as work breakdown structures, network diagrams, Gantt charts, and project management software. Topics will also include project management in different organizational structures and philosophies; creating effective project teams; and managing projects in international settings. Prerequisites: enrolled in MEng program; senior or higher standing.
Credit 3 units.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Description</th>
<th>Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>E44 EECE 599</td>
<td>Master's Research</td>
<td>variable, max 9 units</td>
</tr>
<tr>
<td>E44 EECE 600</td>
<td>Doctoral Research</td>
<td>variable, max 9 units</td>
</tr>
<tr>
<td>E44 EECE 883</td>
<td>Master's Continuing Student Status</td>
<td></td>
</tr>
<tr>
<td>E44 EECE 885</td>
<td>Master's Nonresident</td>
<td></td>
</tr>
</tbody>
</table>