

# Energy, Environmental & Chemical Engineering

## About Energy, Environmental & Chemical Engineering

Our department focuses on environmental engineering, energy systems engineering and chemical engineering. We provide integrated and multidisciplinary programs of scientific education. Our mission is accomplished by: instilling a tradition of "lifelong learning"; a curriculum of fundamental education coupled with applications in advanced focal areas and strengthened by our breadth in other disciplinary areas; participation in cutting-edge research with faculty and industrial partners; and access to state-of-the-art facilities and instrumentation. Most undergraduate students in the department pursue the BS in Chemical Engineering degree, accredited by the Engineering Accreditation Commission of ABET (<http://www.abet.org>). Other students pursue the BS in Applied Science degree with a major in chemical engineering. The department offers a minor in environmental engineering science and, in collaboration with other engineering departments, we co-sponsor a minor in energy engineering and a minor in nanoscale science and engineering. Graduate degrees (Master of Engineering and Doctor of Philosophy) in Energy, Environmental & Chemical Engineering are offered by the department.

Chemical engineers are involved in the transfer of scientific discoveries to modern technologies and novel products that benefit society and minimize the impact on the environment. They deal with multiscale aspects of generating clean energy, producing novel and superior materials, and utilizing the biological revolution to manufacture new products. They are involved in the development and manufacture of consumer products, as well as in design, operation and control of processes in a variety of industries (e.g., petroleum, petrochemical, chemical, consumer products, food, feed and pharmaceuticals). Their broad training in basic sciences (e.g., chemistry, physics, biology, mathematics) coupled with a strong foundation in chemical engineering principles (e.g., thermodynamics, mass and energy balances, transport phenomena, kinetics, separations, reaction engineering, control, product development and process design) makes them invaluable team members and leaders in any engineering enterprise. It also prepares them well for graduate studies in biochemical, biomedical, chemical, environmental and materials engineering. In addition, the BS degree in Chemical Engineering

is a great starting point for pursuing a degree in business, law or medicine.

The curriculum is planned so as to provide students with a strong background in basic chemical engineering concepts, while allowing individual latitude to emphasize study in a specialized area or obtain added breadth both within and outside chemical engineering. A contemporary approach to chemical engineering is focused on the multiscale aspects of the discipline, consistent with modern developments in computer-supported problem solving. Molecular-level understanding is utilized in product development and process design, which in turn are evaluated in terms of their impact on the environment and society according to the principles of green engineering.

## Mission Statement

The mission of the department is to teach chemical engineering principles and their application in an inspiring learning environment and to prepare students for engineering careers by developing the skills of critical thinking, analytical abilities and communication proficiency, and by instilling a sense of professional ethics and societal responsibility.

## Advising

The department takes pride in the mentoring of undergraduate students. Each student who declares chemical engineering as a (potential) major is assigned an academic adviser from the full-time department faculty. Typically, the same adviser follows the student's academic progress and serves as a mentor from the first year through graduation.

**Phone:** 314-935-5545  
**Website:** <http://eece.wustl.edu/undergraduate/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. Wittcoff 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

**Yinjie Tang** (<https://engineering.wustl.edu/Profiles/Pages/Yinjie-Tang.aspx>)  
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

**Jian Wang** (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=126>)  
PhD, California Institute of Technology  
Aerosol properties and processes, nucleation and new particle formation, aerosols in the marine environment, effects of aerosols on cloud microphysical properties and macrophysical structure, and development of advanced aerosol instruments

## 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

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

**Brent Williams** (<https://engineering.wustl.edu/Profiles/Pages/Brent-Williams.aspx>)  
Raymond R. Tucker Distinguished InCEES Career Development Associate Professor  
PhD, University of California, Berkeley  
Aerosols, global climate issues, atmospheric sciences

**Fuzhong Zhang** (<https://engineering.wustl.edu/Profiles/Pages/Fuzhong-Zhang.aspx>)  
PhD, University of Toronto  
Metabolic engineering, protein engineering, synthetic and chemical biology

## Assistant Professors

**Peng Bai** (<https://engineering.wustl.edu/Profiles/Pages/Peng-Bai.aspx>)  
PhD, Tsinghua University, China  
Develop next-generation batteries, probe the in situ electrochemical dynamics of miniature electrodes down to nanoscales, capture the heterogeneous and stochastic nature of advanced electrodes, and identify the theoretical pathways and boundaries for the rational design of materials, electrodes and batteries through physics-based mathematical modeling and simulation

**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

**Fangqiong Ling** (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=178>)  
PhD, University of Illinois at Urbana-Champaign  
Microbial ecosystem analysis and modelling, process modelling, machine learning, NextGen sequencing bioinformatics, environmental microbiology, and bioreactor design

**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** (<https://eece.wustl.edu/faculty/Pages/faculty.aspx?bio=170>)  
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

**Doug Allen**  
PhD, Purdue University  
USDA Research Scientist, Danforth Plant Sciences Center  
Metabolic networks of oilseed plants

**Nathan Ravi**  
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

## Majors

Please refer to the sections below for information about the **Bachelor of Science in Chemical Engineering (BSChE)** (p. 3), **double majors and the pre-medical program** (p. 4), and the **Bachelor of Science in Applied Science (Chemical Engineering)** (p. 4).

## Bachelor of Science in Chemical Engineering

The BSChE degree program is designed to provide students with comprehensive training in chemical engineering fundamentals. This degree program is accredited by the Engineering

Accreditation Commission of ABET (<http://www.abet.org>). The BSChE degree requires satisfactory completion of a minimum of 126 units as indicated in Table 1 (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/cherequirements>). From the courses listed in Table 1, the humanities and social sciences courses (except Engr 450X courses) may be taken pass/fail. A sample year-by-year BSChE curriculum is shown in Table 2 (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/checurriculum>).

The program of study consists of 26 units of physical and biological sciences (i.e., biology, chemistry and physics); 21 units of mathematics and engineering computing; 40 units of core chemical engineering courses; 21 units of humanities, social sciences and technical writing; and 18 units of chemical engineering electives. The chemical engineering electives permit students to tailor their studies toward specific goals such as obtaining more depth in a chemical engineering subdiscipline (e.g., materials) or increasing breadth by choosing courses from different subdisciplines. Some of these 18 units may be taken in other engineering departments or in the natural sciences or physical sciences. Students in collaboration with their advisers design a course of study (subject to certain requirements) for the chemical engineering electives. Consult the EECE department (<https://eece.wustl.edu/undergraduate/programs>) website for more details, including the requirements that must be satisfied by these chemical engineering electives.

Please refer to Table 1: BSChE Requirements (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/cherequirements>).

Please refer to Table 2: Sample BSChE Curriculum (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/checurriculum>).

The curriculum is designed to provide opportunities for students to explore areas of interest within chemical engineering. In addition to the accredited BS degree in Chemical Engineering, another choice is to pursue the course of study leading to the BS degree in Applied Science with a major in chemical engineering.

## Program Educational Objective

The Program Educational Objective for the BSChE degree program is to provide a chemical engineering foundation that enhances the graduate's experiences and abilities in their chosen field.

## Double Majors and Pre-Medical Program

Some students may be able to take more than the 126-unit minimum during a four-year program, especially if they have Advanced Placement units. This permits the choice of additional free electives from such areas as biology, computer science, humanities, social sciences or other engineering courses. It also

provides an opportunity to pursue a double major. The rules for combining majors in engineering and multiple majors involving other university divisions are described in the Combined Majors and/or Multiple Degrees (<http://bulletin.wustl.edu/undergrad/engineering>) section of the School of Engineering & Applied Science.

Traditionally, the undergraduate chemical engineering degrees (both the accredited degree and the applied science option) have been popular with students interested in medicine because the curriculum automatically satisfies many of the pre-medical requirements. Many of the additional needed courses can be taken as electives.

## Bachelor of Science in Applied Science (Chemical Engineering)

This degree serves students who wish to be exposed to key chemical engineering principles yet seek a more flexible curriculum. The BS in Applied Science (Chemical Engineering) requires 18 units of 300-level or higher chemical engineering core courses. Consult the EECE department (<https://eece.wustl.edu/undergraduate/programs>) website for the specific requirements needed to earn this degree.

## Minors

Please visit the following pages for information about the

- Minor in Environmental Engineering Science (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/minor-environmental>)
- Minor in Energy Engineering (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/minor-energy>)
- Minor in Nanoscale Science & Engineering (<http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/minor-nanoscale>)

## Courses

Visit online course listings to view semester offerings for E44 EECE (<https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E44&crslvl=1:5>).

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### E44 EECE 100 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: freshman standing. Credit variable, maximum 3 units.

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### E44 EECE 101 Introduction to Energy, Environmental and Chemical Engineering

Key technical issues that face our society and some of the emerging technologies that hold promise for the future are

examined and discussed. Relationship to chemical engineering principles is emphasized. (Prior to FL2015, this course was numbered: E63 146A.)  
Credit 3 units. EN: TU

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**E44 EECE 112 Earth's Future: Causes and Consequences of Global Climate Change**

Earth's Future: Causes and Consequences of Global Climate Change examines 1) the physical basis for climate change; 2) how climates are changing and how we know and assess that climates are changing; and 3) the effects of climate change on natural and human systems. The course is team-taught and will involve participation by scholars across the university with expertise in specific subjects. This is a broad, introductory course for first year students and presumes no special subject matter knowledge on the part of the student.

Same as I50 InterD 101

Credit 3 units. A&S: FYBB A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

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**E44 EECE 200 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: sophomore standing.

Credit variable, maximum 3 units.

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**E44 EECE 201 Engineering Analysis of Chemical Systems**

Introduction to the use of mathematics and methods of engineering in analysis of chemical and physical processes. Use of conservation balances and basic rate laws to describe processes with and without chemical reaction in both transient and steady state conditions. Prerequisites: Chem 112A, Math 233. Corequisites: EECE 203, Math 217. (Prior to FL2015, this course was numbered: E63 351.)

Credit 3 units. EN: TU

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**E44 EECE 202 Computational Modeling in Energy, Environmental and Chemical Engineering**

Computational tools to solve engineering, design and scientific problems encountered in thermodynamics, transport phenomena, separation processes and reaction kinetics. Introduction to programming skills in MATLAB and use of various MATLAB toolboxes. Theory and application of numerical methods for solution of common problems, including methods for root-finding/optimization, curve fitting (regression, interpolation, and spline), integration, differentiation, and ordinary differential equations and boundary value problems. Illustrative application examples. Prerequisites: Math 233 and Math 217, or permission of instructor.

Credit 3 units. EN: TU

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**E44 EECE 203 Thermodynamics I in EECE**

Classical thermodynamics. First and second laws, properties of pure substances, mixtures, and solutions. Phase equilibria, chemical reaction equilibria. Prerequisites: Chem 111A, Math 132, Physics 117A. (Prior to FL2015, this course was numbered: E63 320.)

Credit 3 units. EN: TU

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**E44 EECE 204 Thermodynamics II in EECE**

Molecular motions, kinetic theory of gases, kinetic theory of dense phases, chemical kinetics. Prerequisite: EECE 203. (Prior to FL2015, this course was numbered: E63 359.)

Credit 3 units. EN: TU

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**E44 EECE 210 Introduction to Environmental Engineering**

The objective of this course is to introduce students to the field of environmental engineering. The course emphasizes basic principles of mass and energy conservation which govern physical, chemical and biological processes. Applications include the estimation of contaminant concentrations and the design of environmental controls. (Prior to FL2015, this course was numbered: E63 262.)

Credit 3 units. EN: TU

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**E44 EECE 300 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: junior standing.

Credit variable, maximum 3 units.

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**E44 EECE 301 Transport Phenomena I: Basics and Fluid Mechanics**

Engineering principles involved in the exchange of heat and matter in chemical processes. Laws governing the flow of liquids and gases in laboratory and plant equipment. Prerequisites: EECE 202, EECE 203, Math 217, ESE 318, or permission of instructor. (Prior to FL2015, this course was numbered: E63 367.)

Credit 3 units. EN: TU

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**E44 EECE 302 Transport Phenomena II: Mass Transfer**

Engineering principles involved in the exchange of heat and matter in chemical processes. Laws governing the flow of liquids and gases in laboratory and plant equipment. Prerequisite: EECE 301 (Prior to FL2015, this course was numbered: E63 368.)

Credit 3 units. EN: TU

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**E44 EECE 303 Transport Phenomena III: Energy Transfer Processes**

Introductory treatment of the principles of heat transfer by conduction, convection or radiation. Mathematical analysis of steady and unsteady conduction along with numerical methods. Analytical and semi-empirical methods of forced and natural convection systems. Boiling and condensation heat transfer. Radiation between black-body and real surfaces. Radiation network analysis. Corequisite: EECE 302 or equivalent. (Prior to FL2015, this course was numbered: E63 369.)

Credit 3 units. EN: TU

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**E44 EECE 304 Mass Transfer Operations**

Stagewise and continuous mass transfer operations, including distillation, gas absorption, humidification, leaching, liquid extraction, and membrane separations. Prerequisites: Math 217, EECE 201 and EECE 203. (Prior to FL2015, this course was numbered: E63 357.)

Credit 3 units. EN: TU

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#### **E44 EECE 305 Materials Science**

Introduces the chemistry and physics of engineering materials. Emphasis on atomic and molecular interpretation of physical and chemical properties, the relationships between physical and chemical properties, and performance of an engineering material. Prerequisite: Math 217, Chem 111A. (Prior to FL2015, this course was numbered: E63 325.)

Credit 3 units. EN: TU

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#### **E44 EECE 311 Green Engineering**

Strategies and methods for waste minimization and pollutant emission reduction. Principles of green engineering. Environmental transport and fate modeling. Design of heat and mass exchange networks for energy and waste reduction. Prerequisite: EECE 203 or permission of instructor. (Prior to FL2015, this course was numbered: E63 345.)

Credit 3 units. EN: TU

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#### **E44 EECE 400 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: senior standing.

Credit variable, maximum 6 units.

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#### **E44 EECE 401 Chemical Process Dynamics and Control**

A state-of-the-art industrial virtual plant is used for the development of dynamic simulations, selection of instrumentation, statistical analysis of variability, and implementation of process control to improve process operation and efficiency. Prerequisites: Math 217 and EECE 201. (Prior to FL2015, this course was numbered: E63 462.)

Credit 3 units. EN: TU

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#### **E44 EECE 402 ChE Capstone**

Application of engineering science and design, fundamentals of process and product development, computational techniques and economic principles to design of chemical and biological processes and procedures. A design project and/or an AIChE national design contest is included. Prerequisites: EECE 203, 301, 302, 304 and 403.

Credit 3 units. EN: TU

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#### **E44 EECE 403 Chemical Reaction Engineering**

Introduction to chemical reaction engineering principles and applications in process and product development. Evaluation of reaction rates from mechanisms and experimental data, quantification of pertinent transport effects and application to reactor and product design. Prerequisites: EECE 201, 203, 204, 301. (Prior to FL2015, this course was numbered: E63 471.)

Credit 3 units. EN: TU

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#### **E44 EECE 405 Unit Operations Laboratory**

Laboratory projects focused on the application of chemical engineering principles (transport, thermodynamics, separations, etc.). Student teams design multi-week experiments utilizing unit operations equipment to solve realistic engineering problems. Includes analysis of safety and instrumentation. One laboratory period each week with supplemental lecture

sessions. Emphasis on independent learning, teamwork, and technical communication skills. Prerequisites: EECE 301, 304; Corequisite: EECE 403.

Credit 4 units. EN: TU

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#### **E44 EECE 411 International Experience in EECE**

This course provides undergraduate students with an international experience related to energy, environmental and/or chemical engineering. The country visited varies from year to year with one or more EECE faculty members developing the program in collaboration with McDonnell Global Energy and Environment Partnership (MAGEEP) universities. Example activities include conducting field or laboratory research, attending short courses taught by MAGEEP university faculty members, and visiting attractions relevant to the course focus (e.g., industrial facilities). Students also gain an understanding of the local culture and history of the country visited. Course content includes a seminar series in the spring semester prior to the international experience, a two-to-three week visit to the location of study, and a follow-up student project and presentations during the fall semester which draw upon the experience. Students enroll in EECE 411 for the fall semester following the trip. (Prior to FL2015, this course was numbered: E33 401.)

Credit 3 units. EN: TU

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#### **E44 EECE 412 Sustainability Exchange: Community and University Practicums**

The Sustainability Exchange will bring together students working in transdisciplinary teams to tackle real-world energy, environmental, and sustainability problems through an experiential form of education. Students will participate in projects with clients and partners on- or off-campus, developed with and guided by faculty advisers drawn from across the university, with the intention of delivering an applicable end-product that explores "wicked" problems requiring innovative methods and solutions. These projects matter to the client or partner. The team-based project will be complemented by a seminar that will explore the field of design and design thinking through problem solving strategies and methodologies drawn from a wide range of creative practices, including design, engineering and science, as well as contemporary topics in energy, environment and sustainability. Students will draw on these topics to influence their projects. This course is open to all undergraduate juniors and seniors. An application is required; students will be accepted off the wait list following the application process.

Same as I50 InterD 405

Credit 3 units. A&S IQ: SSC Arch: SSC Art: SSC EN: S

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#### **E44 EECE 413 Energy Conversion and Storage**

This course takes a thermodynamics perspective to analyzing electricity production and distribution systems, which are imperative to modern society. The course contains a hands-on laboratory component. Traditional and advanced heat engine cycles will be discussed. Opportunities and challenges with renewable energy technologies will be covered. Essential to the widespread adoption of renewable electricity sources, and also to increasing energy efficiency, are smart grid and smart building technologies. The goal is to give the student a quantitative overview, while focusing in on the details of a few important technological examples. Prerequisites: E44 EECE 203 or E37 MEMS 301 and E44 EECE 301 or E37 MEMS 3410; or instructor permission.

Credit 3 units. EN: TU

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**E44 EECE 414 New Product and Process Development**

An overview of product development, innovative solutions to technical problems, designed experimentation, evaluation of abstract data, product design, and the basics of intellectual property. Prerequisites: junior standing and Chem 251, EECE 203 or by permission of the instructor. (Prior to FL2015, this course was numbered: E63 450.)

Credit 3 units. EN: TU

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**E44 EECE 416 Industrial Process Safety**

Analysis and management of fire and explosion hazards. Control of human exposure to toxic materials. Codes, standards, and regulations. Transportation and disposal of noxious substances. Analysis of drift from clouds, flares, and stacks. Venting of pressure vessels. Hazard evaluation and safety review of processes. Emergency plans for accidents and disasters. Prerequisite: EECE 203 or Chem 421 or permission of instructor. (Prior to FL2015, this course was numbered: E63 479/569.)

Credit 3 units. EN: TU

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**E44 EECE 418 Principles of Surface and Colloid Science**

Interfacial phenomena play key roles in such industrial operations as emulsification, catalysis, and detergency. Introduction to principles of surface science. Particular attention to describing the nature of the liquid/gas, liquid/liquid, solid/liquid, and solid/gas interfaces. Specific topics include methods of measuring surface tension, interfacial adsorption, surface area and particle size determinations, dispersion stabilization/flocculation, emulsification, and wetting. Prerequisite: EECE 203 or permission of instructor. (Prior to FL2015, this course was numbered: E63 480.)

Credit 3 units. EN: TU

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**E44 EECE 420 Properties of Materials**

A detailed look at the mechanical, chemical and surface properties of materials. Topics include elastic properties; plastic deformation; viscoelastic behavior; chemical resistance; corrosion resistance; and the electromagnetic properties of metal, plastic, ceramic and composite systems. Prerequisite: EECE 305. (Prior to FL2015, this course was numbered: E63 476.)

Credit 3 units. EN: TU

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**E44 EECE 423 Senior Thesis**

Research project to be selected by the student with the permission and recommendation of a faculty supervisor and the approval of the department chair. At conclusion of project, student prepares a report in the form of a senior thesis. (Prior to FL2015, this course was numbered: E63 499.)

Credit variable, maximum 6 units.

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**E44 EECE 424 Digital Process Control Laboratory**

Applications of digital control principles to laboratory experiments supported by a networked distributed control system. Lecture material reviews background of real-time programming, data acquisition, process dynamics, and process control. Exercises in data acquisition and feedback control design using simple and advanced control strategies. Experiments in flow, liquid level, temperature, and pressure control. Term project. Prerequisite: ESE 441 or EECE 401 or equivalent. (Prior to FL2015, this course was numbered: E63 433.)

Credit 3 units. EN: TU

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**E44 EECE 425 Environmental Engineering Laboratory**

Laboratory experiments to illustrate the application of engineering fundamentals to environmental systems. Applications of experimental design and data analysis principles. Introduction to relevant analytical instrumentation and laboratory techniques. Laboratory work supported by theoretical analysis and modeling as appropriate. Prerequisite: consent of instructor. (Prior to FL2015, this course was numbered: E63 408A/508A.)

Credit 3 units. EN: TU

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**E44 EECE 426 ChE Honors Design Project for AIChE Student Contest Problem**

Application of engineering science and design, fundamentals of process and product development, computational techniques and economic principles to design of chemical and biological processes and procedures in solving the AIChE national student contest problem. Up to two single and up to two group (2-3 per group) solutions may be chosen for national competition. Concurrent with EECE 402. Prerequisites: EECE 203, 301, 302, 304 and 403. (Prior to FL2015, this course was numbered: E63 478B.)

Credit 1 unit. EN: TU

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**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.

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**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 a 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.

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**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.

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**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.

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#### **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: EECE 301, ESE 318 and 319. (Prior to FL2015, this course was numbered: E63 518.) Credit 3 units. EN: TU

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#### **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

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#### **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

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#### **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.

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#### **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.)

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#### **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.

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#### **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

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#### **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

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#### **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

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#### **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: Chem 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**

Introduction to sustainability and sustainable air quality. Systems science as an organizing principle for air quality management. Setting of air quality goals. Observing the status and trends. Establishing causal factors: energy use and chemical processing. Natural sources and variability. Corrective actions to reach air quality goals. Process design for emission reductions. Adoptive response to air pollution episodes. A web-based class project is conducted through the semester. (Prior to FL2015, this course was numbered: E63 549.)

Credit 3 units. EN: TU

**E44 EECE 531 Environmental Organic Chemistry**

Fundamental, physical-chemical examination of organic molecules (focused on anthropogenic pollutants) in aquatic (environmental) systems. Students learn to calculate and predict chemical properties that are influencing the partitioning of organic chemicals within air, water, sediments and biological systems. This knowledge is based on understanding intermolecular interactions and thermodynamic principles. 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 533 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 brain-storming 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, economics and environmental impact are discussed. The main objective of the course is to introduce concepts central to a large-scale integrated biomass bioconversion system. (Prior to FL2015, this course was numbered: E33 495D/595D.)

Credit 3 units. EN: TU

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#### **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

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#### **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.

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#### **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

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#### **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

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#### **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.

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#### **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 behaviour and reaction mechanism will be explained. Present theoretical and methodological knowledge will be illustrated by many examples taken from heterogeneous catalysis (complete and partial oxidation), combustion and enzyme processes. Prerequisite: senior or graduate student standing, or permission of instructor.

Credit 3 units. EN: TU

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#### **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.

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#### **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.

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**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.

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**E44 EECE 599 Master's Research**

Credit variable, maximum 9 units.

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