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; offering a curriculum of fundamental education coupled with applications in advanced focal areas and strengthened by our breadth in other disciplinary areas; participating in cutting-edge research with faculty and industrial partners; and providing access to state-of-the-art facilities and instrumentation. Most undergraduate students in the department will pursue the BS in Chemical Engineering degree, accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org), or the BS in Environmental Engineering degree (launched spring 2019). Other students may 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, Master of Science and Doctor of Philosophy) in Energy, Environmental & Chemical Engineering are also 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 the design, operation and control of processes in a variety of industries (e.g., petroleum, petrochemical, chemical, consumer products, food, feed, 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, 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 in Chemical Engineering is a great starting point for pursuing a degree in business, law or medicine.

Environmental engineers apply scientific and engineering principles to assess, manage and design sustainable systems for the protection of human and ecological health. The designs and technologies that they develop provide safe and sufficient public water supplies, enable effective and efficient treatment and resource recovery from wastewater and other wastes, and control pollutant releases that protect water, soil and air quality. Environmental engineers also seek to understand the effect of technological advances on the environment and to identify opportunities to improve the environmental sustainability of new technologies. Environmental engineers have broad training in basic sciences, mathematics and computational approaches as well as an engineering foundation that includes mass and energy balances, thermodynamics, transport phenomena, and chemical, physical and biological treatment processes. The training of environmental engineers also includes natural science and environmental social science and the humanities. This training prepares environmental engineers to apply technological solutions within specific environmental and societal contexts. Environmental engineering graduates are prepared to enter professional practice and to pursue graduate study in environmental engineering and allied fields.

The curricula are planned to provide students with a strong background in basic engineering concepts while allowing students individual latitude to emphasize study in a specialized area or to obtain added breadth both within and outside of chemical or environmental engineering.

Mission Statement

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

Advising

The department takes pride in its mentoring of undergraduate students. Each student who declares chemical or environmental 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:	https://eece.wustl.edu/academics/undergraduate-programs/index.html (https://eece.wustl.edu/academics/undergraduate-programs/)

Faculty

Chair and Endowed Professor

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

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

Vijay Ramani **(**https://engineering.wustl.edu/faculty/Vijay-Ramani.html**)**
Director of Graduate Studies
Roma B. and Raymond H. Wittcoff Distinguished University Professor
PhD, University of Connecticut
Electrochemical engineering, energy conversion

Professors

Zhen (Jason) He **(**https://engineering.wustl.edu/faculty/Zhen-Jason-He.html**)**
PhD, Washington University
Environmental biotechnology, bioenergy production, biological wastewater treatment, resource recovery, bioelectrochemical systems, sustainable desalination technology, anaerobic digestion, forward osmosis, membrane bioreactors

Young-Shin Jun **(**https://engineering.wustl.edu/faculty/Young-Shin-Jun.html**)**
PhD, Harvard University
Aquatic processes, molecular issues in chemical kinetics, environmental chemistry, surface/physical chemistry, environmental engineering, biogeochemistry, nanotechnology

Randall Martin **(**https://engineering.wustl.edu/faculty/Randall-Martin.html**)**
PhD, Harvard University
Characterizing atmospheric composition to inform effective policies surrounding major environmental and public health challenges ranging from air quality to climate change

Palghat A. Ramachandran **(**https://engineering.wustl.edu/faculty/Palghat-Ramachandran.html**)**
PhD, University of Bombay
Chemical reaction engineering, applied mathematics, process modeling, waste minimization, environmentally benign processing

Yinjie Tang **(**https://engineering.wustl.edu/faculty/Yinjie-Tang.html**)**
PhD, University of Washington, Seattle
Metabolic engineering, bioremediation

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

Jian Wang **(**https://engineering.wustl.edu/faculty/Jian-Wang.html**)**
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 struct

Associate Professors

Rajan Chakrabarty **(**https://engineering.wustl.edu/faculty/Rajan-Chakrabarty.html**)**
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/faculty/Marcus-Foston.html**)**
PhD, Georgia Institute of Technology
Utilization of biomass resources for fuel and chemical production, renewable synthetic polymersure, and development of advanced aerosol instruments

Tae Seok Moon **(**https://engineering.wustl.edu/faculty/Tae-Seok-Moon.html**)**
PhD, Massachusetts Institute of Technology
Metabolic engineering and synthetic biology

Brent Williams (https://engineering.wustl.edu/faculty/Brent-Williams.html)
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/faculty/Fuzhong-Zhang.html)
PhD, University of Toronto
Metabolic engineering, protein engineering, synthetic and chemical biology

Assistant Professors

Peng Bai (https://engineering.wustl.edu/faculty/Peng-Bai.html)
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

Fangqiong Ling (https://engineering.wustl.edu/faculty/Fangqiong-Ling.html)
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/faculty/Kimberly-Parker.html)
PhD, Stanford University
Investigation of environmental organic chemistry in natural and engineered systems

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

Research Assistant Professor

Benjamin Kumfer (https://engineering.wustl.edu/faculty/Benjamin-Kumfer.html)
DSc, Washington University
Advanced coal technologies, biomass combustion, aerosol processes and health effects of combustion-generated particles

Professor of Practice

John Reardon (https://engineering.wustl.edu/faculty/John-Reardon.html)
MS, University of New Mexico
Entrepreneurial engineering

Senior Lecturers

Janie Brennan (https://engineering.wustl.edu/faculty/Janie-Brennan.html)
Director of Undergraduate Studies
PhD, Purdue University
Biomaterials, chemical engineering, engineering education

Raymond Ehrhard (https://engineering.wustl.edu/faculty/Ray-Ehrhard.html)
BS, Missouri University of Science and Technology
Water and wastewater treatment technologies, process energy management

Lecturers

Trent Silbaugh (https://engineering.wustl.edu/faculty/Trent-Silbaugh.html)
PhD, University of Washington
Chemical engineering

Avni Solanki (https://engineering.wustl.edu/faculty/Avni-Solanki.html)
PhD, University of Florida
Wastewater, sustainable development, environmental engineering, and engineering education

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

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

Keith Tomazi
PhD, University of Missouri-Rolla
Process development engineering

Grigoriy Yablonsky
PhD, Boreskov Institute of Catalysis
Chemical reaction engineering and heterogeneous catalysis

Senior Professor

Milorad P. Dudukovic
Laura and William Jens Professor
PhD, Illinois Institute of Technology
Chemical reaction engineering, multiphase reactors, visualization of multiphase flows, tracer methods, environmentally benign processing

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

Majors

Please visit the following pages for information about the energy, environmental and chemical engineering majors:

- Bachelor of Science in Chemical Engineering (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/bs-chemical/)
- Bachelor of Science in Environmental Engineering (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/bs-environmental/)
- Bachelor of Science in Applied Science (Chemical Engineering) (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/bs-applied-chemical/)
- Double Majors and the Pre-Medical Program (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/double-majors-premed/)

Minors

Please visit the following pages for information about the energy, environmental and chemical engineering minors:

- 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).

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.

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.
Credit 3 units. EN: TU

E44 EECE 103 Topics in 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. This course provides a broader context for content delivered in concurrent core chemical and environmental engineering courses.
Credit 1 unit.

E44 EECE 140 To Sustainability and Beyond: People, Planet, Prosperity (P3)
This course combines interdisciplinary instruction with applied project work. Students will be introduced to global concepts in sustainability and examine how they relate to specific issues in the greater St. Louis community, learning what it means to be civic-minded stewards of social and ecological systems. In addition, students will work on developing the critical "soft skills" needed for success on the job, such as effective communication techniques, project management, and leadership. Students will emerge from the course with a systems-level understanding of sustainability, a working knowledge of the fundamentals of community engagement, and an appreciation for values-based civic stewardship. Experience in this course will prepare students for applied project-based work in other courses or internships, regardless of academic discipline. This course is for first-year (non-transfer) students only.
Same as I60 BEYOND 140
Credit 3 units. A&S: FYS A&S IQ: SSC EN: S

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.

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: CSE 131 and Math 217, or permission of instructor
Credit 3 units. EN: TU

E44 EECE 204 Thermodynamics II in EECE
Molecular motions, kinetic theory of gases, kinetic theory of dense phases, chemical kinetics. Prerequisite: EECE 205 or EECE 201 and EECE 203 or permission of instructor.
Credit 3 units. EN: TU

E44 EECE 205 Process Analysis and Thermodynamics
This course is an introduction to the use of mathematics and methods of engineering in the analysis of chemical and physical processes. It will address the use of balances (e.g., mass, energy, entropy) to describe processes with and without chemical reactions in both transient and steady-state conditions as well as classical thermodynamics focused on processes, first and second laws, and properties of pure substances. Prerequisite: Chem 112A or Chem 106. Corequisite: Math 217 or permission of instructor.
Credit 4 units. EN: TU

E44 EECE 210 Introduction to Environmental Engineering
The objective of this course is to introduce students to the field of environmental engineering. The course will emphasize 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. Prerequisites: Chem 112A or Chem 106, Math 132, or permission of instructor
Credit 3 units. EN: TU

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.

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. Corequisite: ESE 318; Prerequisites: EECE 205 or both EECE 201 and EECE 203, or permission of instructor.
Credit 3 units. EN: BME T, TU

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
Credit 3 units. EN: BME T, TU

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.
Credit 3 units. EN: BME T, TU

E44 EECE 304 Mass Transfer Operations
Stagewise and continuous mass transfer operations, including distillation, gas absorption, humidification, leaching, liquid extraction, and membrane separations. Corequisites: EECE 204, EECE 202, or permission of instructor
Credit 3 units. EN: BME T, TU

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 or Chem 105, or permission of instructor.
Credit 3 units. EN: BME T, TU

E44 EECE 306 Biology in EECE
The course provides an introduction to molecular biology, biochemistry, microbiology, and biotechnology. The course focuses on an engineering approach to microbiology and molecular biology. Topics include basics of molecular biology, mathematical analysis of biological systems, genetic engineering, and biotechnological applications. Corequisite: Math 217, or permission of instructor
Credit 3 units. EN: TU

E44 EECE 309 Environmental Engineering Fate and Transport
The objective of this course is to introduce students to the fundamental processes that control contaminant fate and transport in the natural and built environment. The course will highlight mass transport and transformation in surface water, soil and groundwater, and atmosphere. Students will be introduced to environmental transport modeling software to solve applied problems. Prerequisites: EECE 210, EECE 301, or permission of instructor.
Credit 3 units. EN: TU

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: Math 217 or permission of instructor.
Credit 3 units. EN: BME T, TU

E44 EECE 314 Air Quality Engineering with Lab
Introduction to air quality and pollution control. Pollutant emissions, atmospheric chemistry, and fate. Air pollution meteorology and atmospheric dispersion. Application of chemistry, thermodynamics, and fluid mechanics in the selection and design of air pollution control equipment. Labs to measure air quality and demonstrate control principles. Prerequisite: EECE 205 or EECE 201 and EECE 203, or permission of instructor
Credit 4 units. EN: TU

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. Prerequisite: EECE 301, EECE 304, or permission of instructor
Credit 3 units. EN: BME T, TU

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 304, EECE 401, EECE 403, or permission of instructor.
Credit 3 units. EN: BME T, TU

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. Corequisite: EECE 302 or 307, Prerequisite: EECE 204, or permission of instructor
Credit 3 units. EN: BME T, TU

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, EECE 304, ESE 326; Corequisite: EECE 307 or EECE 302, EECE 403, or permission of instructor
Credit 4 units. EN: TU

E44 EECE 407 Environmental Biotechnology
This course aims to provide students with a background in current environmental biotechnology and to stimulate ideas about future potential new technologies. Students will gain qualitative and quantitative skills related to bioreactor designs in environmental applications (e.g., activated sludge, anaerobic digester, membrane bioreactors). Special focus will be placed on the application of mathematical models that are currently widely used in wastewater engineering, such as the International Water Association models. Hands-on experience with biological water treatment process modelling will be provided. Finally, students will be encouraged to explore links between environmental biotechnologies and a "one health" approach to public health. Prerequisites: Biol 2960 or EECE 306, ESE 326, EECE 204, EECE 210, or permission of instructor.
Credit 3 units. EN: TU

E44 EECE 411 International Experience in EECE
This course will provide undergraduate students with an international experience related to energy, environmental and/or chemical engineering. The country visited will vary 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 will also gain an understanding of the local culture and history of the country visited. Course content will include 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 that draw upon the experience. Students will enroll in EECE 411 for the fall semester following the trip.
Credit 3 units. EN: BME T, TU

E44 EECE 412 Sustainability Exchange: Community and University Practicums
The Sustainability Exchange engages interdisciplinary teams of students 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 advisors drawn from across the University, ultimately delivering an applicable end-product that explores "wicked" problems requiring innovative methods and solutions. Past projects have included investigating soil impacts of de-icing practices on campus, collecting data on inequitable trash collection in neighborhoods, working with St. Louis City's building division to make buildings more energy efficient, and developing an understanding of how buildings impact birds on campus. Fall 2020 projects may include previously mentioned projects, and may also include helping a municipality develop a sustainability plan, working on sustainable investing practices, mitigating plastic pollution in the Mississippi, and developing composting toilets. The team-based project will be complemented by a seminar that will explore 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. The course is designed primarily for undergraduates, with preference given to seniors.
Same as I50 INTER D 405
Credit 3 units. A&S IQ: SSC Arch: SSC Art: CPSC, SSC EN: S

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 203 and E44 301.
Credit 3 units. EN: BME T, TU

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 permission of the instructor.

Credit 3 units. EN: TU

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.
Credit variable, maximum 6 units.

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.
Credit 3 units. EN: BME T, TU

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: EECE 210 or EECE 205 (or EECE 201 and EECE 203); Corequisite: ESE 326, or permission of instructor
Credit 3 units. EN: BME T, TU

E44 EECE 480 Entrepreneurial Engineering

Quality education with a background in engineering and science can lead engineers to create innovations with high potential value. Nevertheless, unlocking value from innovation is not an entirely intuitive enterprise, and success is not guaranteed. This course is created to better prepare students for a future of innovation and entrepreneurial success. The course outline comprises three phases of entrepreneurship: the creative phase, the critical phase, and the crusader phase. It endeavors to provide students with useful skills and practical experiences that are relevant to each phase. Each week will include a brief presentation to set the direction, followed by short discussions of the assigned case studies and a review of fundamental principles from the core text. Student teams will regularly present work to the group, create success metrics, and chart progress. The Creative Phase: The class will work in small groups to create a new business concept. Students will learn brainstorming techniques, leadership, teamwork, and business model innovation. With core values set as a foundation, teams will present their proposed business models and rational basis for income forecasting. The Critical Phase: The class will identify and challenge assumptions to assess commercial viability. Students will find third-party market research to size up the opportunity and gather real customer feedback to refine their strategy. Skills gaps will be appreciated and negotiated solutions sought. Financial and growth metrics will be established to measure success, and threats will be faced. Students will present their SWOT analysis (strengths, weaknesses, opportunities, and threats) and link this to their revised strategy (business model). The Crusader Phase: Students will learn what is "acceptable risk" and develop a growth mindset (in contrast with fixed mindset), gain power from emotional intelligence, deal with failures (decide to pivot or punt), and learn the difference between ideation and implementation. Students will make progress and get the word out, and they will prepare a short proposal for grant funding or investment with a suitable income stream. By the end of the semester, students will know how to create business model, how to work with teams, how to assess commercial viability, how to establish a rationale for financial forecast, how to assess skills and resource gaps, how to negotiate to fill in gaps, and how to write high-level proposals. Students will demonstrate their knowledge through written submissions and oral presentations.
Credit 3 units.

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 a unified manner to problems encountered in the areas of energy, environmental and chemical processes. A systems approach will be followed so that the general principles can be grasped, and the skills needed to develop mathematical models of seemingly different processes will be emphasized. This provides the students with general tools that they can apply later in their chosen field of research.
Credit 3 units.

E44 EECE 502 Advanced Thermodynamics in EECE

The objective of this course is to understand classical thermodynamics at a deeper level then is reached during typical undergraduate work. Emphasis will be placed on solving problems relevant to chemical engineering materials science. Prerequisite: E44 203 or equivalent.
Credit 3 units.

E44 EECE 503 Mathematical Methods in EECE

The course will introduce students to mathematical principles essential for graduate study in any engineering discipline. Applied mathematical concepts will be demonstrated by applications to various areas in energy, environmental, biomedical, chemical, mechanical, aerospace, electrical and civil engineering.
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: EECE 301, ESE 318 and 319.
Credit 3 units. EN: BME T, 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. Prerequisites: senior or graduate level standing, or permission of instructor
Credit 3 units. EN: BME T, 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.
Credit 3 units. EN: BME T, TU

E44 EECE 507 Kinetics and Reaction Engineering Principles

This course is aimed at a modern multiscale treatment of kinetics of chemical and biochemical reactions and the application of these fundamentals to analyze and design reactors. Application of reaction engineering principles in areas related to energy generation, pollution prevention, chemical and biochemical processes will be 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.
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 will require the student to work under the guidance of a faculty member.

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.
Credit 1 unit.

E44 EECE 510 Advanced Topics in Aerosol Science & Engineering

This course will be focused on the discussion of advanced topics in aerosol science and engineering and their applications in a variety of fields, including materials science, chemical engineering, mechanical engineering, and environmental engineering. Prerequisite: EECE 504.
Credit 3 units. EN: BME T, TU

E44 EECE 512 Combustion Phenomena

This course provides an introduction to fundamental aspects of combustion phenomena, including relevant thermochemistry, fluid mechanics, and transport processes as well as the interactions among them. Emphasis is on elucidation of the physico-chemical processes, problem formulation and analytic techniques. Topics covered include non-premixed and premixed flames, deflagrations and detonations, particle combustion, flame extinction, flame synthesis, pollutant formation and methods of remediation. Contemporary topics associated with combustion are discussed throughout. Prerequisites: graduate standing or permission of instructor.
Credit 3 units. EN: BME T, TU

E44 EECE 514 Atmospheric Science and Climate

This course will cover 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 will be placed on how our atmosphere and climate are altered in a world of changing energy production and land use. Prerequisites: Chemistry 112A, Physics 198, and junior or higher standing.
Credit 3 units. EN: BME T, 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 will focus on the following: (1) integral moment measurement techniques; (2) particle sizing and size distribution measuring techniques; and (3) particle composition measurement techniques. Related issues such as particle sampling and transportation, instrument calibration, and particle standards will also be covered.
Credit 3 units. EN: BME T, 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 will be 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. Prerequisites: EECE 210 or EECE 205 (or EECE 201 and EECE 203); Chem 261, or permission of instructor
Credit 3 units. EN: BME T, 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. Corequisites: EECE 204 and EECE 210 or equivalents, or permission of instructor
Credit 3 units. EN: BME T, 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; and (4) explores connections between environmental nanochemistry and environmental kinetic analysis at larger scales. This course will help 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.
Credit 3 units. EN: BME T, TU

E44 EECE 535 Environmental Data Science
Many of the grand challenges that we face today require understanding and manipulation of processes at the interface of natural and manmade environments. Oftentimes, such knowledge is acquired through data. Skills to effectively visualize and analyze data and build predictive models are valued across different sectors of the society. This is an application-driven course. Prerequisites: EECE 503 or equivalent, Math 217 or equivalent, EECE 503 or equivalent, and ESE 326 or equivalent; or permission of instructor.
Credit 3 units. EN: TU

E44 EECE 537 Environmental Resource Recovery
This course will focus on key concepts of resource recovery from wastes. Topics include energy, water, nutrient, and value-added compounds. The course will discuss technological advancements, environmental impacts, and techno-economic assessment of environmental resource recovery. The cutting-edge recovery technologies in full-scale applications or laboratory studies will be introduced. Students will be trained for critical thinking and review of literature information, practice technical analysis and writing, and conduct a concept design of recovery systems using the data from local wastewater treatment facilities. The course is valuable as a prerequisite to more advanced research in environmental engineering, as a technical education to stimulate graduate students' interest in environmental sustainability, and as an introduction to environmental constraints that are increasingly important to other engineering disciplines.
Credit 3 units.

E44 EECE 551 Metabolic Engineering and Synthetic Biology
Synthetic Biology is a transformative view of biology from "observation approach" to "synthesis approach." It is 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. No prerequisite. Both undergrad and graduate students can take this course.
Credit 3 units. EN: BME T, 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 includes relevant topics relating to biomass feedstock origin, harvest, transportation, storage, processing and pretreatment along with matters concerning thermo- and bio-chemical conversion technologies required to produce fuels, energy, chemicals, and materials. Also, various issues with respect to biomass characterization, economics and environmental impact will be discussed. The main objective of the course is to introduce concepts central to a large-scale integrated biomass bioconversion system.
Credit 3 units. EN: BME T, 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 will cover 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 will be 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, to learn basic experimental skills, and to solve current research problems. Prerequisites: EECE 101, Bio 2960, Bio 4810.
Credit 3 units. EN: BME T, 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.
Credit 3 units. EN: BME T, 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, and copper deposition will be explored. Pre-/corequisites: EECE 501-502 (or equivalent) or permission of instructor.
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 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: BME T, 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.

E44 EECE 599 Master's Research
Credit variable, maximum 9 units.