Energy, Environmental & Chemical Engineering

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

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

The department is a key participant in the university's Energy, Environment & Sustainability initiative, and it supports both the International Center for Energy, Environment and Sustainability (InCEES) and the McDonnell Academy Global Energy and Environment Partnership (MAGEEP). Major externally funded research centers in the department include the Consortium for Clean Coal Utilization, the Nano Research Facility (NRF) and Jens Environmental Molecular and Nanoscale Analysis Laboratory (Jens Lab), and the Center for Aerosol Science and Engineering (CASE).

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

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
Stifel and Quinette Jens Professor
PhD, University of California, Davis
Combustion, advanced energy systems, clean coal, aerosols, nanoparticle synthesis, rechargeable battery materials, thermal science

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. Wittecoff 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

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

PhD, University of Washington, Seattle
Metabolic engineering, bioremediation

Vice Dean for Education
DSc, Washington University
Air quality planning and management; aerosol science and engineering, green engineering

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

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

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

PhD, University of Virginia
Aerosol properties and processes, nucleation and new particle formation, aerosols in the marine environment, effects of aerosols on cloud microphysical properties and macrophysical structure

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

### Degree Requirements

Please visit the following pages for information about the degrees offered:

- PhD in Energy, Environmental & Chemical Engineering (EECE) (http://bulletin.wustl.edu/grad/engineering/energy-environmental-chemical/phd/)
- Master of Science (MS) in Energy, Environmental & Chemical Engineering (EECE) (http://bulletin.wustl.edu/grad/engineering/energy-environmental-chemical/ms/)
- Master of Engineering (MEng) in Energy, Environmental & Chemical Engineering (EECE) (http://bulletin.wustl.edu/grad/engineering/energy-environmental-chemical/meng/)
- Combined Master of Engineering/Master of Business Administration (MEng/MBA) (given jointly with Olin Business School) (http://bulletin.wustl.edu/grad/engineering/energy-environmental-chemical/meng-mba/)

### Courses

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

**E44 EECE 500 Independent Study**

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

Credit variable, maximum 9 units.

**E44 EECE 501 Transport Phenomena in EECE**

The aim of the course is for students to develop skills in applying principles of momentum, heat and mass transport in 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 than 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
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.

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 study. 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-redduction, 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.

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
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. Prerequisites: 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.

E44 EECE 600 Doctoral Research
Credit variable, maximum 9 units.