

# 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, 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 advisor from the full-time department faculty. Typically, the same advisor 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>

## Faculty

### Department Chair and Professor

#### Joshua Yuan

Lucy & Stanley Lopata Professor  
PhD, University of Tennessee  
Design-based engineering to address challenges in energy, the environment and health

## Endowed Professors

### **Richard L. Axelbaum**

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

### **Daniel E. Giammar**

Walter E. Browne Professor of Environmental Engineering  
Director, Center for the Environment  
PhD, California Institute of Technology  
Aquatic chemistry, environmental engineering, water quality, water treatment

### **Zhen (Jason) He**

Laura and William Jens Professor of Energy, Environmental & Chemical Engineering  
Director of Graduate Studies  
PhD, Washington University  
Environmental biotechnology, bioenergy production, biological wastewater treatment, resource recovery, bioelectrochemical systems, sustainable desalination technology, anaerobic digestion, forward osmosis, membrane bioreactors

### **Feng Jiao**

Elvera and William R. Stuckenberg Professor  
Director, Center for Carbon Management  
PhD, University of St. Andrews  
Electrocatalysis, carbon dioxide utilization, electrochemical devices, energy storage

### **Randall Martin**

Raymond R. Tucker Distinguished Professor  
PhD, Harvard University  
Characterizing atmospheric composition to inform effective policies surrounding major environmental and public health challenges ranging from air quality to climate change

### **Vijay Ramani**

Vice Provost for Graduate Education and International Affairs  
Roma B. and Raymond H. Wittcoff Distinguished University Professor  
PhD, University of Connecticut  
Electrochemical engineering, energy conversion

### **Jay R. Turner**

Head of the Division of Engineering Education  
Vice Dean for Education  
James McKelvey Professor of Engineering Education  
DSc, Washington University  
Air quality planning and management, aerosol science and engineering, green engineering

## Professors

### **Young-Shin Jun**

PhD, Harvard University  
Aquatic processes, molecular issues in chemical kinetics, environmental chemistry, surface/physical chemistry, environmental engineering, biogeochemistry, nanotechnology

### **Xinhua Liang**

PhD, University of Colorado Boulder  
Gas-phase synthesis, surface science and catalysis, nanostructured films and devices, energy and environmental applications

### **Yinjie Tang**

PhD, University of Washington  
Metabolic modeling, fermentation engineering, algal bioprocesses

### **Jian Wang**

Director of the Center for Aerosol Science and Engineering (CASE)  
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

### **Fuzhong Zhang**

PhD, University of Toronto  
Metabolic engineering, protein engineering, synthetic and chemical biology

## Associate Professors

### **Peng Bai**

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; identify the theoretical pathways and boundaries for the rational design of materials, electrodes, and batteries through physics-based mathematical modeling and simulation

### **Rajan Chakrabarty**

Harold D. Jolley Career Development Associate Professor  
PhD, University of Nevada, Reno  
Characterizing the radiative properties of carbonaceous aerosols in the atmosphere, researching gas-phase aggregation of aerosols in cluster-dense conditions

### **Marcus Foston**

Director of Diversity Initiatives  
PhD, Georgia Institute of Technology  
Utilization of biomass resources for fuel and chemical production, renewable synthetic polymers, development of advanced aerosol instruments

### **Elijah Thimsen**

PhD, Washington University in St. Louis  
Gas-phase synthesis of inorganic nanomaterials for energy applications, novel plasma synthesis approaches

## Assistant Professors

### Christopher Cooper

PhD, Stanford University  
Responsive, soft materials for applications in energy storage, environmental sustainability and human health

### Jenna Ditto

PhD, Yale University  
Chemical composition of indoor and outdoor air, indoor air chemistry, health impacts of air pollution exposure

### Fangqiong Ling

PhD, University of Illinois at Urbana-Champaign  
Microbial ecosystem analysis and modelling, process modelling, machine learning, NextGen sequencing bioinformatics, environmental microbiology, bioreactor design

### Kimberly M. Parker

PhD, Stanford University  
Investigation of environmental organic chemistry in natural and engineered systems

### Lu Xu

PhD, Georgia Institute of Technology  
Air quality, climate change, atmospheric chemistry

## Research Assistant Professor

### Benjamin Kumfer

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

## Senior Lecturers

### Janie Brennan

Director of Undergraduate Studies  
PhD, Purdue University  
Chemical engineering education, biomaterials

### Raymond Ehrhard

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

### Trent Silbaugh

PhD, University of Washington  
Chemical engineering education, catalysis, carbon capture and conversion

### Kristen Wyckoff

PhD, University of Tennessee  
Environmental engineering education, stormwater runoff, environmental microbiology

## Lecturer

### Kurt Russell

PhD, Purdue University  
Chemical engineering education, catalysis

## Affiliated Faculty

### Gary Moore

Senior Lecturer for the Joint Engineering Program  
MS, Missouri University of Science and Technology  
Environmental management

## Adjunct Faculty

### Grigoriy Yablonsky

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

## Emeritus Professor

### Milorad P. Dudukovic

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

## Majors

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

- Bachelor of Science in Chemical Engineering
- Bachelor of Science in Environmental Engineering
- Bachelor of Science in Applied Science (Chemical Engineering)
- Double Majors and the Pre-Medical Program

## Minors

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

- Minor in Environmental Engineering Science
- Minor in Energy Engineering
- Minor in Nanoscale Science & Engineering

## Courses

Visit online course listings to view semester offerings for E44 EECE.

### 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.  
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. Prerequisite: Freshman standing or permission of instructor.

Credit 3 units. EN: TU

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**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. Emphasizes providing a broader context for content delivered in concurrent core chemical and environmental engineering courses. Prerequisite: Sophomore or higher standing or permission on instructor.

Credit 1 unit. EN: TU

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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.

Credit variable, maximum 3 units.

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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: E81 CSE 131 and L24 Math 217, or permission of instructor

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 205 or permission of instructor.

Credit 3 units. EN: TU

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**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: L07 Chem 112A or Chem 106. Corequisite: L24 Math 217 or permission of instructor.

Credit 4 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 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: (L07 Chem 112A or L07 Chem 106), and L24 Math 132, or permission of instructor. Students considering taking this course without all prerequisites should contact the instructor for a list of concepts required for the course.

Credit 3 units. EN: BME T, 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.

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. Corequisite: E35 ESE 318; Prerequisites: E44 EECE 205 or permission of instructor.

Credit 3 units. EN: BME T, 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. Corequisites: E44 EECE 204, E44 EECE 202, or permission of instructor

Credit 3 units. EN: BME T, 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: L07 Chem 111A or L07 Chem 105, or permission of instructor.

Credit 3 units. EN: BME T, TU

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**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: E44 EECE 205, or permission of instructor

Credit 3 units. EN: TU

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**E44 EECE 307 Transport Phenomena II: Energy and Mass Transfer**

This course covers introductory treatment of the principles of heat transfer by conduction, convection, and 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; and principles of mass transfer (diffusion and convection) introduced by analogy to heat transfer. Prerequisite: E44 EECE 301; corequisite: E35 ESE 319.

Credit 4 units. EN: BME T, TU

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**E44 EECE 308 Water Resources Engineering**

This course further develops student knowledge of water resources engineering specific to the movement of water through natural and built environments. Combines existing fluid mechanics knowledge with hydrology and hydrogeology to introduce students to the design and analysis of surface water, open channel flow, pipe flow, and groundwater systems. Students will have an opportunity to

describe, model, and calculate surface water and stormwater runoff hydrology; design and analyze open channel flow; quantify flow in partially full pipes; predict and analyze groundwater flow conditions for confined and unconfined aquifers using hydrogeology; and calculate groundwater flow and well drawdown.  
Credit 3 units.

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#### **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: E44 EECE 210, E44 EECE 301, or permission of instructor.  
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: L24 Math 217 or permission of instructor.  
Credit 3 units. EN: BME T, TU

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#### **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: E44 EECE 205 or permission of instructor  
Credit 4 units. EN: TU

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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. Prerequisite: E44 EECE 301, E44 EECE 304, or permission of instructor  
Credit 3 units. EN: BME T, 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: E44 EECE 304, E44 EECE 401, E44 EECE 403, E44 EECE 409, or permission of instructor.  
Credit 3 units. EN: BME T, 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. Prerequisite: E44 EECE 204; Corequisite: E44 EECE 307 or permission of instructor  
Credit 3 units. EN: BME T, TU

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#### **E44 EECE 404 Environmental Engineering Capstone**

Methodology for formulating and solving open-ended design problems. The methodology is illustrated through a series of team projects drawn from multiple areas of environmental engineering practice. Topics addressed include the design process, cost estimation, consideration of codes and regulations, sustainability, and reliability. The course also provides content on professional practice, ethics, and professional licensure. Prerequisites: E44 EECE 314, E44 EECE 407, E44 EECE 409, or permission of instructor  
Credit 3 units. EN: TU

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

This course involves laboratory projects focused on the application of chemical engineering principles (e.g., transport, thermodynamics, separations). Student teams design multi-week experiments using unit operations equipment to solve realistic engineering problems, including the analysis of safety and instrumentation. The course has one laboratory period each week, with supplemental lecture sessions. Emphasis is on independent learning, teamwork, and technical communication skills. Prerequisites: E44 EECE 301, E44 EECE 304, and (E35 ESE 326 or E60 ENGR 328) Corequisites: E44 EECE 307, E44 EECE 403, E60 Engr 310 or permission of instructor.  
Credit 4 units. EN: TU

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#### **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 modeling will be provided. Finally, students will be encouraged to explore links between environmental biotechnologies and a "one health" approach to public health. Prerequisites: (L41 Biol 2960 or E44 EECE 306), (E35 ESE 326 or E60 ENGR 328), E44 EECE 205, E44 EECE 210, or permission of instructor.  
Credit 3 units. EN: BME T, TU

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#### **E44 EECE 409 Process Design, Economics and Simulation**

This is a lecture and computer lab-based course covering engineering science and design, fundamentals of process and product development, process safety and sustainability, computational techniques, and economic principles used for the design of chemical, biological, and environmental processes and procedures. A guided design project is included. Prerequisite: E44 EECE 304 or E44 EECE 533 or permission of instructor.  
Credit 2 units. EN: TU

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#### **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 which draws upon the experience. Students will enroll in EECE 411 for the fall semester following the trip.

Credit 3 units. EN: BME T, TU

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

Renewable electricity from solar and wind will be the primary energy source for our future distributed energy and mobility system. At the foundation of that energy system are the electrochemical energy devices including fuel cells, electrolyzers and batteries. The objectives of this course are to introduce basic concepts and principles of electrochemistry as well as their potential applications. The chemical engineering fundamentals (e.g., mass & energy balances, thermodynamics, and mass & heat transport) will be applied to describe in mathematical terms the catalytic and mass transport processes. Prerequisites: (EECE 205 and EECE 301) or permission of instructor

Credit 3 units. EN: BME T, TU

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#### **E44 EECE 416 Industrial Process Safety**

This course covers the 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; and emergency plans for accidents and disasters. Prerequisites: E44 EECE 204 and E44 EECE 307, or graduate standing or permission of instructor.

Credit 3 units. EN: TU

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#### **E44 EECE 423 Senior Thesis**

Research project to be selected by the student in senior standing 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.

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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: E35 ESE 441 or E44 EECE 401 or permission of instructor

Credit 3 units. EN: BME T, TU

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#### **E44 EECE 425 Environmental Engineering Laboratory**

This course includes laboratory experiments to illustrate the application of engineering fundamentals to environmental systems. Applications of experimental design and data analysis principles are also included, and relevant analytical instrumentation and laboratory techniques are introduced. Laboratory work supported by theoretical analysis and modeling is performed as appropriate. Prerequisite: E44 EECE 210 or E44 EECE 205 Corequisite: E35 ESE 326 or E60 ENGR 328, or permission of instructor.

Credit 3 units. EN: BME T, TU

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#### **E44 EECE 428 Introduction into Zymurgy**

This course will introduce students to beer brewing and fermentation by combining clear and detailed lectures with practical, hands-on brewing and laboratory tests. This course presents the fundamentals of the underlying chemistry critical to successful extract and all-

grain brewing. Topics covered in this course include beer brewing terminology, brewing materials and supplies, laboratory tests, and basic chemical and biochemical interactions. The students will select and brew three batches of beer typically used in home brew recipes using a malt extract method and all grain methods. The class will attend field trips to a large brewer and a small craft brewer to gain experience in this growing industry. This class prepares students for further instruction and for positions as brewers in commercial breweries and microbreweries. Prerequisite: Age of 21 or approval by instructor. Students registering for this course will be placed on a waitlist. A separate course application will be provided to the students to be submitted to the course instructor for approval. Prerequisites: (L07 Chem 106 or L07 Chem 112A), L07 Chem 152, E44 EECE 205; Corequisites: E44 EECE 301, (E44 EECE 304 or E44 EECE 533); Students must be age 21 or obtain approval by instructor.

Credit 3 units. EN: TU

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#### **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.

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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 will be followed so that the general principles can be grasped and the skills to develop mathematical models of seemingly different processes will be emphasized. This provides the students with a general tool which they can apply later in their chosen field of research. Prerequisite: graduate level standing or permission of instructor  
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 will be placed on solving problems relevant to chemical engineering materials science. Prerequisite: E44 EECE 205 or graduate level standing or permission of instructor  
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: E44 EECE 301, E35 ESE 318 and E35 ESE 319 or graduate level standing or permission of instructor.  
Credit 3 units. EN: BME T, 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: Senior or graduate-level standing or permission of instructor. Students enrolling in this course should have a knowledge of general chemistry.  
Credit 3 units. EN: BME T, 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 E44 EECE 306 or graduate level standing or permission of instructor.  
Credit 3 units. EN: BME T, 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 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. Prerequisites: (E44 EECE 503 or (E35 ESE 318 and E35 ESE 319)) and E44 EECE 403 or permission of instructor  
Credit 3 units.

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#### **E44 EECE 508 Research Rotation**

First-year doctoral students in EECE should undertake this 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.

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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. This course is required of all graduate students every semester of residency in the program.  
Credit 1 unit.

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#### **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 or permission of instructor  
Credit 3 units. EN: BME T, TU

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#### **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. Prerequisite: Senior or graduate standing or permission of instructor.  
Credit 3 units. EN: BME T, TU

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#### **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. Suggested prerequisites: 1 year of general chemistry (Chem 111A-112A or 105-106) and 1 year of general physics (191/191L-191/192L). Prereqs: Junior, senior or graduate level standing or permission of instructor  
Credit 3 units. EN: BME T, TU

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**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. Prerequisites: E44 EECE 504 or graduate level standing or permission of instructor  
Credit 3 units. EN: BME T, TU

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**E44 EECE 520 Special Topics: Plasma Science and Engineering**

This course will focus on a select set of fundamentals and technology related to nonequilibrium plasmas, which are partially ionized gases. Fundamental discussion will focus on the set of state variables that define the plasma and the interaction of the plasma with surfaces, suspended dust particles, and chemically reactive molecular species. The technology used to generate and sustain plasma will be discussed. Diagnostic probes that can be used to ascertain key aspects of the discharge will be covered. Envisioned application areas for the knowledge include semiconductor processing and electrified chemical processing (e.g., advanced oxidation processes). Students enrolling in this course should have a knowledge of chemical engineering thermodynamics; the physics of electricity and magnetism and electrical circuits; aerosol science and technology; chemical reaction engineering and reactor design; and physical chemistry. Prerequisites: Graduate level standing or permission of instructor  
Credit 3 units. EN: TU

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**E44 EECE 521 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: E44 EECE 205 or permission of instructor  
Same as E44 EECE 314  
Credit 4 units. EN: TU

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**E44 EECE 531 Environmental Organic Chemistry**

This course covers the fundamental physical-chemical examination of organic molecules (focused on anthropogenic pollutants) in aquatic (environmental) systems. Students learn to calculate and predict the 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 (e.g., structure-reactivity relationships) for assessing environmental fate or human exposure potential. Prerequisites: (E44 EECE 210 or E44 EECE 205) and L07 Chem 261, or graduate level standing or permission of instructor.  
Credit 3 units. EN: BME T, TU

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**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. Prerequisite: E44 EECE 205 Corequisite: E44 EECE 210 or graduate level standing or permission of instructor  
Credit 3 units. EN: BME T, TU

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**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 would also (1) examine the thermodynamics and kinetics of nanoscale reactions at solid-water interfaces in the presence of inorganic or organic compounds and microorganisms; (2) investigate how nanoscale interfacial reactions affect the fate and transport of contaminants; (3) introduce 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) explore 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. Students enrolling in this course should have a knowledge of general chemistry. Prerequisites: Senior or graduate level standing or permission of instructor  
Credit 3 units. EN: BME T, TU

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**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: L24 Math 217, E35 ESE 318 and (E35 ESE 326 or E60 ENGR 328) or graduate level standing or permission of instructor.  
Credit 3 units. EN: BME T, TU

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**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. Prerequisites: E44 EECE 210 and E44 EECE 409 or graduate level standing or permission of instructor  
Credit 3 units. EN: TU

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**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

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#### **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. Prerequisites: Senior or graduate level standing or permission of instructor

Credit 3 units. EN: BME T, 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 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, learn basic experimental skills and solve current research problems. Prerequisites: (E44 EECE 101 or E44 EECE 103), (L41 Biol 2960 or E44 EECE 306), L41 Biol 4810, or graduate level standing or permission of instructor.

Credit 3 units. EN: BME T, 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 microfluidic devices. Prerequisites: E44 EECE 501 or (E44 EECE 301 and E44 EECE 307), or permission of instructor

Credit 3 units. EN: BME T, TU

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#### **E44 EECE 573 Polymers for Energy, Sustainability, and Human Health**

Polymeric materials are critical to solving global challenges related to energy (e.g., batteries, membranes, and energy harvesting devices), sustainability (e.g., upcycling, compatibilizers, water purification, and bio-based plastics), and human health (e.g., wearable and implantable bioelectronics, stimuli-responsive soft robots, and hydrogels for drug delivery). This course covers how polymers are designed and processed across many length and time scales to achieve specific

target properties for applications in energy, sustainability, and human health. Ideal and real chain conformations, persistence length, polymer architectures, scaling and blob theories, dispersity, networks and defects, and programmed interactions in heteropolymers will be covered. Analysis of polymer structure and dynamics will include: macroscopic and microscopic phase separation, crystallization and melting, glass transition behavior, rouse dynamics, linear viscoelasticity, processing methods, and network elasticity. Key polymer characterization methods including rheology and small- and wide-angle x-ray scattering will be introduced. The course will emphasize individual problem sets, in-class journal club participation, and team-based project work. Prerequisites: EECE 204 or MEMS 301 or equivalent; EECE 301 or MEMS 3410 or equivalent

Credit 3 units.

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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. Prerequisites: E44 EECE 501 or (E44 EECE 301 and E44 EECE 307) or permission of instructor

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: BME T, TU

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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 graduate level standing or permission of instructor

Credit 3 units.

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#### **E44 EECE 599 Masters Research**

Credit variable, maximum 9 units.