

CIVIL AND ENVIRONMENTAL ENGINEERING

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The Department of Civil and Environmental Engineering (CEE) at Stanford conducts fundamental and applied research to advance the civil and environmental engineering professions, educate future academic and industry leaders, and prepare students for careers in professional practice. Civil and environmental engineers work to protect and sustain the natural environment while creating and maintaining a resilient, sustainable built environment. Civil and environmental engineers are essential to providing the necessities of human life, including water, air, shelter, the infrastructure, and energy, in increasingly more efficient and renewable ways.

Research and teaching in the department focus on the theme of engineering for sustainability, including three core areas: built environment, environmental and water studies, and atmosphere/energy. In the area of sustainable built environments, the focus is on processes, techniques, materials, and monitoring technologies for planning, design, construction and operation of environmentally sensitive, economically efficient, performance-based buildings and infrastructure, and managing associated risks from natural and man-made hazards. In the area of environmental and water studies, the focus is on creating plans, policies, science-based assessment models and engineered systems to manage water in ways that protect human health, promote human welfare, and provide freshwater and coastal ecosystem services. In the atmosphere/energy area, research and teaching focus on fundamental energy and atmospheric engineering and science, assessment of energy-use effects on atmospheric processes and air quality, and analysis and design energy-efficient generation and use systems with minimal environmental impact.

The department oversees undergraduate programs in Civil Engineering and in Environmental Systems Engineering. The department also hosts the School of Engineering undergraduate major in Architectural Design and the undergraduate major in Atmosphere/Energy - both of which lead to a B.S. in Engineering.

Mission of the Undergraduate Program in Civil Engineering

The mission of the undergraduate program in Civil Engineering is to equip students with the knowledge and skills needed for world-class civil engineering practice. This pre-professional program balances the fundamentals common to many specialties in civil engineering and allows for concentration in any of seven areas: structures, construction, environmental, energy/climate, fluid mechanics/hydrology, urban systems, or sensors/analytics. Students in the major learn to apply knowledge of mathematics, science, and civil engineering to conduct experiments, design structures and systems to creatively solve engineering problems, and communicate their ideas effectively. The major prepares students for careers in consulting, industry and government, as well as for graduate studies in science and engineering.

Mission of the Undergraduate Program in Environmental Systems Engineering

The mission of the undergraduate program in Environmental Systems Engineering is to prepare students for incorporating environmentally sustainable design, strategies and practices into natural and built systems and infrastructure involving buildings, water supply, and urban coastal regions. Courses in the program are multidisciplinary in nature, combining math/science/engineering fundamentals, and tools and skills considered essential for an engineer, along with a choice of one of three focus areas for more in-depth study: coastal environments, freshwater environments, or urban environments. This major offers somewhat more flexibility in the curriculum than the Civil Engineering degree program, and requires fewer units. The program of study, which includes a capstone experience, aims to equip engineering students to take on the complex challenges of the twenty-first century involving natural and built environments, in consulting and industry as well as in graduate school.

Learning Outcomes (Undergraduate)

Undergraduates in the Civil Engineering and the Environmental Systems Engineering programs are expected to achieve the following learning outcomes through their major. These learning outcomes are used both in evaluating students and the department's undergraduate programs. Students are expected to demonstrate the ability to:

1. identify, formulate, and solve complex engineering problems by applying principles of engineering, science and mathematics.
2. apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. communicate effectively with a range of audiences.
4. recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. acquire and apply new knowledge as needed, using appropriate learning strategies.

Learning Outcomes (Graduate)

The purpose of the master's program is to equip students with the knowledge and skills necessary for a successful professional career or for the pursuit of doctoral studies. Students are prepared through course work that is organized into three broad areas including the built environment, atmosphere and energy, and environmental engineering. Graduate students must master the analytical, quantitative, and interpretive skills necessary for successful leadership in their chosen field.

The Ph.D. is conferred upon candidates who have demonstrated substantial original scholarship and the ability to conduct independent research. The Ph.D. program prepares students to make original contributions to the theory and practice of Civil and Environmental Engineering and related fields.

Graduate Programs in Civil and Environmental Engineering

The Department of Civil and Environmental Engineering (CEE) offers graduate degrees structured in three areas of study.

- The Atmosphere/Energy Program offers degrees with the designation of Atmosphere/Energy.
- The Sustainable Built Environment Program offers degrees with two designations:
 - Structural Engineering and Geomechanics
 - Sustainable Design and Construction
- The Environmental Engineering Program offers degrees with the designation of Environmental Engineering

For detailed information on these programs and degree designations, see the "Programs of Graduate Study in Civil and Environmental Engineering" section of this bulletin.

Admissions and Financial Aid

Applications require online submission of the application form and statement of purpose, followed by three letters of recommendation, results of the General Section of the Graduate Record Examination, and transcripts of all courses taken at colleges and universities. See <http://gradadmissions.stanford.edu>. Policies for each of the programs in the department are available on the department website. See: <http://cee.stanford.edu>. Successful applicants are advised as to the degree and program for which they are admitted. If students wish to transfer from one CEE program to another after being accepted, an application for the intradepartmental change must be filed within the department. If, after enrollment at Stanford, students wish to continue toward a degree beyond that for which they were originally admitted, a written application must be made to the Department of Civil and Environmental Engineering.

The department maintains a continuing program of merit-based financial aid for graduate students. Merit-based financial aid consists of teaching assistantships and/or research assistantships for up to half-time work, with the assumption that students spend the rest of their time on coursework and research required for completion of the degree. Fellowship and scholarship awards or loans may supplement assistantships and other basic support. Continued support is generally provided for further study toward the Engineer or Ph.D. degree based on the student's performance, the availability of research funds, and requisite staffing of current research projects.

Research Centers and Facilities

Environmental engineering research in the department is conducted primarily in the Bob and Norma Street Environmental Fluid Mechanics Laboratory (EFML) and the Environmental Engineering and Science Laboratory (EESL). The EESL is home to the National Science Foundation (NSF) supported Engineering Research Center for Re-inventing the Nation's Urban Water Infrastructure (ReNUWIt), a four-university consortium that seeks more sustainable solutions to urban water challenges in the arid west; the William and Cloy Codiga Resource Recovery Center (CR2C), a new facility for pilot-scale testing of resource recovery technology; and one of the sites for the U.S. Department of Energy supported Energy-Water Desalination Hub entitled the National Alliance for Water Innovation. Other centers and groups in the department related to environmental engineering include the Environmental Informatics Group, the National Performance of Dams Program (NPDP), and the center for Sustainable Development and Global Competitiveness (SDGC). There is also extensive collaboration with research centers and groups throughout the university, including the Stanford Woods Institute for the Environment, the Stanford Program on Water, Health & Development, the Bill Lane Center for the American

West, the Carnegie Institution, the Center for Innovation in Global Health, Stanford Bio-X, the Environmental and Natural Resources Law and Policy Program, the Freeman Spogli Institute for International Studies, and the Precourt Institute for Energy.

Several research centers in the department focus on improving the sustainability of the built environment. The John A. Blume Earthquake Engineering Center conducts research on earthquake engineering including advanced sensing and control, innovative materials, and risk hazard assessment. Research and advanced global teamwork education is conducted in the Project Based Learning (PBL) Laboratory. The Center for Integrated Facility Engineering (CIFE) employs advanced information technologies and concepts to integrate the facility development process and enhance the usability, buildability, operability, and sustainability of the built environment. The Global Projects Center (GPC) is a multi-discipline, multi-university research program aimed at improving the performance of global engineering and construction projects, with a special focus on financing and governance of sustainable civil and social infrastructure projects. The Stanford Sustainable Systems Lab (S3L) aims to advance the state of the art in the design, monitoring and management of built environment systems, with a special focus on smart grid, smart buildings and smart infrastructures.

Programs of Graduate Study in Civil and Environmental Engineering

Atmosphere/Energy Program

The Atmosphere/Energy Program in Civil and Environmental Engineering combines atmospheric science with energy science and engineering. The main goals of the program are to educate students and the public, through courses, research, and public outreach, about the causes of climate, air pollution, and weather problems and methods of addressing these problems through renewable and efficient energy systems. In addition, students learn about feedback between the atmosphere and renewable energy systems and the effects of the current energy infrastructure on the atmosphere.

Major focus areas of energy research include examining the resource availability of renewable energies, such as wind, solar, and wave, and studying optimal methods of combining renewable energies together to match energy supply with instantaneous demand. This type of work is generally done through a combination of data analysis, three-dimensional atmospheric computer modeling of wind, solar, wave, and hydroelectric power resources, and transmission load flow computer modeling. Other energy research, performed through three-dimensional computer modeling, focuses on the effects, for example, of hydrogen fuel cell vehicles on air pollution and the ozone layer and the effects of ethanol and diesel vehicles on air quality and climate. Studies also examine the feedback of wind turbines to the atmosphere and the effects of climate change on wind and solar energy resources.

Atmospheric research in the program generally involves laboratory work, field measurements, or three-dimensional computer modeling of the combined atmosphere, ocean, and land surface. An example of laboratory work includes measuring the properties of organic particulate matter that forms in the atmosphere. Examples of fieldwork include measuring exposures to secondhand smoke, allergens, and emissions from building materials.

Computer modeling is performed at a variety of spatial scales, from the globe down to the size of a building or smaller. Some examples of modeling studies include examining the effects of air pollution particles on clouds, rainfall, water supply, ultraviolet radiation, the stratospheric ozone layer, and climate, simulating the dispersion of toxic contaminants in an urban street canyon, studying the effects of aircraft exhaust and biomass burning on climate, studying the effects of carbon dioxide

domes over cities on air pollution mortality, and studying the leading causes of global warming and their impacts.

Students interested in the Atmosphere and also Clean Renewable Energy systems would most likely apply to the Atmosphere/Energy Program.

Those interested in the Atmosphere and also Water systems would most likely apply to the Environmental Engineering Program. Those interested in Atmospheric topics alone (e.g. weather, climate, pollution and its impacts) could apply to either, depending on the courses of interest.

Environmental Engineering Program

The mission of the Environmental Engineering program is to develop state-of-the-art knowledge, models, and processes which form the core of environmental engineering practice, and to train and educate current and future academic and professional environmental leaders.

We do this by synthesizing physical, biological, and chemical facets of engineering and science along with elements of the social sciences into our research and teaching. Ultimately, the goal is to protect and sustain our natural resources and human health and contribute to the sustainable development of physical infrastructure, including systems for wastewater treatment, water supply, renewable energy, and resilient coastal environments.

Research and coursework in the Environmental Engineering program are centered around five focus areas:

- Aquatic Chemistry, Biology, and Process Engineering
- Environmental and Geophysical Fluid Mechanics
- Environmental Data, Statistics, and Modeling
- Human Health and the Environment
- Hydrology and Water Resources

Research in the program spans the physical, chemical, and biological dimensions of Environmental Engineering. The physical aspects are the primary focus of research in the Bob and Norma Street Environmental Fluid Mechanics Laboratory (EFML), whereas research on the chemical and biological aspects is conducted in the Environmental Engineering and Science Laboratory (EESL). The EESL is home to the National Science Foundation (NSF) supported Engineering Research Center for Re-inventing the Nation's Urban Water Infrastructure (ReNUWit), a four-university consortium that seeks more sustainable solutions to urban water challenges in the arid west, the William and Cloy Codiga Resource Recovery Center (CR2C), a facility for pilot-scale testing of resource recovery technology, and one of the sites for the U.S. Department of Energy supported Energy-Water Desalination Hub entitled the National Alliance for Water Innovation. There is extensive crossover between the EFML and the EESL, reflecting the interdisciplinary nature of environmental engineering that seeks to quantify physical, biological, and chemical processes in the environment in an integrated way. Environmental research is also conducted in numerous centers and groups in the department including the Environmental Informatics Group, the National Performance of Dams Program (NPDP), and the center for Sustainable Development and Global Competitiveness (SDGC). There is also extensive collaboration with research centers and groups throughout the university, including the Stanford Woods Institute for the Environment, the Bill Lane Center for the American West, the Carnegie Institution, the Center for Innovation in Global Health, Stanford Bio-X, the Environmental and Natural Resources Law and Policy Program, the Freeman Spogli Institute for International Studies, and the Precourt Institute for Energy.

Courses in the Environmental Data, Statistics and Modeling, Environmental and Geophysical Fluid Mechanics, and Hydrology and Water Resources focus areas concentrate on developing an understanding of the physical processes controlling the movement of mass, energy, and momentum in aquatic environments and the atmosphere. Specific course topics include experimental methods, fluid transport and mixing processes, the fluid mechanics of stratified flows, natural flows in coastal waters, estuaries, lakes, and open channels,

turbulence and its modeling, flow and transport in porous media, stochastic methods in both surface and subsurface hydrology, watershed hydrology and modeling, water resources infrastructure and systems, global atmospheric circulation, the atmospheric boundary layer, air pollution from global to indoor scales, and wind energy.

Courses in the Aquatic Chemistry, Biology, and Process Engineering and Human Health and the Environment focus areas emphasize the chemical, biological, and engineering aspects of air and water quality and pollution fate and transport, along with characterizing human health risks and developing testing strategies to protect public health. Specific course topics include chemical principles and their application to the analysis and solution of problems in aqueous environments, biochemical and biophysical principles of biochemical reactions, physical and chemical unit operations for water treatment, microbial processes for the transformation of environmental contaminants, microbial metabolic pathways in microbial bioenergy systems, the movement and survival of pathogens in the environment, use of microbial bioreactors for degradation of contaminants and recovery of clean water, quantification of human exposure to toxic chemicals and pathogens in the environment, methods to enumerate and isolate organisms used to assess risk of enteric illnesses in drinking and recreational waters, and the impacts of water supply and wastewater management approaches on public health around the globe.

Sustainable Built Environment Program

The Sustainable Built Environment program includes subprograms in Structural Engineering and Geomechanics, and Sustainable Design and Construction. These programs focus on educating practitioners and researchers to plan, design, build, and operate more sustainable buildings and infrastructure.

The Structural Engineering and Geomechanics (SEG) subprogram educates designers and researchers who want to progress beyond traditional life safety code-based design, to develop and disseminate performance-based structural and geotechnical engineering methods and tools that maximize the lifecycle economic value of facilities.

The Sustainable Design and Construction (SDC) subprogram provides courses in sustainable, multi-stakeholder design methods and tools that incorporate lifecycle assessment, project planning and entitlement, green architectural design, lighting, and energy analysis, power systems, transportation, water supply and wastewater treatment to educate students interested in promoting more sustainable development of buildings and infrastructure.

Admission is managed separately for these two subprograms; prospective students should indicate their preference on their application.

Structural Engineering and Geomechanics

The Structural Engineering and Geomechanics (SEG) subprogram encompasses teaching and research in structural design and analysis, structural materials, earthquake engineering and structural dynamics, advanced sensing and structural health monitoring, data science for smart structures and cities, risk and reliability analysis, disaster resilience, computational science and engineering, solid mechanics, computational mechanics, and geomechanics. The SEG subprogram prepares students for industrial or academic careers.

Students can balance engineering fundamentals with modern computational and experimental methods to customize programs to launch careers as consultants on large and small projects, designers, and engineering analysts.

Structural design and analysis focuses on the conceptual design of structural systems and on computational methods for predicting the static and dynamic, linear and nonlinear responses of structures.

Structural materials research and teaching focuses on the design and analysis of high-performance as well as low-environmental impact materials.

Earthquake engineering and structural dynamics addresses earthquake phenomena, ground shaking, and the behavior, analysis, and design of structures under seismic and other dynamic forces.

Advanced sensing and data science focuses on development and application of sensing, signal processing, and machine learning for structural systems. The goal is to better understand those systems and improve their performance as well as user experience. Applications include structural health monitoring, intelligent transportation system, occupant activity/health monitoring, and interactive space.

Reliability and risk analysis focuses on assessing damage and losses to structures and lifeline systems under earthquakes, wind and other hazards; insights from these assessments are used to engineer more sustainable structures and more resilient communities.

Computational science and engineering emphasizes the application of modern computing methods to structural engineering and geomechanics, and encompasses numerical, structural, and geotechnical analysis.

In the area of geomechanics, students focus on the application of the principles of computational and applied mechanics to problems involving geologic materials including soil and rock, as well as on the use of computational methods for analysis and design of foundations and earth structures.

Sustainable Design and Construction

The Sustainable Design and Construction (SDC) subprogram prepares students for careers in managing the planning, design, construction, and operation of sustainable buildings and infrastructure so that their lifecycle economic value, their net contribution to environmental functions and services, and their social equity are maximized. To give students the breadth and depth necessary to become leaders in practice or research in sustainable design and construction, the SDC program offers four tracks of study: construction, energy, structures, water and sustainable urban systems. In addition to providing critical skills and the necessary industry context, each track offers courses in the following areas of competency: Construction engineering and management; building and infrastructure development; structural performance, design, and analysis; infrastructure systems; energy systems, energy efficiency, and atmosphere.

Classes address advanced topics like modern company and project management methods; cutting-edge information technology, metrics and tools to enhance lifecycle sustainability of the built environment; sensor networks embedded in intelligent buildings and infrastructure; strategy, economics, entrepreneurship and organization design for new businesses; and corporate or governmental initiatives aimed at enhancing the sustainability of buildings and infrastructure.

The SDC subprogram is intended for students with undergraduate degrees in architecture, engineering, science, construction management, economics, or business who wish to pursue careers that enhance the sustainability of the built environment.

Employers of past SDC graduates include: architectural and engineering design firms, constructors, design-build firms, and developers focused on delivering green buildings and infrastructure; energy and sustainability consultants; facility management or sustainability departments within large companies; clean-tech start ups, and venture funds.

SDC Construction (SDC-C)

The SDC-C track includes courses in construction engineering and management and introduces advanced modeling and visualization methods and tools - including artificial intelligence and data science applications - known as virtual design and construction. This track

prepares technically qualified students for leadership roles in engineering and management in all phases of the development of major constructed facilities. It emphasizes management techniques useful in organizing, planning, and controlling the activities of diverse specialists working within the unique project environment of the construction industry, and it covers construction engineering aspects of heavy, industrial, and building construction. Additional related course work is available from other programs within the department, from other engineering departments, and from other schools in the University such as Earth Sciences and the Graduate School of Business. SDC-C allows students substantial flexibility to tailor their program of study for careers with general contractors, specialty contractors, real estate or infrastructure developers, or facility owners and operators.

SDC-Energy (SDC-E)

The SDC-Energy (SDC-E) track includes courses on design and construction of buildings and infrastructure systems to produce, distribute, and consume energy sustainably. SDC-E prepares students for careers in design and construction of building energy systems, renewable power generating systems, and smart power grids connected to smart buildings and infrastructure, cleantech venture capital, sustainability-focused public policy, green real estate development, and sustainability management positions.

SDC-E includes courses from the CEE department and several other departments at Stanford on sustainable HVAC design and construction of small scale and large structures, the planning, design and construction of renewable power systems, and sensing and control technologies to link integrated smart grids with intelligent buildings, data centers and infrastructure systems.

SDC-Structures (SDC-S)

The SDC-Structures (SDC-S) track includes courses from construction engineering and management and Structural Engineering and Geomechanics (SEG) to prepare students for careers in design and construction firms that provide integrated design-build project delivery, construction management, and pre-construction services.

This track prepares students for multidisciplinary collaborative teamwork in an integrated design and construction process. The subprogram extends a student's design or construction background with core courses in each of these areas and develops the background needed to understand the concerns and expertise of the many project stakeholders. It includes a comprehensive project-based learning experience.

The SDC-S track is intended for applicants with backgrounds in engineering and science. Applicants should also have a background in the planning, design, or construction of built structures by virtue of work experience and/or their undergraduate education. Knowledge in subjects from the traditional areas of civil engineering is necessary for students to receive the degree and to satisfy prerequisite requirements for some of the required graduate courses. Students with an undergraduate degree in Civil Engineering, and who expect to pursue careers with design or construction firms that emphasize design-build, EPC, or turnkey projects should consider SDC-S.

SDC-Sustainable Urban Systems (SDC-SUS)

The SDC-Sustainable Urban Systems (SDC-SUS) track combines courses by several faculty from the Department of Civil and Environmental Engineering with courses on sustainable design and construction to focus on the urban scale of the built environment. The SDC-SUS track prepares students for careers in sustainable design, construction, and operation of infrastructure systems and communities.

This track offers courses in frameworks for urban-scale planning of infrastructure systems, technologies to model, simulate, analyze, and visualize the built environment at the urban scale, urban planning, and data analysis. The track includes a significant project-based experience on an actual project in a community.

This track is intended for students with a background in urban planning and systems-level understanding of the built environment from economic, environmental, or social perspectives with an interest to enhance the sustainability of the built environment through leadership roles in public agencies, city government, financial institutions, engineering firms, or technology providers.

Bachelor of Science in Civil Engineering

The B.S. in Civil Engineering is an ABET accredited program, which integrates research with engineering education. The B.S. in Civil Engineering offers a core providing a strong foundation in engineering, plus a choice of the following seven focus areas offering students the flexibility to align their studies with their interests: structures; construction; energy and climate; environmental engineering and health; fluid mechanics and hydrology; urban systems; or sensing, analytics and control.

Three educational objectives structure the Civil Engineering degree program. Graduates of the program are expected within a few years of graduation, to have the ability to:

1. Establish themselves as practicing professionals in civil or environmental engineering or a related field.
2. Pursue graduate study in civil or environmental engineering or other fields.
3. Work effectively as responsible professionals independently or in teams handling increasingly complex professional and societal expectations.

Students who major in Civil Engineering must complete the appropriate requirements for the B.S. degree listed. Because the undergraduate engineering curriculum provides breadth of study, students who intend to enter professional practice in civil engineering should plan to obtain their professional education at the graduate level.

A number of undergraduate programs at Stanford may be of interest to students looking at the Civil Engineering major. Students may consider related programs in the department in Atmosphere/Energy and Environmental Systems Engineering. For structures or construction, students might consider Architectural Design. And for construction, the urban focus area within Environmental Systems Engineering may be of interest.

Civil Engineering (CE)

Completion of the undergraduate program in Civil Engineering leads to the conferral of the Bachelor of Science in Civil Engineering.

Mission of the Undergraduate Program in Civil Engineering

The mission of the undergraduate program in Civil Engineering is to provide students with the principles of engineering and the methodologies necessary for civil engineering practice. This pre-professional program balances the fundamentals common to many specialties in civil engineering and allows for concentration in any of seven areas: structures, construction, environmental, energy/climate, fluid mechanics/hydrology, urban systems, or sensors/analytics. Students in the major learn to apply knowledge of mathematics, science, and civil engineering to conduct experiments, design structures and systems to creatively solve engineering problems, and communicate their ideas effectively. The major prepares students for careers in consulting, industry and government, as well as for graduate studies in engineering.

Requirements

	Units
Mathematics and Science	45
45 units minimum; see Basic Requirement 1 and 2 ¹	
Technology in Society	
One course required	
CEE 102A	3
	Legal / Ethical Principles in Design, Construction, Project Delivery
Engineering Fundamentals	
Two courses required	
ENGR 14	3
	Intro to Solid Mechanics
ENGR 90/CEE 70	3
	Environmental Science and Technology
Engineering Depth	
Minimum of 68 Engineering Fundamentals plus Engineering Depth; see Basic Requirement 5	
CEE 100	4
	Managing Sustainable Building Projects ²
CS 106A	5
	Programming Methodology (or CS 106B, CS 106X, CEE 101D)
ME 30	3
	Engineering Thermodynamics (or CHEMENG 110A)
CEE 146S	3
	Engineering Economics and Sustainability
CEE 183	4
	Integrated Civil Engineering Design Project (Senior Capstone Design Course)
Focus Area Electives: at least 12 units in 1 major focus area, + at least 6 units each in 3 other focus areas (see below; no double counting) ⁴	30
Additional CEE elective units (either select from focus areas below, from additional approved courses (see Footnote 5), or must be pre-approved by CEE Curriculum Comm.)	13
Total Units	116

¹ Mathematics must include CME 100 Vector Calculus for Engineers and CME 102 Ordinary Differential Equations for Engineers (or MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications and Differential Calculus of Several Variables and MATH 53 Ordinary Differential Equations with Linear Algebra) and a Statistics course (STATS 101 Data Science 101 or STATS 110 Statistical Methods in Engineering and the Physical Sciences or CEE 106 Introduction to Probability and Statistics for Engineers or CEE 203 Probabilistic Models in Civil Engineering). Science must include PHYSICS 41 Mechanics (or PHYSICS 41E Mechanics, Concepts, Calculations, and Context); either PHYSICS 43 Electricity and Magnetism or PHYSICS 45 Light and Heat; either CHEM 31A Chemical Principles I or CHEM 31M Chemical Principles: From Molecules to Solids; at least one of CEE 177 Aquatic Chemistry and Biology (required for major focus in fluid mechanics/hydrology or environmental quality) or GEOLSCI 1 Introduction to Geology (required for major focus in structural, construction, urban systems, energy/climate or sensing/analytics); and additional physics, chemistry or mathematics to reach 45 units.

² CEE 100 meets the Writing in the Major (WIM) requirement

³ A course may only be counted towards one requirement; it may not be double-counted. All courses taken for the major must be taken for a letter grade if that option is offered by the instructor. Minimum Combined GPA for all courses in Engineering Fundamentals and Depth is 2.0.

⁴ To satisfy ABET criteria, electives must include at least 2 of the following 4 courses: CEE 101A, 101B, 101C, 101D.

⁵ Preapproved courses for additional CEE elective units: ENGR 10, 15, 21, 25E, 40M (or 40A), 50 (or 50E or 50M); CEE 74N, 80N; and up to 4 units of CEE 199 or CEE 199L.

Construction Engineering Focus

		Units
CEE 120A	Building Modeling for Design & Construction	3
CEE 122A & CEE 122B	Computer Integrated Architecture/Engineering/Construction and Computer Integrated A/E/C (each quarter = 2 units; must take both quarters)	4
CEE 131C	How Buildings are Made – Materiality and Construction Methods	4
CEE 141A	Infrastructure Project Development	3
CEE 141B	Infrastructure Project Delivery	3
CEE 144	Design and Innovation for the Circular Economy	3
CEE 241	Managing Fabrication and Construction	4

Energy and Climate Focus

		Units
CEE 63	Weather and Storms	3
CEE 64	Air Pollution and Global Warming: History, Science, and Solutions	3
CEE 107A	Understanding Energy (or CEE 107S)	3-5
CEE 107R	E ³ : Extreme Energy Efficiency	3
CEE 156	Building Systems Design & Analysis	4
CEE 172	Air Quality Management	3
CEE 176A	Energy Efficient Buildings	3
CEE 176B	100% Clean, Renewable Energy and Storage for Everything	3-4

Environmental Fluid Mechanics & Hydrology Focus

		Units
CEE 101B	Mechanics of Fluids	4
CEE 161I	Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation	3
CEE 162D	Introduction to Physical Oceanography	4
CEE 162F	Coastal Processes	3
CEE 162I	Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation	3
CEE 166A	Watershed Hydrologic Processes and Models	3
CEE 166B	Water Resources and Hazards	3
CEE 175A	California Coast: Science, Policy, and Law	3-4

Environmental Quality Engineering for Human Health Focus

		Units
CEE 172	Air Quality Management	3
CEE 174A	Providing Safe Water for the Developing and Developed World	3
CEE 174B	Wastewater Treatment: From Disposal to Resource Recovery	3
CEE 175A	California Coast: Science, Policy, and Law (alt. years)	3-4
CEE 178	Introduction to Human Exposure Analysis	3
CEE 265D	Water and Sanitation in Developing Countries	3

Sensing, Analytics and Control Focus

		Units
CEE 101D	Computations in Civil and Environmental Engineering	3
CEE 154	Data Analytics for Physical Systems	3-4
CEE 155	Introduction to Sensing Networks for CEE	3-4
CEE 156	Building Systems Design & Analysis	3
CEE 177L	Smart Cities & Communities	3
ME 161	Dynamic Systems, Vibrations and Control	3-4
ME 210	Introduction to Mechatronics	4

Structural Engineering and Mechanics Focus

		Units
CEE 101A	Mechanics of Materials	4
CEE 101C	Geotechnical Engineering	4
CEE 101D	Computations in Civil and Environmental Engineering	3
CEE 180	Structural Analysis	4
CEE 182	Structural Design	4
CEE 192	Properties of Rocks and Geomaterials	3-4
ME 151	Introduction to Computational Mechanics	4

Urban Systems Focus

		Units
CEE 120A	Building Modeling for Design & Construction	3
CEE 130	Architectural Design: 3-D Modeling, Methodology, and Process	5
CEE 156	Building Systems Design & Analysis	4
CEE 176A	Energy Efficient Buildings	3-4
CEE 177L	Smart Cities & Communities	3
CEE 243	Intro to Urban Sys Engrg	3

Honors Program

This program leads to a B.S. with honors for undergraduates majoring in Civil Engineering or in Environmental Systems Engineering. It is designed to encourage qualified students to undertake a more intensive study of civil and environmental engineering than is required for the normal majors through a substantial, independent research project.

The program involves an in-depth research study in an area proposed to and agreed to by a Department of Civil and Environmental Engineering faculty adviser and completion of a thesis of high quality. A written proposal for the research to be undertaken must be submitted and approved by the faculty adviser in the fourth quarter prior to graduation. At the time of application, the student must have an overall grade point average (GPA) of at least 3.3 for course work at Stanford; this GPA must be maintained to graduation. The thesis is supervised by a CEE faculty adviser and must involve input from the School of Engineering writing program by means of ENGR 202S Directed Writing Projects or ENGR 199W Writing of Original Research for Engineers. The written thesis must be approved by the thesis adviser. Students are encouraged to present their results in a seminar for faculty and students. Up to 10 units of CEE 199H Undergraduate Honors Thesis, may be taken to support the research and writing (not to duplicate ENGR 202S or ENGR 199W). These units are beyond the normal Civil Engineering or Environmental Systems Engineering major program requirements.

For additional information on the major, minor, honors and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (<http://ughb.stanford.edu>).

Bachelor of Science in Environmental Systems Engineering

For undergraduate studies focusing on Environmental Engineering, two options are available. The undergraduate Civil Engineering major (which is ABET-accredited) offers the ability to focus on environmental topics, and the Environmental Systems Engineering major (which is not ABET-accredited) offers a choice of focusing on coastal environments, freshwater environments, or urban environments.

Environmental Systems Engineering (EnvSE)

Completion of the undergraduate program in Environmental Systems Engineering leads to the conferral of the Bachelor of Science in Environmental Systems Engineering.

Mission of the Undergraduate Program in Environmental Systems Engineering

The mission of the undergraduate program in Environmental Systems Engineering is to prepare students for incorporating environmentally sustainable design, strategies and practices into natural and built systems and infrastructure involving buildings, water supply, and coastal regions. Courses in the program are multidisciplinary in nature, combining math/science/engineering fundamentals, and tools and skills considered essential for an engineer, along with a choice of one of three focus areas for more in-depth study: coastal environments, freshwater environments, or urban environments. This major offers somewhat more flexibility in the curriculum than the Civil Engineering degree program, and requires fewer units. The program of study, which includes a capstone experience, aims to equip engineering students to take on the complex challenges of the twenty-first century involving natural and built environments, in consulting and industry as well as in graduate school.

Degree Requirements

	Units
Mathematics and Science	
See Basic Requirement 1 and 2 ¹	36
Technology in Society (TiS)	
One 3-5 unit course required, course chosen must be on the SoE Approved Courses list at <ughb.stanford.edu> the year taken; see Basic Requirement 4 ⁴	3-5
Engineering Fundamentals	
Two courses minimum (see Basic Requirement 3), including:	
CS 106A Programming Methodology	5
(or CS 106X)	
ENGR 14 Intro to Solid Mechanics	3
Fundamental Tools/Skills ²	9
in visual, oral/written communication, and modeling/analysis	
Specialty Courses, in either	40
Coastal environments (see below)	
or Freshwater environments (see below)	
or Urban environments (see below)	
Total Units	96-98

- ¹ Math must include CME 100 Vector Calculus for Engineers (or MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications), and either a Probability/Statistics course or CME 102 Ordinary Differential Equations for Engineers (or MATH 53 Ordinary Differential Equations with Linear Algebra). Science must include PHYSICS 41 Mechanics; and either CHEM 31B Chemical Principles II or CHEM 31M Chemical Principles: From Molecules to Solids (or PHYSICS 43 Electricity and Magnetism, for Urban focus area only).
- ² Fundamental tools/skills must include:
 1. CEE 1 Introduction to Environmental Systems Engineering;
 2. at least one visual communication class from CEE 31 Accessing Architecture Through Drawing / CEE 31Q Accessing Architecture Through Drawing, DESINST 270 Visual Design Fundamentals, ME 101 Visual Thinking, ME 110 Design Sketching, ARTSTUDI 160 Intro to Digital / Physical Design, or OSPPARIS 44 EAP: Analytical Drawing and Graphic Art;
 3. at least one oral/written communication class from ENGR 103 Public Speaking, CEE 102W Technical and Professional Communication, ENGR 202W Technical Communication, CEE 151 Negotiation, EARTHYSYS 191 Concepts in Environmental Communication or ORALCOMM 117 The Art of Effective Speaking;
 4. at least one modeling/analysis class from CEE 101D Computations in Civil and Environmental Engineering (or CEE 101S) if not counted as Math, CEE 120A Building Modeling for Design & Construction (online only), CEE 146S Engineering Economics and Sustainability (online only), CEE 118X Shaping the Future of the Bay Area, CEE 155 Introduction to Sensing Networks for CEE, CEE 226 Life Cycle Assessment for Complex Systems, CME 211 Software Development for Scientists and Engineers, CS 102, EARTHYSYS 140, EARTHYSYS 142 Remote Sensing of Land, EARTHYSYS 144 Fundamentals of Geographic Information Science (GIS), or ESS 227 Decision Science for Environmental Threats
- ³ A course may only be counted towards one requirement; it may not be double-counted. All courses taken for the major must be taken for a letter grade if that option is offered by the instructor. Minimum Combined GPA for all courses in Engineering Fundamentals and Depth is 2.0.
- ⁴ Basic Requirement 4: Technology in Society (TiS) requirement.

Urban Environments Focus Area (40 units)

	Units
Required	
CEE 100 Managing Sustainable Building Projects	4
CEE 101B Mechanics of Fluids	4
CEE 146S Engineering Economics and Sustainability	3
CEE 176A Energy Efficient Buildings	3
or	
CEE 176B 100% Clean, Renewable Energy and Storage for Everything	3-4
Electives (at least two of the 4 areas below must be included with at least 3 units from 2nd area)	
Building Systems	
CEE 102A Legal / Ethical Principles in Design, Construction, Project Delivery	3
CEE 120B Advanced Building Modeling Workshop	2-4
CEE 130 Architectural Design: 3-D Modeling, Methodology, and Process	5
or	
CEE 131C How Buildings are Made -- Materiality and Construction Methods	4
CEE 156 Building Systems Design & Analysis	4
Energy Systems	
CEE 107A Understanding Energy (or CEE 107S, Sum. 3-4 units)	4-5
CEE 176B 100% Clean, Renewable Energy and Storage for Everything ((if not counted as req'd course))	3-4
ENERGY 104 Sustainable Energy for 9 Billion	3

CEE 173S	Electricity Economics	3
or		
ENERGY 171	Energy Infrastructure, Technology and Economics	3
or		
ENERGY 191	Optimization of Energy Systems	3-4
Water Systems		
CEE 166A	Watershed Hydrologic Processes and Models	4
CEE 166B	Water Resources and Hazards	4
CEE 170	Aquatic and Organic Chemistry for Environmental Engineering	3
CEE 174A	Providing Safe Water for the Developing and Developed World	3
CEE 174B	Wastewater Treatment: From Disposal to Resource Recovery	3
Urban Planning, Design, Analysis		
CEE 6	Physics of Cities	3
CEE 136	Planning Calif: the Intersection of Climate, Land Use, Transportation & the Economy	3
or		
CEE 275D	Environmental Policy Analysis	3-4
or		
CEE 273B	The Business of Water	2
CEE 177L	Smart Cities & Communities	3
URBANST 113	Introduction to Urban Design: Contemporary Urban Design in Theory and Practice	5
or		
URBANST 164	Sustainable Cities	4-5
or		
URBANST 165	(alt. years)	4-5
ME 267	Ethics and Equity in Transportation Systems	3
Capstone (one class required)		
CEE 131D	Urban Design Studio ((or CEE 131E))	5
CEE 141A	Infrastructure Project Development	3
CEE 141B	Infrastructure Project Delivery	3
CEE 226E	Techniques and Methods for Decarbonized and Energy Efficient Building Design	2-3
CEE 218Y	Shaping the Future of the Bay Area	3-5
CEE 218Z	Shaping the Future of the Bay Area	3-5
CEE 243	Intro to Urban Sys Engrg	3
CEE 265F	Environmental Governance and Climate Resilience	3
CEE 199	Undergraduate Research in Civil and Environmental Engineering	3-4

Freshwater Environments Focus Area (40 units)

		Units
Required		
CEE 70	Environmental Science and Technology	3
CEE 101B	Mechanics of Fluids	4
CEE 177	Aquatic Chemistry and Biology ((or CEE 170))	4
CEE 166A	Watershed Hydrologic Processes and Models	4
or		

CEE 174A	Providing Safe Water for the Developing and Developed World	3
or		
CEE 162E	Rivers, Streams, and Canals	3
Electives		
CEE 162E	Rivers, Streams, and Canals (if not counted as a required course)	3
CEE 162F	Coastal Processes	3
CEE 166A	Watershed Hydrologic Processes and Models (if not counted as a required course)	4
CEE 166B	Water Resources and Hazards	4
CEE 136	Planning Calif: the Intersection of Climate, Land Use, Transportation & the Economy	3
or		
CEE 275D	Environmental Policy Analysis	3-4
or		
CEE 273B	The Business of Water	2
CEE 174A	Providing Safe Water for the Developing and Developed World ((prereq: CHEM 31B) (if not counted as a req'd course))	3
CEE 174B	Wastewater Treatment: From Disposal to Resource Recovery ((prereq: CEE 174A))	3
CEE 177L	Smart Cities & Communities	3
or		
CEE 260D	Remote Sensing of Hydrology (prerequisite CS 106A)	3
CEE 265A	Resilience, Sustainability and Water Resources Development (offered occasionally)	3
CEE 265D	Water and Sanitation in Developing Countries	3
BIOHOPK 150H	Ecological Mechanics (alternate years)	3
Capstone (1 class required)		
CEE 141A	Infrastructure Project Development (recommended prerequisite: CEE 136)	3
CEE 218Y	Shaping the Future of the Bay Area	3-5
CEE 218Z	Shaping the Future of the Bay Area	3-5
CEE 199	Undergraduate Research in Civil and Environmental Engineering (must petition CEE UG Committee for approval, prior to enrollment; must have completed at least 6 focus area classes, excluding Breadth)	3-4

Coastal Environments Focus Area (40 units)

		Units
Required		
CEE 70	Environmental Science and Technology	3
CEE 101B	Mechanics of Fluids	4
And two of the following 4 classes:		
CEE 162F	Coastal Processes	3
CEE 162D	Introduction to Physical Oceanography	4
CEE 162I	Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation	3
CEE 175A	California Coast: Science, Policy, and Law	3-4
Electives		
CEE 162D	Introduction to Physical Oceanography (if not counted as a required class)	4
CEE 162F	Coastal Processes (if not counted as a required class)	3

CEE 162I	Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation (if not counted as a req'd class)	3
CEE 166A	Watershed Hydrologic Processes and Models	4
CEE 136	Planning Calif: the Intersection of Climate, Land Use, Transportation & the Economy	3
or		
CEE 275D	Environmental Policy Analysis	3-4
or		
CEE 273B	The Business of Water	2
CEE 174A	Providing Safe Water for the Developing and Developed World	3
CEE 174B	Wastewater Treatment: From Disposal to Resource Recovery	3
CEE 175A	California Coast: Science, Policy, and Law	3-4
CEE 177	Aquatic Chemistry and Biology	4
or CEE 170	Aquatic and Organic Chemistry for Environmental Engineering	
CEE 272	Coastal Contaminants	3-4
BIOHOPK 150H	Ecological Mechanics	3
BIO 30	Ecology for Everyone	4
or		
BIO 81	Introduction to Ecology	4
or		
BIOHOPK 81	Introduction to Ecology	4
or		
EARTHSYS 116	Ecology of the Hawaiian Islands	4
or		
OSPAUSTL 32	Coastal Ecosystems	3
or		
OSPGEN 53		2
or		
OSPSANTG 85	Marine Ecology of Chile and the South Pacific	5
DESINST 250	Oceans by Design	3
ESS 8	The Oceans: An Introduction to the Marine Environment	4
or		
ESS 240	Advanced Oceanography	3
or		
BIOHOPK 182H	Stanford at Sea (Oceanography portion - only 4 units may count)	4
EARTHSYS 141	Remote Sensing of the Oceans	3-4
EARTHSYS 151	Biological Oceanography	3-4
to be taken concurrently with		
EARTHSYS 152	Marine Chemistry	3-4
Capstone (1 class required)		
CEE 141A	Infrastructure Project Development	3
CEE 218Y	Shaping the Future of the Bay Area	3-5
CEE 218Z	Shaping the Future of the Bay Area	3-5
CEE 199	Undergraduate Research in Civil and Environmental Engineering (must petition CEE UG Committee for approval, prior to enrollment; must have completed at least 6 focus area classes, excluding Breadth)	3-4

Honors Program

This program leads to a B.S. with honors for undergraduates majoring in Civil Engineering or in Environmental Systems Engineering. It is designed to encourage qualified students to undertake a more intensive study of civil and environmental engineering than is required for the normal majors through a substantial, independent research project.

The program involves an in-depth research study in an area proposed to and agreed to by a Department of Civil and Environmental Engineering faculty adviser and completion of a thesis of high quality. A written proposal for the research to be undertaken must be submitted and approved by the faculty advisor in the fourth quarter prior to graduation. At the time of application, the student must have an overall grade point average (GPA) of at least 3.3 for course work at Stanford; this GPA must be maintained to graduation. The thesis is supervised by a CEE faculty adviser and must involve input from the School of Engineering writing program by means of ENGR 202S Directed Writing Projects or ENGR 199W Writing of Original Research for Engineers. The written thesis must be approved by the thesis adviser. Students are encouraged to present their results in a seminar for faculty and students. Up to 10 units of CEE 199H Undergraduate Honors Thesis, may be taken to support the research and writing (not to duplicate ENGR 202S or ENGR 199W). These units are beyond the normal Civil Engineering or Environmental Systems Engineering major program requirements.

For additional information on the major, minor, honors, and sample programs see the Handbook for Undergraduate Engineering Programs (UGHB) (<http://ughb.stanford.edu>).

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Minor in Civil Engineering or Environmental Systems Engineering

The department offers a minor in Civil Engineering and a minor in Environmental Systems Engineering. Departmental expertise and undergraduate course offerings are available in the areas of environmental engineering and science, environmental fluid mechanics and hydrology, and atmosphere/energy. The courses required for the minors typically have prerequisites. Minors are not ABET-accredited programs.

Civil Engineering (CE) Minor

The civil engineering minor is intended to give students a focused introduction to one or more areas of civil engineering. Departmental expertise and undergraduate course offerings are available in the areas of Architectural Design, Construction Engineering and Management, and Structural and Geotechnical Engineering. Students interested in Environmental and Water Studies should refer to the Environmental Systems Engineering minor.

The minimum prerequisite for a civil engineering minor is MATH 19 Calculus (or MATH 20 Calculus or MATH 21 Calculus); however, many courses of interest require PHYSICS 41 Mechanics and/or MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications as prerequisites. The minimum prerequisite for a Civil Engineering minor focusing on architectural design is MATH 19 Calculus (or MATH 20 Calculus or MATH 21 Calculus). Students should recognize that a minor in civil engineering is not an ABET-accredited degree program.

Since undergraduates having widely varying backgrounds may be interested in obtaining a civil engineering minor, and the field itself is so broad, no single set of course requirements will be appropriate for all students. Instead, interested students are encouraged to propose their own set of courses within the guidelines listed below. Additional information, including example minor programs, are provided on the CEE web site (http://cee.stanford.edu/prospective/undergrad/minor_overview.html) and in Chapter 6 of the Handbook for Undergraduate Engineering Programs (<http://ughb.stanford.edu/>).

General guidelines are:

1. A civil engineering minor must contain at least 24 units of course work not taken for the major, and must consist of at least six classes of at least 3 units each of letter-graded work, except where letter grades are not offered.
2. The list of courses must represent a coherent body of knowledge in a focused area, and should include classes that build upon one another. Example programs are given on the CEE webpage.

Professor Anne Kiremidjian (kiremidjian@stanford.edu) is the CEE undergraduate minor adviser in Structural Engineering and Construction Engineering and Management. John Barton (jhbarton@stanford.edu (<http://www.stanford.edu/dept/registrar/bulletin/jhbarton@stanford.edu>)), Program Director for Architectural Design, is the undergraduate minor adviser in Architectural Design. Students must consult the appropriate adviser when developing their minor program, and obtain approval of the finalized study list from them.

Environmental Systems Engineering (EnvSE) Minor

The Environmental Systems Engineering minor is intended to give students a focused introduction to one or more areas of Environmental Systems Engineering. Departmental expertise and undergraduate course offerings are available in the areas of environmental engineering and science, environmental fluid mechanics and hydrology, and atmosphere/energy. The minimum prerequisite for an Environmental Systems Engineering minor is MATH 19 Calculus (or MATH 20 Calculus or MATH 21 Calculus); additionally, many courses of interest require PHYSICS 41 Mechanics and/or MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications as prerequisites. Students should recognize that a minor in Environmental Systems Engineering is not an ABET-accredited degree program.

Since undergraduates having widely varying backgrounds may be interested in obtaining an Environmental Systems Engineering minor, no single set of course requirements is appropriate for all students. Instead, interested students are encouraged to propose their own set of courses within the guidelines listed below. Additional information on preparing a

minor program is available in the Undergraduate Engineering Handbook (<http://web.stanford.edu/group/ughb/cgi-bin/handbook/index.php/Handbooks/>).

General guidelines are—

- An Environmental Systems Engineering minor must contain at least 24 units of course work not taken for the major, and must consist of at least six classes of at least 3 units each of letter-graded work, except where letter grades are not offered.
- The list of courses must represent a coherent body of knowledge in a focused area, and should include classes that build upon one another. Example programs are available on the CEE web site (<https://cee.stanford.edu/academics/undergraduate-programs/minor/>).

Professor Nicholas Ouellette (nto@stanford.edu) is the CEE undergraduate minor adviser in Environmental Systems Engineering. Students must consult with Professor Ouellette (<https://cee.stanford.edu/people/nicholas-t-ouellette/>) in developing their minor program, and obtain approval of the finalized study list from him.

Coterminal M.S. Program in Civil and Environmental Engineering

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program at Stanford must have earned a minimum of 120 units towards graduation. This includes allowable Advanced Placement (AP) and transfer credit. Applicants must submit their application no later than the quarter prior to the expected completion of their undergraduate degree and are expected to meet the Department of Civil and Environmental Engineering application deadlines for coterminal applicants for graduate study (the third Friday of January). Applications are considered once a year during Winter Quarter. An application must display evidence of potential for strong academic performance as a graduate student.

It is recommended that students who contemplate advanced study at Stanford discuss their plans with their advisers in the junior year.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (<http://exploreddegrees.stanford.edu/cotermdegrees/>)" section. University requirements for the master's degree are described in the "Graduate Degrees (<http://exploreddegrees.stanford.edu/graduatedegrees/#masterstext>)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree

Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Master of Science in Civil and Environmental Engineering

The following programs are available leading to the M.S. degree in Civil and Environmental Engineering:

- Atmosphere/Energy
- Environmental Engineering
- Structural Engineering and Geomechanics
- Sustainable Design and Construction

Students admitted to graduate study with a B.S. in Civil Engineering, or equivalent, from an accredited curriculum can satisfy the requirements for the M.S. degree in Civil and Environmental Engineering by completing a minimum of 45 units beyond the B.S. All 45 units must be taken at Stanford. A minimum 2.75 grade point average (GPA) is required for candidates to be recommended for the M.S. degree. No thesis is required.

The program of study must be approved by the faculty of the department and should include at least 45 units of courses in engineering, mathematics, science, and related fields unless it can be shown that other work is pertinent to the student's objectives. Additional program area requirements are available on the department web site and from the department's student services office (Y2E2 room 316).

Candidates for the M.S. in Civil and Environmental Engineering who do not have a B.S. in Civil Engineering may, in addition to the above, be required to complete those undergraduate courses deemed important to their graduate programs. In such cases, more than three quarters is often required to obtain the degree.

Engineer in Civil and Environmental Engineering

A student with an M.S. in Civil Engineering may satisfy the requirements of the degree of Engineer in Civil and Environmental Engineering by completing 45 unduplicated course work and research units for a total of 90 units. Engineer candidates must submit an acceptable thesis (12-15 units) and maintain a minimum GPA of 3.0. The program of study must be approved by a faculty member in the department.

This degree is recommended for those desiring additional graduate education, especially those planning a career in professional practice. The thesis normally should be started in the first quarter of graduate study after the M.S. degree. Programs are offered in the fields of specialization mentioned for the M.S. degree. For students who will continue study toward a CEE Ph.D., the Engineer thesis topic must be significantly different from their doctoral research.

Graduate students who lack adequate background in their area of specialization (e.g. lack a prior degree in civil engineering, if required in their program) or who are not full-time students should expect to be enrolled for more than two years. Engineer degree candidates should develop individually tailored expected-progress timetables in consultation with their program advisers.

For graduate students not currently attending Stanford, admission to study for the Engineer degree in the Department of Civil and Environmental Engineering begins with the office of Graduate Admissions (<http://www.stanford.edu/home/admission/index/html/>).

If you are currently pursuing a graduate degree at Stanford, and wish to apply for the Engineer degree program, submit an Application for Post-Masters Study (available in the department office, Y2E2 Room 314). This form is typically filed during your second quarter of graduate study, by

January 15, so that your application may be reviewed during the normal graduate admissions cycle. You may apply at a later date if your adviser feels that it is appropriate to do so.

A minimum of 90 quarter units of full-time graduate study (or equivalent part-time graduate study) is required for the Engineer degree. For most students, the master's degree supplies 45 of these units.

If your master's degree was obtained at another school, you can apply to transfer up to 45 quarter units of residency credit by completing an Application for Transfer Credit for Graduate Work Done Elsewhere. No units need to be transferred if you hold an M.S. degree from Stanford.

Doctor of Philosophy in Civil and Environmental Engineering

The Ph.D. is offered under the general regulations of the University as set forth in the "Graduate Degrees" section of this bulletin. This degree is recommended for those who expect to engage in a professional career in research, teaching, or technical work of an advanced nature. The Ph.D. program requires a total of 135 units of graduate study, at least 90 units of which must be at Stanford. Up to 45 units of graduate study can be represented by the M.S. program described above. Additionally, up to 45 units of graduate study can be represented by the Engineer (ENG) program as described above if both the M.S. and ENG units were all completed at Stanford. Students must maintain a minimum GPA of 3.0 in post-M.S. course work. All candidates for the Ph.D. degree are required to complete CEE 200 in conjunction with a one-quarter teaching assistantship/course assistantship to gain training and instructional experience. Further information on Ph.D. requirements and regulations is found in the department Graduate Handbook.

The program of study is arranged via consultation between the prospective candidate and their dissertation research adviser. This program of study considers the interests of the student, and the background needed for their thesis topic, within the framework of the requirements of the department and the University.

By the end of a student's sixth quarter as an enrolled PhD student, excluding summers, the student is expected to pass both parts of the department's General Qualifying Examination (GQE) to be admitted to candidacy for the doctoral degree. The purpose of the GQE is to ensure that the student is adequately prepared to undertake doctoral research and has a well planned research topic. The exam include (1) a written and/or oral general examination of the candidate's doctoral major field, (2) a presentation and defense of the candidate's doctoral research dissertation proposal, or (3) a combination research proposal and general examination. The GQE is administered by an advisory committee consisting of at least three Stanford faculty members, including a chair who is a faculty member in Civil and Environmental Engineering, and the student's doctoral adviser. When the primary advisor is not a member of the CEE faculty (CEE-Academic Council), there must be a CEE faculty (CEE-Academic Council) co-adviser, and the committee will consist of four examiners, with a minimum of two members who are Academic Council in the CEE department. All members are normally on the Stanford Academic Council. A petition for appointment of one advisory committee member who is not on the Academic Council may be made if the proposed person contributes an area of expertise that is not readily available from the faculty. Such petitions are subject to approval by the department chair. When the primary research adviser is not a member of the CEE Academic Council faculty, there must be a CEE faculty (CEE-Academic Council) co-adviser, and the committee will consist of four examiners, with a minimum of two members who are Academic Council faculty in the CEE department.

Ph.D. Minor in Civil and Environmental Engineering

A Ph.D. minor is a program outside a major department. Requirements for a minor are established by the minor department. Acceptance of

the minor as part of the total Ph.D. program is determined by the major department. Application for the Ph.D. minor must be approved by both the major and the minor department, and the minor department must be represented at the University oral examination.

A student desiring a Ph.D. minor in Civil and Environmental Engineering (CEE) must have a minor program adviser who is both a CEE faculty member and a member of the Academic Council. The faculty member must be in the program of the designated minor subfield of CEE. This adviser must be a member of the student's University oral examination committee and the reading committee for the doctoral dissertation.

The program must include at least 20 units of graduate-level course work (courses numbered 200 or above, excluding special studies and thesis) in CEE completed at Stanford University. Units taken for the minor cannot be counted as part of the 45 unduplicated units for the PhD major. The list of courses must form a coherent program and must be approved by the minor program adviser and the CEE chair. A minimum GPA of 3.0 must be achieved in these courses.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (<http://exploreddegrees.stanford.edu/covid-19-policy-changes/#tempdeptemplatetabtext>)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a "credit" or "no credit" grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a "credit" or "satisfactory" grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements

Grading

Students in the Atmosphere/Energy (A/E), Architectural Design (AD), Civil Engineering (CE), and Environmental Systems Engineering (EnvSE) majors may count S/NC and CR/NC classes taken in 2020-21 (Autumn, Winter, Spring, or Summer) towards their Math, Science, Engineering Fundamentals, TiS, WIM, and Depth Requirements. For classes taken in 2020-21, there are no limits on the number of S/NC or CR/NC courses, or the number of S/NC or CR/NC units, which may count towards any of these four majors.

"Depth Requirements" are labelled in various ways in these four majors, including Engineering Depth, Required Core, Required Specialty, Focus Area Requirements, Depth Electives, Specialty Electives, Focus Electives, Depth Options, Breadth Electives, Additional Units, Senior Capstone, and Fundamental Tools/Skills; all of these categories are depth requirements, and may be taken S/NC or CR/NC in 2020-21 and counted as part of the major.

Graduate Degree Requirements

Grading

Grade Type Requirement Courses taken to satisfy the requirements for a graduate degree (M.S., Engineer, or Ph.D.) normally should be taken for a letter grade (A, B, C, or D). Core courses taken to satisfy a degree's subplan (AE, EnvEng, EES, EFMH, , SDC or SEG) require a letter grade. An exception to this policy is made when a course is offered only on a satisfactory/no credit (S/NC) basis.

The following additional exception to this policy applies: there is no restriction on the number of units taken for CR/NC in Summer 2020, Autumn 2020, Winter 2021, Spring 2021, and Summer 2021 which may be counted to satisfy the requirements for a CEE graduate degree. However, students should inform themselves of the limits to the number of S/NC units their subplans will accept toward a degree. Unless the program specifies otherwise, the Graduate School of Business (GSB) and Law School grading systems are considered to be graded units.

Graduate Advising Expectations

Faculty advisers serve as intellectual and professional mentors to their graduate students. They are expected to provide knowledgeable support concerning policies for graduate studies, help prepare their students to be competitive for employment, maintain a high level of professionalism, and establish expectations concerning adviser/advisee relationship consistent with University and department standards. General University policies on advising and the conduct of research can be found at VPGE's Advising and Mentoring (<https://vpge.stanford.edu/academic-guidance/advising-mentoring/>) web site.

It is important to distinguish between master's and doctoral advising. Master's students are assigned academic program advisers randomly, unless they explicitly request a specific faculty to advise them. The process by which a master's student can change advisers is flexible and can be done without any paperwork, provided that the change of adviser is made within the same program. The student, however, is expected to inform their old and new academic advisers, as well as the department's students services office, of such a change. Doctoral students, on the other hand, are expected to be advised by the faculty who admitted them throughout the duration of their doctoral studies. Any change in adviser requires a formal admit letter from the new adviser that includes an explicit commitment to support the student financially throughout the duration of their doctoral studies.

Master's students are expected to meet with their academic program advisers at the beginning of the school year to discuss their courses and proposed year-long academic plans. They are empowered to request an appointment with their adviser at any time throughout the school year to discuss any problems that arise with their studies, or changes with their academic plans.

Doctoral students and their faculty advisers are expected to discuss and agree on how regular meetings will be set up within a day or two of the student's start as a Ph.D. student. The discussion should include meeting frequency and deliverables associated with any of those meetings. They should discuss and agree on how the degree progress will be monitored, for example, through a department annual review process or regular meetings with adviser and thesis committees. They should also discuss all the requirements of the Ph.D. degree, including expectations for the General Qualifying Examination, how and when to select and convene the dissertation reading or thesis committee, when and how to decide when a student is ready to graduate, and when to take the University Oral Examination.

For a statement of University policy on graduate advising, see the "Graduate Advising (<http://exploreddegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext>)" section of this bulletin.

Emeriti: (Professors) James O. Leckie, Raymond E. Levitt*, Gilbert M. Masters*, Perry L. McCarty*, Henry W. Parker, Martin Reinhard*, Haresh C. Shah, Robert L. Street*, Clyde B. Tatum*, Paul M. Teicholz

Chair: Lynn M. Hildemann

Associate Chairs: Ronaldo I. Borja, Michael D. Lepech

Co-Directors of Graduate Studies: David L. Freyberg, Nicholas T. Ouellette

Professors: Jack W. Baker, Sarah L. Billington, Alexandria B. Boehm, Ronaldo I. Borja, Craig S. Criddle, Jennifer Davis, Gregory G. Deierlein, Martin A. Fischer, Oliver B. Fringer, Lynn M. Hildemann, Mark Z. Jacobson, Anne S. Kiremidjian, Peter K. Kitanidis (on sabbatical Winter Quarter), Jeffrey R. Koseff, Kincho H. Law, Richard G. Luthy, Eduardo Miranda, William A. Mitch, Stephen G. Monismith, Leonard Ortolano, Nicholas T. Ouellette, Alfred M. Spormann

Associate Professors: David L. Freyberg, Michael D. Lepech, Christian Linder, Meagan Mauter, Haeyoung Noh, Ram Rajagopal

Assistant Professors: Sarah Fletcher, Catherine Gorré, Rishie Jain

Emeritus Courtesy Professor: Peter M. Pinsky

Courtesy Professor: Margot G. Gerritsen

Courtesy Associate Professor: Leif Thomas

Courtesy Assistant Professor: Jenny Suckale

Senior Lecturer: John Barton

Lecturers: Michael Azgour, Thomas Beischer, Michael Bennon, Beverly Choe Harris, Stanley Christensen, Daniel Colvard, Kyle Douglas, Derek Fong, Renate Fruchter, Diana Gragg, Darryl Goodson, Robert Groves, Kenneth Hayes, Daniel Johnson, Glenn Katz, David Kleiman, Drew Krafcik, Nelson Koen Cohen, Royal Kopperud, Amy Larimer, Michael Lyons, René Morkos, Jose Luis Moscovich, Andrew Peterman, Alexander (Sandy) Robertson, Peter Rumsey, Hattie Stroud, Anand Subramani, Sebastien Tilmans, Ethen J. Wood, Jon Wren, Jiaona Zhang

Adjunct Lecturers: Leo Chow, Dimitris Farmakis, Erik Kolderup, Ashby Monk, Peter Rumsey, Mark Sarkisian, Bryan Shiles, Kristen Stasio, Christopher Wasney, Allison Williams

Adjunct Professors: Howard Ashcraft, Vladimir Bazjanac, Terry Beaubois, James Cloern, Angelos Findikakis, Robert Groves, Robert Hickey, Jeremy Isenberg, Calvin Kam, Michael Kavanaugh, Gloria Lau, Mike Lyons, Andrew Manning, Martin McCann Jr, Paul Meyer, Pedram Mokrian, Piotr Moncarz, Jose Luis Moscovitch, Colin Ong, Wayne Ott, Benedict Schwegler, Brian Sedar, Patrick Shiel, Michael Steep, Avram Tucker, Jie Wang, Jane Woodward, Jon Wren

Visiting Professor:

* Recalled to active duty.

Overseas Studies Courses in Civil and Environmental Engineering

The Bing Overseas Studies Program (<http://bosp.stanford.edu>) (BOSP) manages Stanford international and domestic study away programs for Stanford undergraduates. Students should consult their department or program's student services office for applicability of Overseas Studies courses to a major or minor program.

The BOSP course search site (<https://undergrad.stanford.edu/programs/bosp/explore/search-courses/>) displays courses, locations, and quarters relevant to specific majors.

For course descriptions and additional offerings, see the listings in the Stanford Bulletin's ExploreCourses (<http://explorecourses.stanford.edu>) or Bing Overseas Studies (<http://bosp.stanford.edu>).

Due to COVID-19, all BOSP programs have been suspended for Autumn Quarter 2020-21. All courses and quarters of operation are subject to change.

		Units
OSPAUSTL 10	Coral Reef Ecosystems	3
OSPAUSTL 28	Terrestrial Ecology and Conservation	3
OSPAUSTL 32	Coastal Ecosystems	3
OSPPARIS 44	EAP: Analytical Drawing and Graphic Art	2
OSPSANTG 85	Marine Ecology of Chile and the South Pacific	5
SINY 162	Sustainable and Resilient Urban Systems in NYC	3-4

Note: OSPAUSTL 10 and OSPAUSTL 28 may count towards the ENVSE-BS Breadth. OSPAUSTL 32 and OSPSANTG 85 may count towards the ENVSE-BS, Coastal Environments Focus Area Electives. SINY 162 may count towards the ENVSE-BS, Urban Environments Focus Area Electives. OSPPARIS 44 may count towards the ENVSE-BS, Fundamental Tools/Skills in visual, oral/written communication.

Courses

CEE 1. Introduction to Environmental Systems Engineering. 1 Unit.

Field trips visiting environmental systems installations in Northern California, including coastal, freshwater, and urban infrastructure. Requirements: Several campus meetings, and field trips. Enrollment limited; priority given to undergraduates who have declared Environmental Systems Engineering major, and undeclared Fr/Sophs.

CEE 1A. Graphics Course. 2 Units.

This course, intended for students taking a design studio, will focus on presentation theories, skills and design approaches. Through readings and exercises, and ultimately the student's own work, students will develop skill and complexity in their graphic and verbal presentations.

CEE 6. Physics of Cities. 3 Units.

An introduction to the modern study of complex systems with cities as an organizing focus. Topics will include: cities as interacting systems; cities as networks; flows of resources and information through cities; principles of organization, self-organization, and complexity; how the properties of cities scale with size; and human movement patterns. No particular scientific background is required, but comfort with basic mathematics will be assumed. Prerequisites: MATH 19 and 20, or the equivalent. Same as: URBANST 109

CEE 10A. Introduction to Architecture. 2 Units.

This class introduces students to the discipline of architecture and to the fundamental question: What is an architect and how is architecture distinct from other arts and sciences? To answer this question, the class will focus on concepts important to the practice of architecture including: project conception, drawing, modeling, materials, structure, form, and professionalism. These terms will be investigated through short talks, site visits, historical precedent, in-class exercises, panel discussions and two on-campus case studies. No prior knowledge of architecture is required.

CEE 10B. Presentation Skills. 0 Units.

TBD.

CEE 31. Accessing Architecture Through Drawing. 5 Units.

Preference to Architectural Design and CEE majors; others by consent of instructor. Drawing architecture to probe the intricacies and subtleties that characterize contemporary buildings. How to dissect buildings and appreciate the formal elements of a building, including scale, shape, proportion, colors and materials, and the problem solving reflected in the design. Students construct conventional architectural drawings, such as plans, elevations, and perspectives. Limited enrollment.

CEE 31Q. Accessing Architecture Through Drawing. 5 Units.

Preference to sophomores. Drawing architecture provides a deeper understanding of the intricacies and subtleties that characterize contemporary buildings. How to dissect buildings and appreciate the formal elements of a building, including scale, shape, proportion, colors and materials, and the problem solving reflected in the design. Students construct conventional architectural drawings, such as plans, elevations, and perspectives. Limited enrollment.

CEE 32A. Psychology of Architecture. 3 Units.

This course argues that architecture often neglects the interdisciplinary investigation of our internal psychological experience and the way it impacts our creation of space. How does our inner life influence external design? How are we impacted emotionally, physically, psychologically by the spaces we inhabit day to day? How might we intentionally imbue personal and public spaces with specific emotions? This seminar serves as a call to action for students interested in approaching architecture with a holistic understanding of the emotional impact of space. Sample topics addressed will include: conscious vs. unconscious design; the ego of architecture; psycho-spatial perspectives; ideas of home; integral/holistic architecture; phenomenology of inner and outer spaces; exploring archetypal architecture; and translating emotion through environment.

CEE 32B. Design Theory. 4 Units.

This seminar focuses on the key themes, histories, and methods of architectural theory -- a form of architectural practice that establishes the aims and philosophies of architecture. Architectural theory is primarily written, but it also incorporates drawing, photography, film, and other media. One of the distinctive features of modern and contemporary architecture is its pronounced use of theory to articulate its aims. One might argue that modern architecture is modern because of its incorporation of theory. This course focuses on those early-modern, modern, and late-modern writings that have been and remain entangled with contemporary architectural thought and design practice. Rather than examine the development of modern architectural theory chronologically, it is explored architectural through thematic topics. These themes enable the student to understand how certain architectural theoretical concepts endure, are transformed, and can be furthered through his/her own explorations. CEE 32B is a crosslisting of ARTHIST 217B/417B.

CEE 32D. Construction: The Writing of Architecture. 4 Units.

This seminar focuses on the construction of architectural writing. The class will analyze this idea through four topics: formal analysis, manifesto, translation, and preservation. The seminar is divided into two-week modules with each of these four concepts functioning as organizing principles. The first week of each module will involve familiarizing the seminar with both the terms and rhetorical tactics of the given theme by reading and analyzing specific texts and completing a short written analysis (1-2 pages). The second week will expand upon this foundation and involve further analysis in addition to each student writing a short paper (3-4 pages) drawing on the examples discussed and their own experiences in the discipline. The goal of the seminar is for each student to be able to analyze how an architectural writing is constructed and to develop his/her skills in the construction of his/her own writing.

CEE 32F. Light, Color, and Space. 3 Units.

This course explores color and light as a medium for spatial perception. Through the introduction of color theory, color mixing, and light analyses, students will learn to see and use light and color fields as a way to shape experience. We will examine the work of a range of architects and artist who use light and color to expand the field of perception (i.e. Rothko, Turrell, Eliasson, Holl, Aalto).

CEE 32G. Architecture Since 1900. 4 Units.

Art 142 is an introduction to the history of architecture since 1900 and how it has shaped and been shaped by its cultural contexts. The class also investigates the essential relationship between built form and theory during this period.

Same as: ARTHIST 142

CEE 32H. Responsive Structures. 3 Units.

This Design Build seminar investigates the use of metal as a structural, spatial and organizational medium. We will examine the physical properties of post-formable plywood, and develop a structural system and design which respond to site and programmatic conditions. The process includes model building, prototyping, development of joinery, and culminates in the full scale installation of the developed design on campus. This course may be repeated for credit (up to three times). Class meeting days/times are as follows: 1st session : April 4, 10am - 6pm 2nd session : April 25th, 10am - 6pm 3rd session: May 5, 6pm-9pm (Jun will not attend) Final Build dates: May 16 10am-evening May 17th. 10am- 6:30 pm.

Same as: CEE 132H

CEE 32Q. Place: Making Space Now. 3 Units.

This seminar argues that architects are ultimately "placemakers," and questions what that means in the contemporary world. Part I investigates the meaning of the word "place." Additional background for understanding contemporary place making will include a critique of the history of modern place-making through an examination of modern form. Part II examines two traditional notions of place by scale: from "home" to "the city." What elements give these conceptions of space a sense of place? To answer this question, themes such as memory, mapping, and boundary, among others, will be investigated. Part III presents challenges to the traditional notions of place discussed in Part II. Topics addressed include: What does it mean to be "out of place"? What sense of place does a nomad have, and how is this represented? What are the "non-places" and how can architects design for these spaces? Part IV addresses the need to re-conceptualize contemporary space. The role of digital and cyber technologies, the construction of locality in a global world, and the in-between places that result from a world in flux are topics discussed in this section of the seminar. Learning goals: Specific goals include close reading of texts, understanding of philosophical thinking and writing, argument under uncertainty, and developed concepts of place, space and architecture.

CEE 32R. American Architecture. 4 Units.

A historically based understanding of what defines American architecture. What makes American architecture American, beginning with indigenous structures of pre-Columbian America. Materials, structure, and form in the changing American context. How these ideas are being transformed in today's globalized world.

Same as: AMSTUD 143A, ARTHIST 143A, ARTHIST 343A

CEE 32S. The Situated Workplace and Public Life. 4 Units.

The modern workplace has undergone fundamental change and continues to evolve. The context of work in many industries is today being shaped substantially by changing workforce demographics, the pervasiveness of mobile and embedded information technologies, hyper-connected work models on a global scale, evolving notions of health and well being, etc. Our public realm is changing too. People are moving to cities in greater numbers than ever before posing both challenges and opportunities related to new levels of density, sustainable resource management, resilient infrastructures, as well as new forms of civic engagement at neighborhood levels, to name but a few. These changes at an urban scale impact how and where public life happens and how it interacts with new modalities at work. This course will combine research, conceptual explorations, studio design work, seminars and guest lectures to explore the impact of the changing workplace on the morphology of the city by examining these bi-coastal seats of innovation. As the creative workplace continues to evolve, how will it engage the public realm within both well-established urban frameworks such as San Francisco and Boston, and emerging suburban contexts, such as Silicon Valley? The course will join graduate students from the Northeastern University School of Architecture with students from the Stanford University Architectural Design program. Students will reside primarily at their prospective universities and will travel selectively for site research, team charrettes and project reviews. Project sites on both coasts will be utilized for research and studio work. This is an opportunity for students from two top universities, both situated in the epicenters of workplace change, to explore and conduct valuable research on an issue that is changing their urban environments.

CEE 32T. Making and Remaking the Architect: Edward Durell Stone and Stanford. 4 Units.

How does an architect establish a career? How is an architect remembered? What makes a building significant and how should it be preserved, if at all? Fundamental questions about the practice and production of architecture will be examined in this seminar that focuses on the work of Edward Durell Stone (1902-78) and specifically on his work at Stanford and in Palo Alto. By 1955, Stone was so well established that he founded an office in Palo Alto to design the Stanford Medical Center (currently slated for destruction) and several other significant local public buildings, such as the Palo Alto Civic Center. Through site visits to his buildings, research in the Stanford archives, and interviews with architects who worked in his office (among other strategies), students will question how architecture produced in the immediate post-WWII period is thought about historically and how and when it should be preserved.

CEE 32U. California Modernism: The Web of Apprenticeship. 4 Units.

This course will study the development of Modernism in pre and post WWII California. The class will investigate responses to climatic, technological, and cultural changes that were specific to the state but have now become an idealized trend. We will look at architects and landscape architects who apprenticed with significant design leaders and track how their involvement and explore resulted in changes in building technologies, and influenced the next generation of design thinking and experimentation. The investigations will occur through research, drawings and models, as well as site visits.

CEE 32V. Architectural Design Lecture Series Course. 1 Unit.

This seminar is a companion to the Spring Architecture and Landscape Architecture Lecture Series. Students will converse with lecturers before the lectures, attend the lecture, and prepare short documents (written, graphic, exploratory) for two of the lectures. The four course meeting dates will correspond with the lecture dates TBD. The meeting times are 4:30 PM -5:30 PM for the seminar and 6:30 - 7:45 for the lecture.

CEE 32W. Making Meaning: A Purposeful Life in Design. 3 Units.

As designers, how do we lead a life with meaning? What is a fulfilling life in design and how do we develop personal and professional practices that support this aim? This experiential course will explore how to nourish a purposeful life amidst a culture that can value productivity over presence in the field, identifying "busyness" as a marker of personal worth. How do we bring depth to not only the design process but our individual and collective lives as well? Investigations will include: exploring personal passions, discovering meaningful work in design, understanding work/life/play balance, practicing self-reflection, integrating wellness, cultivating community, and practicing design with integrity. Our time in class will be enjoyed sharing discourse, play, and reflections with both the class cohort and designers that lead lives of purpose and meaning.

CEE 32X. Modern and Contemporary World Architecture: A Cultural History in Twenty Five Buildings. 4 Units.

This survey course is a guided tour of twenty five case studies from the last hundred years; interrogates how architecture responds to the aesthetic, technological, political, and cultural issues of the societies they belong to, all over the world.

Same as: ARTHIST 141

CEE 32Y. Architecture & Gender. 4 Units.

This advanced seminar introduces students to the seemingly inconspicuous relation between architecture and gender. The course studies how modern societies create easily controlled docile spaces, thus pursuing the absent bodies of its members - be it through symbolic or material means. This troubled history of the powers of architecture to neglect sexuality and impose strict gender roles is analyzed in class discussions through recent feminist and queer theoretical approaches and tested on case studies.

Same as: ARTHIST 248A

CEE 33A. Michelangelo Architect. 5 Units.

The architecture of Michelangelo Buonarroti (1475-1564), "Father and Master of all the Arts," redefined the possibilities of architectural expression for generations. This course considers his civic, ecclesiastic, and palatial works. It proceeds from his beginnings in Medicean Florence to his fulfillment in Papal Rome. It examines the anxiety of influence following his death and his enduring legacy in modernism. Topics include: Michelangelo's debt to Classical and Early Renaissance prototypes; his transformation of the canon; the iterative sketch as disegno; architecture and the body; the queering of architectural language; sketch, scale, and materiality; Modernism and Michelangelo. The historiography of Michelangelo has predominantly favored studies in painting and sculpture. Our focus on architecture encourages students to test new ideas and alternative approaches to his work.

Same as: ARTHIST 416A, ITALIAN 216

CEE 33B. Japanese Modern Architecture. 4 Units.

This seminar will examine Japanese architecture and theory since 1900. Through a combination of case studies, readings, and chronological overview, students will develop an in-depth understanding of the aesthetic, expression of construction, structural dynamics, material choices, and philosophical viewpoints that impact Japanese modern and contemporary architectural design. Through lectures, class discussions, a series of weekly writing assignments, and a longer paper and presentation, students will develop the tools to analyze and understand Japanese design of today.

CEE 33C. Housing Visions. 3 Units.

This course provides an introduction to American Housing practices, spanning from the Industrial Age to the present. Students will examine a range of projects that have aspired to a range of social, economic and/or environmental visions. While learning about housing typologies, students will also evaluate the ethical role that housing plays within society. The course focuses on the tactical potentials of housing, whether it is to provide a strong community, solve crisis situations, integrate social services, or encourage socio-economic mixture. Students will learn housing design principles and organizational strategies, and the impact of design on the urban environment. They will discuss themes of shared spaces and defensible spaces; and how design can accommodate the evolving demographics and culture of this country. For example, how can housing design address the changing relationship between living and working? What is the role of housing and ownership in economic mobility? These issues will be discussed within the context of the changing composition of the American population and economy.

This course will be primarily discussion-based, using slideshows, readings and field trips as a departure points for student-generated conversations. Each student will be asked to lead a class discussion based on his/her research topic. Students will evaluate projects, identifying which aspects of the initial housing visions were realized, which did not, and why. Eventually, students might identify factors that lead to successful projects, and/or formulate new approaches that can strengthen or redefine the progressive role of housing: one inclusive of the complex social, economic, and ethical dimensions of design.

Same as: URBANST 103C

CEE 40. Approaching Palau: Preparation and Research Ideation and Development. 1 Unit.

This class is a seminar designed to prepare students participating in the 2019 Palau Seminar for possible research activities. Enrollment by approval of the instructors.

Same as: ESS 40

CEE 63. Weather and Storms. 3 Units.

Daily and severe weather and global climate. Topics: structure and composition of the atmosphere, fog and cloud formation, rainfall, local winds, wind energy, global circulation, jet streams, high and low pressure systems, inversions, el Niño, la Niña, atmosphere/ocean interactions, fronts, cyclones, thunderstorms, lightning, tornadoes, hurricanes, pollutant transport, global climate and atmospheric optics.

Same as: CEE 263C

CEE 64. Air Pollution and Global Warming: History, Science, and Solutions. 3 Units.

Survey of air pollution and global warming and their renewable energy solutions. Topics: evolution of the Earth's atmosphere, history of discovery of chemicals in the air, bases and particles in urban smog, visibility, indoor air pollution, acid rain, stratospheric and Antarctic ozone loss, the historic climate record, causes and effects of global warming, impacts of energy systems on pollution and climate, renewable energy solutions to air pollution and global warming. UG Reqs: GER: DBNatSci.

Same as: CEE 263D

CEE 70. Environmental Science and Technology. 3 Units.

Introduction to environmental quality and the technical background necessary for understanding environmental issues, controlling environmental degradation, and preserving air and water quality. Material balance concepts for tracking substances in the environmental and engineering systems.

Same as: ENGR 90

CEE 70N. Water, Public Health, and Engineering. 3 Units.

Preference to frosh. Linkages between water, wastewater and public health, with an emphasis on engineering interventions. Topics include the history of water and wastewater infrastructure development in the U.S. and Europe; evolution of epidemiological approaches for water-related health challenges; biological and chemical contaminants in water and wastewater and their management; and current trends and challenges in access to water and sanitation around the world. Identifying ways in which freshwater contributes to human health; exposure routes for water- and sanitation-illness. Classifying illnesses by pathogen type and their geographic distribution. Identifying the health and economic consequences of water- and sanitation-related illnesses; costs and benefits of curative and preventative interventions. Interpreting data related to epidemiological and environmental concepts. No previous experience in engineering is required.

CEE 73. Water: An Introduction. 3 Units.

Lake Tahoe's waters are so clear you can follow a diver 70 feet below your boat. A Lake Erie summer often means that nearshore waters have a green surface scum obscuring everything below. California, suffering from drought, is seriously considering reclamation and direct potable reuse of sewage -- aka toilet to tap. Can we (or should we) do this? Why is Tahoe clear, Erie green? This class introduces students to the fundamental tools and science used to understand and manage both natural and human-engineered water systems. Each student will use these tools to explore a water topic of their choosing.

CEE 74N. Grand Challenges in Environmental Engineering. 3 Units.

In 2019, the U.S. National Academies of Science assembled a team of leading scientists and engineers to identify the most pressing environmental challenges of the 21st century. From sustainably supplying food, water, and energy to a growing population to curbing climate change and adapting to its impacts, this report highlights the essential role that environmental engineers will play in preparing humanity to face a new and uncertain future. This Introductory Seminar will engage students in classroom lectures, small group problem solving, large group discussion, on-site field trips, and an independent research report to explore the key scientific questions and technical innovations needed to address environmental grand challenges. At the end of the course, students will be literate in pressing environmental issues, master the basic principles of environmental engineering, and understand the role of environmental engineers in the broader science, policy, and political ecosystem of scholars and practitioners dedicated to addressing environmental grand challenges. Students from all backgrounds and interest areas are welcome.

CEE 80N. Engineering the Built Environment: An Introduction to Structural Engineering. 3 Units.

In this seminar, students will be introduced to the history of modern bridges, buildings and other large-scale structures. Classes will include presentations on transformations in structural design inspired by the development of new materials, increased understanding of hazardous overloads and awareness of environmental impacts. Basic principles of structural engineering and how to calculate material efficiency and structural safety of structural forms will be taught using case studies. The course will include a field trip to a Bay Area large-scale structure, hands-on experience building a tower and computational modeling of bridges, and a paper and presentation on a structure or structural form of interest to the student. The goal of this course is for students to develop an understanding and appreciation of modern structures, influences that have led to new forms, and the impact of structural design on society and the environment. Students from all backgrounds are welcome.

CEE 83. Seismic Design Workshop. 2 Units.

Introduction to seismic design for undergraduate students. Structural design concepts are introduced based on physical and mathematical principles. General overview of mechanics of materials, structural analysis, structural systems and earthquake resistant design. The class is intended to prepare students for the EERI 2018 Seismic Design Competition, where students design, analyze and fabricate a five-foot tall balsa wood structure. Hands on workshops focus on numerical simulation using commercial software and experimental testing. All majors are welcome. Pre-requisite: Physics 41, recommended: ENGR 14.

CEE 100. Managing Sustainable Building Projects. 4 Units.

Managing the life cycle of buildings from the owner, designer, and contractor perspectives emphasizing sustainability goals; methods to define, communicate, coordinate, and manage multidisciplinary project objectives including scope, quality, life cycle cost and value, schedule, safety, energy, and social concerns; roles, responsibilities, and risks for project participants; virtual design and construction methods for product, organization, and process modeling; lifecycle assessment methods; individual writing assignment related to a real world project.

CEE 101A. Mechanics of Materials. 4 Units.

Introduction to beam and column theory. Normal stress and strain in beams under various loading conditions; shear stress and shear flow; deflections of determinate and indeterminate beams; analysis of column buckling; structural loads in design; strength and serviceability criteria. Lab experiments. Prerequisites: ENGR 14.

CEE 101B. Mechanics of Fluids. 4 Units.

Physical properties of fluids and their effect on flow behavior; equations of motion for incompressible ideal flow, including the special case of hydrostatics; continuity, energy, and momentum principles; control volume analysis; laminar and turbulent flows; internal and external flows in specific engineering applications including pipes and open channels; elements of boundary-layer theory. Prerequisites: E14, Physics 41, Math 51, or CME 100.

CEE 101C. Geotechnical Engineering. 3-4 Units.

Introduction to the principles of soil mechanics. Soil classification, shear strength and stress-strain behavior of soils, consolidation theory, analysis and design of earth retaining structures, introduction to shallow and deep foundation design, slope stability. Lab projects. Prerequisite: ENGR 14. Recommended: 101A.

CEE 101D. Computations in Civil and Environmental Engineering. 3 Units.

Computational and visualization methods in the design and analysis of civil and environmental engineering systems. Focus is on applications of MATLAB. How to develop a more lucid and better organized programming style.

Same as: CEE 201D

CEE 101S. Science & Engineering Problem-Solving with MatLab.. 3 Units.

Introduction to the application of MATLAB as a powerful tool to solve a variety of science and engineering problems. Exposure to computational and visualization tools available through MATLAB to analyze, solve, and visualize some common problems of interest in science and engineering. Prerequisite: Calculus. Note: students enrolling in CEE 201S must seek the consent of instructor.

Same as: CEE 201S

CEE 102A. Legal / Ethical Principles in Design, Construction, Project Delivery. 3 Units.

Introduction to the key legal principles affecting design, construction and the delivery of infrastructure projects. The course begins with an introduction to the structure of law, including principles of contract, negligence, professional responsibility, intellectual property, land use and environmental law, then draws on these concepts to examine current and developing means of project delivery. Limited class size. Enrollment preference given to undergraduates majoring in CE and EnvSE. Undergraduates wishing to have CEE 102A count as their Technology in Society (TiS) class must take it for a letter grade.

CEE 102W. Technical and Professional Communication. 3 Units.

Effective communication skills will help you advance quickly. Learn the best technical and professional techniques in writing and speaking. Group workshops and individual conferences with instructors. Designed for undergraduates going into industry. Allowed to fulfill WIM for Atmosphere/Energy and Environmental Systems Engineering majors only. Same as: ENGR 102W

CEE 103S. Machine Learning: Concepts & Applications in Civil & Environmental Engineering. 3 Units.

Introduction to machine learning concepts, tools and methodologies for incorporating intelligence and smart technology into environmental data applications. Learning algorithms and development of a machine learning pipeline. Set-up of a machine learning platform on an IoT edge sensor device. Prerequisite: CS 106A or equivalent Python programming experience.

Same as: CEE 203S

CEE 107A. Understanding Energy. 3-5 Units.

Energy is the number one contributor to climate change and has significant consequences for our society, political system, economy, and environment. Energy is also a fundamental driver of human development and opportunity. In taking this course, students will not only understand the fundamentals of each energy resource – including significance and potential, conversion processes and technologies, drivers and barriers, policy and regulation, and social, economic, and environmental impacts – students will also be able to put this in the context of the broader energy system. Both depletable and renewable energy resources are covered, including oil, natural gas, coal, nuclear, biomass and biofuel, hydroelectric, wind, solar thermal and photovoltaics (PV), geothermal, and ocean energy, with cross-cutting topics including electricity, storage, climate change and greenhouse gas emissions (GHG), sustainability, green buildings, energy efficiency, transportation, and the developing world. The course is 4 units, which includes lecture and in-class discussion, readings and videos, homework assignments, virtual field trips, and a small-group discussion section once a week for 50 minutes (live participation is required, many different times will be offered). Lectures will be recorded and available on Canvas. No in-person field trips will be offered for AY 2020-2021, but alumni of the class can optionally attend field trips in future quarters. Enroll for 5 units to also attend the Workshop, an interactive discussion section on cross-cutting topics that meets once per week for 80 minutes (timing TBD). The 3-unit option requires instructor approval - please contact Diana Gragg. Open to all: pre-majors and majors, with any background! Website: <https://energy.stanford.edu/understanding-energy>. CEE 107S/207S Understanding Energy: Essentials is a shorter (3 unit) version of this course, offered summer quarter. Students should not take both for credit. Prerequisites: Algebra. Same as: CEE 207A, EARTHSYS 103

CEE 107H. Applied Hope: Whole-Systems Thinking on Energy Solutions. 2 Units.

Whole-systems thinking has yielded transformative insights about prospects for sustainability across a series of energy and environmental challenges. Taught by Amory Lovins, co-founder of Rocky Mountain Institute, this seminar will cover four decades of ground-breaking analysis and validated results that have transformed what is thought to be possible across multiple fields. Topics will include highly efficient buildings, vehicles, and industrial processes; winning the fossil fuel endgames; nuclear power and security; natural capitalism; distributed energy and resilience; and profitable climate protection.

Same as: CEE 207H

CEE 107R. E³: Extreme Energy Efficiency. 3 Units.

Be part of a unique course about extreme energy efficiency and integrative design! We will meet remotely for once a week throughout the winter quarter. E³ will focus on efficiency techniques' design, performance, choice, evolution, integration, barrier-busting, profitable business-led implementation, and implications for energy supply, competitive success, environment, development, security, etc. Examples will span very diverse sectors, applications, issues, and disciplines, covering different energy themes throughout the quarter: buildings, transportation, industry, and implementation and implications, including renewable energy synergy and integration. Solid technical grounding and acquaintance with basic economics and business concepts will both be helpful. The course will be composed of keynote lectures, exercises, and interactive puzzlers synthesizing integrative design principles. Students will be introduced to Factor 10 Engineering, the approach for optimizing the whole system for multiple benefits. Students will work closely and interactively with RMI staff including Amory Lovins, cofounder and Chief Scientist of Rocky Mountain Institute (RMI), and Dr. Holmes Hummel, founder of Clean Energy Works. Exercises will illuminate challenges RMI has faced and solutions it has created in real-world design. Students will explore clean-sheet solutions that meet end-use demands and optimize whole-system resource efficiency, often with expanding rather than diminishing returns to investments, i.e. making big savings cheaper than small ones. All backgrounds and disciplines, both undergraduate and graduate, are welcome to enroll. There is no application this year. Prerequisite - completion of one of the following courses or their equivalent is required: CEE 107A/207A/ Earthsys 103, CEE 107S/ CEE 207S, CEE 176A, CEE 176B. Course details are available at the website: <https://energy.stanford.edu/extreme-energy-efficiency>. Same as: CEE 207R

CEE 107S. Understanding Energy - Essentials. 3-4 Units.

Energy is the number one contributor to climate change and has significant consequences for our society, political system, economy, and environment. Energy is also a fundamental driver of human development and opportunity. Students will learn the fundamentals of each energy resource – including significance and potential, drivers and barriers, policy and regulation, and social, economic, and environmental impacts – and will be able to put this in the context of the broader energy system. Both depletable and renewable energy resources are covered, including oil, natural gas, coal, nuclear, biomass and biofuel, hydroelectric, wind, solar thermal and photovoltaics (PV), geothermal, and ocean energy, with cross-cutting topics including electricity, storage, climate change and greenhouse gas emissions (GHG), sustainability, green buildings, energy efficiency, transportation, and the developing world. The course is 3 units, which includes lecture, readings and videos, assignments, and one required off-site field trip. Field trip offerings differ each quarter but may include Diablo Canyon nuclear power plant, Shasta dam, Tesla Gigafactory, NextEra wind farm, San Ardo oil field, Geyser's geothermal power plants, NEXTracker Solar PV, etc. Enroll for 4 units to also attend the Workshop, an interactive discussion section on cross-cutting topics that meets once per week for 80 minutes (timing TBD). This is a course for all: pre-majors and majors, with any background - no prior energy knowledge necessary. For a course that covers all of this plus goes more in-depth, check out CEE 107A/207A/ EarthSys 103 Understanding Energy offered in the autumn and spring quarters (students should not take both for credit). Website: <http://web.stanford.edu/class/cee207a/> Prerequisites: Algebra. Same as: CEE 207S

CEE 112A. Industry Applications of Virtual Design & Construction. 2-4 Units.

Building upon the concept of VDC Scorecard, CEE 112A/212A investigates in the management of Virtual Design and Construction (VDC) programs and projects in the building industry. Interacting with experts and professionals in real estate, architecture, engineering, construction and technology providers, students will learn from the industry applications of Building Information Modeling and its relationship with Integrated Project Delivery, Sustainable Design and Construction. Students will conduct case studies to evaluate the maturity of VDC planning, adoption, technology and performance in practice. Students taking 3 or 4 units will be paired up with independent research or case study projects on the industry applications of VDC. No prerequisite. See CEE112B/212B in the Winter Quarter and CEE 112C/212C in the Spring Quarter.

CEE 112B. Industry Applications of Virtual Design & Construction. 2-4 Units.

CEE 112B/212B is a practicum on the Industry Applications on Virtual Design and Construction (VDC). Students will gain insights and develop skills that are essential for academic research, internships or industry practice in VDC and Building Information Modeling (BIM). Students can choose between one of the two project topics: [1] Industrialized Construction with Virtual Parts (No Prerequisite) or [2] Industry Benchmarking & Applications of the VDC Management Scorecard (Suggested Prerequisite: CEE 112A/212A). Same as: CEE 212B

CEE 112C. Industry Applications of Virtual Design & Construction. 2-4 Units.

Following the Autumn- and Winter-quarter course series, CEE 112C/212C is an industry-focused and project-based practicum that focuses on the industry applications of Virtual Design and Construction (VDC). Students will be paired up with industry-based VDC projects with public owners and private developers, such as GSA Public Buildings Service, the Hong Kong Mass Transit Railway, Optima, Walt Disney Imagineering, Microsoft facilities and/or other CIFE International members. Independently, students will conduct case studies and/or develop VDC and building information models (BIM) using off-the-shelf technologies for project analysis, collaboration, communication and optimization. Students will gain insights and develop skills that are essential for academic research, internships or industry practice in VDC. Prerequisite: CEE 112A/212A, CEE 112B/212B, CEE 159C/259C, CEE 159D/259D, or Instructor's Approval. Same as: CEE 212C

CEE 112D. Industry Applications of Virtual Design and Construction. 2-4 Units.

A continuation of the CEE 112/212 series, CEE 112D/212D is an industry-focused and project-based practicum that focuses on the industry applications of Virtual Design and Construction (VDC). Students will be paired up with industry-based VDC research or application opportunities with public owners and private developers, professional associations, and/or other member organizations of the Center for Integrated Facility Engineering at Stanford. Independently, students will conduct case studies, research activities, and/or develop VDC and building information models (BIM) using off-the-shelf technologies for project analysis, collaboration, communication and optimization. Students will gain insights and develop skills that are essential for academic research, internships or industry practice in VDC. Prerequisite: CEE110/210, CEE 112C/212C, CEE 122B/222B, or Instructor's Approval. Same as: CEE 212D

CEE 113. Patterns of Sustainability. 1-4 Unit.

This seminar examines the interrelated sustainability of the natural, built and social environments of places in which we live. Several BOSP centers and the home Stanford campus will hold this 1-2 unit seminar simultaneously and collaborate with a shared curriculum, assignments, web conference and a Wiki. The goal of the collaborative arrangement is to expose, share, compare and contrast views of sustainability in different parts of the world. We will look at and assess aspects of sustainability of the places we are living from a theoretical perspective from the literature, from observations and interviews in the countries in which we study. Same as: CEE 213

CEE 114. Frontier Technology: Understanding and Preparing for Technology in the Next Economy. 2 Units.

The next wave of technological innovation and globalization will affect our countries, our societies, and ourselves. This interdisciplinary course provides an introduction to frontier technology, the intersection where radical forward thinking and real-world implementation meet. Topics covered include artificial intelligence, additive manufacturing and advanced robotics, smart cities and urban mobility, telecommunications with 5G, and other key emerging technologies in society. These technologies have vast potential to address the largest global challenges of the 21st century, ushering in a new era of progress and change. Limited enrollment, contact instructors for application. Same as: CEE 214, MED 114, MED 214, PSYC 114

CEE 118X. Shaping the Future of the Bay Area. 3-5 Units.

The complex urban problems affecting quality of life in the Bay Area, from housing affordability and transportation congestion to economic vitality and social justice, are already perceived by many to be intractable, and will likely be exacerbated by climate change and other emerging environmental and technological forces. Changing urban systems to improve the equity, resilience and sustainability of communities will require new collaborative methods of assessment, goal setting, and problem solving across governments, markets, and communities. It will also require academic institutions to develop new models of co-production of knowledge across research, education, and practice. This XYZ course series is designed to immerse students in co-production for social change. The course sequence covers scientific research and ethical reasoning, skillsets in data-driven and qualitative analysis, and practical experience working with local partners on urban challenges that can empower students to drive responsible systems change in their future careers. The Autumn (X) course is specifically focused on concepts and skills, and completion is a prerequisite for participation in the Winter (Y) and/or Spring (Z) practicum quarters, which engage teams in real-world projects with Bay Area local governments or community groups. X is composed of four modules: (A) participation in two weekly classes which prominently feature experts in research and practice related to urban systems; (B) reading and writing assignments designed to deepen thinking on class topics; (C) fundamental data analysis skills, particularly focused on Excel and ArcGIS, taught in lab sessions through basic exercises; (D) advanced data analysis skills, particularly focused on geocomputation in R, taught through longer and more intensive assignments. X can be taken for 3 units (ABC), 4 units (ACD), or 5 units (ABCD). Open to undergraduate and graduate students in any major. For more information, visit <http://bay.stanford.edu>.

Same as: CEE 218X, ESS 118X, ESS 218X, GEOLSCI 118X, GEOLSCI 218X, GEOPHYS 118X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

CEE 118Y. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 218Y, ESS 118Y, ESS 218Y, GEOLSCI 118Y, GEOLSCI 218Y, GEOPHYS 118Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

CEE 118Z. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 218Z, ESS 118Z, ESS 218Z, GEOLSCI 118Z, GEOLSCI 218Z, GEOPHYS 118Z, GEOPHYS 218Z, POLISCI 218Z

CEE 120A. Building Modeling for Design & Construction. 3 Units.

The foundational Building Information Modeling course introduces techniques for creating, managing, and applying of building information models in the building design and construction process. The course covers processes and tools for creating, organizing, and working with 2D and 3D computer representations of building components and geometries to produce models used in architectural design, construction planning and documentation, rendering and visualization, simulation, and analysis.

Same as: CEE 220A

CEE 120B. Advanced Building Modeling Workshop. 2-4 Units.

This course builds upon the Building Information Model concepts introduced in 120A/220A and illustrates how BIM modeling tools are used to design, analyze, and model building systems including structural, mechanical, electrical, plumbing and fire protection. Course covers the physical principles, design criteria, and design strategies for each system and explores processes and tools for modeling those systems and analyzing their performance. Topics include: building envelopes, access systems, structural systems modeling and analysis, mechanical / HVAC systems, plumbing and fire protection systems, electrical systems, and systems integration/coordination.

Same as: CEE 220B

CEE 120C. Parametric Design and Optimization. 2-4 Units.

This course explores tools and techniques for computational design and parametric modeling as a foundation for design optimization. Class sessions will introduce several parametric design modeling platforms and scripting environments that enable rapid generation of 3D models and enable rapid evaluation of parametrically-driven design alternatives. Topics to be featured include: Principles of parametric design vs. direct modeling; Design exploration using parametric modeling platforms (Revit/FormIt, Rhino); Visual scripting languages and environments (Dynamo, Grasshopper, DesignScript); Single- and multi-dimensional optimization techniques and guidance strategies.

Same as: CEE 220C

CEE 120S. Building Information Modeling Special Study. 2-4 Units.

Special studies of Building Information Modeling strategies and techniques focused on creating, managing, and applying models in the building design and construction process. Processes and tools for creating, organizing, and working with 2D and 3D computer representations of building components to produce models used in design, construction planning, visualization, and analysis. Contact glkatz@stanford.edu for more information.

Same as: CEE 220S

CEE 122A. Computer Integrated Architecture/Engineering/Construction. 2 Units.

Undergraduates serve as apprentices to graduate students in the AEC global project teams in CEE 222A. Apprentices participate in all activities of the AEC team, including the goals, objectives, constraints, tasks, and process of a crossdisciplinary global AEC teamwork in the concept development phase of a comprehensive building project. Prerequisite: consent of instructor.

Same as: A/E/C

CEE 122B. Computer Integrated A/E/C. 2 Units.

Undergraduates serve as apprentices to graduate students in the AEC global project teams in CEE 222B. Project activity focuses on modeling, simulation, life-cycle cost, and cost benefit analysis in the project development phase. Prerequisite: CEE 122A.

CEE 124. Sustainable Development Studio. 1-5 Unit.

(Graduate students register for 224A.) Project-based. Sustainable design, development, use and evolution of buildings; connections of building systems to broader resource systems. Areas include architecture, structure, materials, energy, water, air, landscape, and food. Projects use a cradle-to-cradle approach focusing on technical and biological nutrient cycles and information and knowledge generation and organization. May be repeated for credit.

CEE 124E. Ethics in Urban Systems. 3 Units.

This course will explore a comprehensive understanding of ethical challenges across dimensions of sustainability, resilience, equity, and well-being in urban systems, and the professional responsibilities of engineers in addressing those ethical challenges. We will cover theoretical and philosophical concepts and examine case studies in historical and current context, as well as produce written work, so as to prepare students' ethical systems before they engage in project-based learning. Students will build practical skills in ethical reasoning, including statistics, accounting, needfinding, and communication.

CEE 124S. Sustainable Urban Systems Seminar. 1 Unit.

The Sustainable Urban Systems (SUS) Seminar Series will feature speakers from academia, practice, industry, and government who are on the forefront of research and innovation in sustainable urban systems. The SUS Seminar will be open to the public; students will have the option of obtaining 1 unit of course credit based on attendance and completion of writing assignments.

Same as: CEE 224S

CEE 124X. Shaping the Future of the Bay Area. 3-5 Units.

Note to students: please be advised that the course number for this course has been changed to: CEE 218X, which is offered Autumn 2019-20. If you are interested in taking this course, please enroll in CEE 218X instead for Autumn 2019-20.

Same as: CEE 224X

CEE 125. Defining Smart Cities: Visions of Urbanism for the 21st Century. 3-4 Units.

Technological innovations have and will disrupt all domains of urban life, from housing to healthcare to city management to transportation. This seminar is aimed at future technologists, entrepreneurs, policymakers, and urban planners to define and evaluate the smartness of a city through three lenses: technology, equity, and policy. Through readings, seminar discussions, guest speakers, and a final project, we will explore how a smart city can leverage technology for a higher quality of life, less inequality in access to services, and tighter human communities. You will come away with a framework for understanding how to maximize the social good of emerging technologies. Course material is appropriate for students from all disciplines. Students who enroll in the course for 4 units will participate in an off-campus field component during Spring Break.

Same as: CEE 225, URBANST 174

CEE 126. International Urbanization Seminar: Cross-Cultural Collaboration for Sustainable Urban Development. 4-5 Units.

(formerly IPS 274) Comparative approach to sustainable cities, with focus on international practices and applicability to China. Tradeoffs regarding land use, infrastructure, energy and water, and the need to balance economic vitality, environmental quality, cultural heritage, and social equity. Student teams collaborate with Chinese faculty and students partners to support urban sustainability projects. Limited enrollment via application; see internationalurbanization.org for details. Prerequisites: consent of the instructor(s).

Same as: EARTHSYS 138, INTLPOL 274, URBANST 145

CEE 126X. Hard Earth: Environmental Justice. 1 Unit.

Environmental policies often have disparate impacts on marginalized people. The fall 2019 Hard Earth series will feature biweekly talks by Stanford graduate students who are investigating pressing questions at the intersection of environmental justice and health, energy, and climate change. On the alternate weeks, students who have enrolled to take the full Hard Earth series as a one-unit course (CEE 126XYZ | EARTH 126XYZ) meet for a deeper discussion about the prior week's presentation. There will be one culminating talk by a non-student sustainability expert. Learn more about Hard Earth here: <https://robesustainability.stanford.edu/initiatives/hard-earth>.

Same as: EARTH 126X

CEE 126Y. Hard Earth: Stanford Graduate-Student Talks Exploring Tough Environmental Dilemmas. 1 Unit.

Environmental disasters are striking with alarming frequency. Many, including wildfires and ecosystem collapse, are hitting California. The winter 2019 Hard Earth series will feature biweekly talks by Stanford graduate students whose research probes how people are coping with, adapting to, and changing their lives in the face of environmental catastrophe. Their talks will focus on events close to home in California. Students who choose to enroll in the entire quarterly series as a 1-unit class will, in the weeks between the talks, discuss what's happening in California in the context of the rest of the world.

Same as: EARTH 126Y

CEE 126Z. Hard Earth: The Interconnected Impacts of Global Climate Change. 1 Unit.

The COVID crisis makes one thing clear: society is ill-equipped to deal with disasters that do not respect borders and can cripple social and economic systems. Climate change, though radically different from a virus, similarly is a global threat. This class will feature virtual biweekly talks by four graduate students whose research probes a changing climate's already-occurring impacts on livelihoods, jobs, food, and social safety nets around the world. In the weeks in between the talks, we will hold a group discussion to explore how we can, as a global society, re-imagine our response to disaster.

Same as: EARTH 126Z

CEE 130. Architectural Design: 3-D Modeling, Methodology, and Process. 5 Units.

Preference to Architectural Design majors; others by consent of instructor. Projects investigate conceptual approaches to the design of key architectural elements, such as wall and roof. Functional and structural considerations. Focus is on constructing 3-D models in a range of materials; 3-D computer modeling. Students keep a graphic account of the evolution of their design process. Final project entails design of a simple structure. Limited enrollment. Pre- or corequisite: CEE 31 or 31Q.

CEE 130B. Quest for an Inclusive Clean Energy Economy. 3 Units.

Building bridges across the clean energy divide involves addressing barriers to participation. These barriers affect the pace of investment, especially for distributed energy solutions such as building energy upgrades, on-site solar, and transportation electrification. This course will explore innovative business models that are responsive to calls for equity and inclusion, and it will give special attention to California's ongoing clean energy finance rulemaking in the utility sector to open the clean energy economy for all.

Same as: CEE 330B

CEE 130R. Racial Equity in Energy. 2-3 Units.

The built environment and the energy systems that meet its requirements is a product of decisions forged in a context of historical inequity produced by cultural, political, and economic forces expressed through decisions at individual and institutional levels. This interdisciplinary course will examine the imprint of systemic racial inequity in the U.S. that has produced a clean energy divide and a heritage of environmental injustice. Drawing on current events, students will also explore contemporary strategies that center equity in the quest for rapid technology transitions in the energy sector to address climate change, public health, national security, and community resilience.

Prerequisites: By permission of the instructor. Preferable to have completed Understanding Energy (CEE 107A/207A/EarthSys 103/CEE 107S/207S) or a similar course at another institution if a graduate student.

Same as: CEE 330

CEE 131A. Professional Practice: Mixed-Use Design in an Urban Setting. 4 Units.

The delivery of a successful building design program involves unique collaboration between architect and client. This course will endeavor to teach the skills necessary for a designer to identify, evaluate, conceptualize and fully document a complex mixed-use urban design. Students will complete the course with a detailed knowledge of the consultants, engineers and other professionals needed for a complete program. Course deliverables will include three short assignments and a final project consisting of basic schematic drawings for the selected project. Guest presenters will cover topics of interest. Lectures, discussions, in-class studio-work and an oral presentation. Pre-requisite: CEE 130.

CEE 131B. Financial Management of Sustainable Urban Systems. 3 Units.

Focus is on financial management of sustainable urban systems. The course will study different kinds of financial services available, the management of financial resources, and relationships to financial service providers. The course will also study how financial services and relationships to financial service providers can be used to accomplish construction management, energy, and architecture work in sustainable urban systems. The learning outcome is an understanding of how financial services can be used in development of sustainable urban systems. The course work is structured so that there are three modules: 1) general knowledge of financial management, 2) in-depth application in construction management, energy, or architecture, and 3) comparison of similarities and differences in-between the in-depth applications. Students will focus on one of the in-depth applications in a group work, and present the result of this application to students that make other applications. A key learning aspect is the understanding of how finance is used in construction management, energy, and architecture work. Students should be able to show the value, financial viability, and risk management of sustainable urban system development in construction management, energy, and architecture. Students should be able to finance construction management, energy, and architecture work. Readings include applications of finance and management to construction management, energy, or architecture. Guest speakers include developers, financial managers at construction firms, managers at energy firms, construction managers.

CEE 131C. How Buildings are Made -- Materiality and Construction Methods. 4 Units.

This course will provide an introduction to the materials and methods used in building construction. A combination of in-class lectures, reading assignments, and building site visits will provide students with an awareness of construction materials and their use within building systems. All relevant building types and construction materials will be explored, including wood, steel, concrete and masonry. Building foundations and basic structural systems will be explained. Building envelope elements will be considered, with an analysis of various glass and glazing materials, cladding types, and roofing systems. Interior Floor, wall and ceiling finishes will be discussed. New and emerging building trends will also be examined, such as prefabricated and modular construction. Guest presenters, drawn from Bay Area consulting firms, will cover several topics of interest. Students will have an opportunity to experience real world material applications at local construction sites, and gain a thorough understanding of the construction process.

CEE 131D. Urban Design Studio. 5 Units.

The practical application of urban design theory. Projects focus on designing neighborhood and downtown regions to balance livability, revitalization, population growth, and historic preservation. Same as: URBANST 171

CEE 131E. Team Urban Design Studio. 5 Units.

This new class offers an exciting variation on the 'individual project' studio format. Students work as a team to propose a single consensus solution to a real-world design challenge. This collaborative studio experience more closely reflects the creative process in the design and planning professions where a group of individuals works together to brainstorm, shape, develop, and illustrate a community design solution. There are a number of benefits to this team-oriented approach: it is a more nurturing environment for students that do not have design backgrounds, it allows for more peer-to-peer learning, and it takes best advantage of varied student skill sets. But perhaps the greatest benefit is that a team of students working together on a common project will be able to develop a more comprehensive solution than any one student working alone. This means that the class "deliverable" at the end of quarter could be detailed enough to be of significant value to a stakeholder or client group from the larger community. This studio class, working under the guidance of an experienced instructor, functions like a design firm in providing professional-grade deliverables to real-world community design "clients".
Same as: URBANST 183

CEE 131G. Fabrication in Architectural Design. 4 Units.

Design course focused on architectural fabrication processes. Students build individual design projects using wood and metalworking process. This is a lab-based course operating out of the Product Realization Lab (PRL), with one lecture and one lab session per week. Lectures focus on design development as well as the theory and practice of fabrication processes. Structured labs take students' skills from paper-based modeling to full-scale construction processes using actual materials. Prior PRL/Room 036 experience is desirable but not required. Prerequisites: CEE 31, CEE 31Q (required), E 14 (recommended).

CEE 132H. Responsive Structures. 3 Units.

This Design Build seminar investigates the use of metal as a structural, spatial and organizational medium. We will examine the physical properties of post-formable plywood, and develop a structural system and design which respond to site and programmatic conditions. The process includes model building, prototyping, development of joinery, and culminates in the full scale installation of the developed design on campus. This course may be repeated for credit (up to three times). Class meeting days/times are as follows:
1st session : April 4, 10am - 6pm
2nd session : April 25th, 10am - 6pm
3rd session: May 5, 6pm-9pm (Jun will not attend)
Final Build dates: May 16 10am-evening
May 17th. 10am- 6:30 pm.
Same as: CEE 32H

CEE 133G. Architectural History & Drawing in Eastern Europe. 2 Units.

Students in this seminar will travel to Prague, Czech Republic and Krakow, Poland for a week of historical morning walks and discussions about architectural and urbanism in each city. Afternoon sketching sessions will focus attention on some of the locations visited earlier that day. Buildings, sites and monuments from the Middle Ages to the present will be assessed, questioned, and drawn. Short reading assignments and/or films provide a background for each day's examination of a section of these two cities. Possible day trips may include site visits to Auschwitz and the Wieliczka Salt Mine. Casual late afternoon excursions will complement themes of the course. Upon returning to Stanford, the seminar will meet four times to discuss observations and organize a small exhibition of the sketches made during the trip.

CEE 133H. Painting: Architecture in the Environment. 3 Units.

This five-week course engages students in deconstructing architectural structures in relation to the environment by way of observational painting with acrylics. Through on location painting and studio sessions, students build creative capacities and develop critical thinking skills as we focus on the fundamentals of painting, discuss precedents from art and architectural history, and engage in constructive group critiques. Color theory, as it relates to value and applies to light on form and material, is examined and put into practice as students mix paint and explore a variety of techniques. Volume is a major component as we apply principles of proportion, perspective, and depth to convincingly articulate spatial relationships. Composition and design principles are investigated throughout the painting process, from preparatory graphite sketches through project completion. Active painting is enhanced by focused exercises, demonstrations, slide lectures, readings, and museum visits, all which facilitate a deeper understanding of architecture via painting. (Note: this course meets for only 5 weeks: Jan 8 - Feb 7, 2019).

CEE 134B. Intermediate Arch Studio. 5 Units.

This studio offers students experience in working with a real site and a real client program to develop a community facility. Students will develop site analysis, review a program for development and ultimately design their own solutions that meet client and community goals. Sustainability, historic preservation, community needs and materials will all play a part in the development of students final project. Students will also gain an understanding of graphic conventions, verbal and presentation techniques. Course may be repeated for credit.
Same as: CEE 234B

CEE 136. Planning Calif: the Intersection of Climate, Land Use, Transportation & the Economy. 3 Units.

Cities and urban areas have always been transformed by major external changes like pandemics and public health crises. California is both in the midst of its greatest economic recession since the Great Depression and experiencing a pandemic that has the potential to reshape many aspects of life. Planning for cities and regions, however, is a long game that requires follow-through on decisions made sometimes over many decades. How do we balance the shocks to our assumptions from the current Covid world with the need to plan long-term for issues like affordable housing and equitable cities, and perhaps most fundamentally, prepare our cities and communities for the inevitability of climate change and climate impact?
This course takes an interdisciplinary view of the key contemporary planning topics in California. It does so from looking at the intersection of climate laws, land use changes, the need for housing, travel patterns and the availability of high quality jobs and employment. This course will give you an understanding of the roles of key levels of government, from the state to the region/metropolitan scale, to the city and county, down to the neighborhood and parcel level. It will give students insight into leading themes and issues of the day in California such as the future of downtowns, the role of high speed rail, the impact of telework, automation in the construction of housing, drawing from examples in San Jose and San Francisco, the Central Valley, the state legislature, Southern California. Within each of these topics we will look at the impact of decisions on equity as well as climate and the economy.
The instructors are Kristy Wang, formerly SPUR's Community Planning Policy Director, and Egon Terplan, Senior Advisor for Economic Development and Transportation in the California Governor's Office, formerly SPUR's Regional Planning Director. (Affiliations for identification purposes only).
Same as: CEE 236, PUBLPOL 130, PUBLPOL 230, URBANST 130

CEE 137B. Advanced Architecture Studio. 6 Units.

This course will focus on the topic of interdisciplinary collaboration and its role in the development of design concepts. Specifically, the integration of structural with architectural considerations to produce a unified urban, spatial, tectonic and structural proposition will be our field of investigation. This course is an architecture studio course where class time will be spent primarily in individual or group desk critiques and pin-up sessions. May be repeat for credit. Total completions allowed: 3. Additionally, there will be lectures, case study presentations and a field trip. Prerequisites: required: CEE 31 (or 31Q) Drawing, CEE 120A and CEE 130 Design.

Same as: CEE 237B

CEE 139. Design Portfolio Methods. 4 Units.

The portfolio is an essential creative tool used to communicate academic work, design philosophies, and professional intent. This course will explore elements of graphic design, presentation, communication, binding, printing, and construction, yielding a final portfolio (physical and digital) for professional, academic or personal purposes. Limited enrollment. Prerequisites: two Art, Design, or Architecture studio courses, or consent of instructor. Note: CEE139 will run M/W from 10:30am-12:20pm, Autumn 2020-21.

Same as: CEE 239

CEE 141A. Infrastructure Project Development. 3 Units.

Infrastructure is critical to the economy, global competitiveness and quality of life. Topics include energy, transportation, water, public facilities, and communications sectors. Analysis of the condition of the nation's infrastructure and how projects are planned and financed. Focus is on public works in the U.S. The role of public and private sectors through a step-by-step study of the project development process. Case studies of real infrastructure projects. Industry guest speakers. Student teams prepare project environmental impact statements.

Same as: CEE 241A

CEE 141B. Infrastructure Project Delivery. 3 Units.

Infrastructure is critical to the economy, global competitiveness and quality of life. Topics include energy, transportation, water, public facilities, and communications sectors. Analysis of how projects are designed, constructed, operated, and maintained. Focus is on public works projects in the U.S. Alternative project delivery approaches and organizational strategies. Case studies of real infrastructure projects. Industry guest speakers. Student teams prepare finance/design/build/operate/maintain project proposals.

Same as: CEE 241B

CEE 141C. Global Infrastructure Projects Seminar. 1-2 Unit.

Nine current global infrastructure projects presented by top project executives or company leaders from industry. Water, transportation, energy and communication projects are featured. Course provides comparisons of project development, win and delivery approaches for mega-projects around the world. Alternative project delivery methods, the role of public and private sector, different project management and construction strategies, and lessons learned. The course also includes field trips to local mega-projects. Grade (one unit) is based on attending all 9 lectures and at least 2 field trips.

Same as: CEE 241C

CEE 144. Design and Innovation for the Circular Economy. 3 Units.

The last 150 years of our industrial evolution have been material and energy intensive. The linear model of production and consumption manufactures goods from raw materials, wells and uses them, and then discards the products as waste. Circular economy provides a framework for systems-level redesign. It builds on schools of thought including regenerative design, performance economy industrial ecology, blue economy, biomimicry, and cradle to cradle. This course introduces the concepts of the circular economy and applies them to case studies of consumer products, household goods, and fixed assets. Students will conduct independent projects on circular economy. Students may work alone or in small teams under the guidance of the teaching team and various collaborators worldwide. Class is limited to 14 students. All disciplines are welcome. This class fulfills the Writing & Rhetoric 2 requirement. Prerequisite: PWR 1.

CEE 146S. Engineering Economics and Sustainability. 3 Units.

Engineering Economics is a subset of the field of economics that draws upon the logic of economics, but adds that analytical power of mathematics and statistics. The concepts developed in this course are broadly applicable to many professional and personal decisions, including making purchasing decisions, deciding between project alternatives, evaluating different processes, and balancing environmental and social costs against economic costs. The concepts taught in this course will be increasingly valuable as students climb the career ladder in private industry, a non-governmental organization, a public agency, or in founding their own startup. Eventually, the ability to make informed decisions that are based in fundamental analysis of alternatives is a part of every career. As such, this course is recommended for engineering and non-engineering students alike. This course is taught exclusively online in every quarter it is offered. (Prerequisites: MATH 19 or 20 or approved equivalent.)

Same as: ENGR 60

CEE 151. Negotiation. 3 Units.

Students learn to prepare for and conduct negotiations in a variety of arenas including getting a job, managing workplace conflict, negotiating transactions, and managing personal relationships. Interactive class. The internationally travelled instructor who has mediated cases in over 75 countries will require students to negotiate real life case studies and discuss their results in class. Application required before first day of class; students should enroll on Axess and complete the application on Canvas before March 20, 2020. Note: there is a class fee of \$130 for access to case files and readings.

Same as: CEE 251, EARTH 251, PUBLPOL 152

CEE 151A. Race in Science. 1 Unit.

What are the roles of race and racism in science, technology, and medicine? 3-course sequence; each quarter can be taken independently. Fall quarter focuses on science. What is the science of race and racism? How does race affect scientific work? Weekly guest speakers will address such issues as the psychology and anthropology of race and racism; how race, language, and culture affect education; race in environmental science and environmental justice; the science of reducing police violence; and the role of race in genomic research. Talks will take a variety of forms, from panel discussions to interviews and lectures. Weekly assignments: read a related article and participate in an online discussion.

Same as: AFRICAAM 51A, COMM 51A, CSRE 51A, HUMBIO 71A, STS 51A

CEE 151B. Race in Technology. 1 Unit.

What are the roles of race and racism in science, technology, and medicine? 3-course sequence; each quarter can be taken independently. Winter quarter focuses on technology. How do race and racism affect the design and social impact of technology, broadly defined? Can new or different technology help to reduce racial bias? Invited speakers will address the role of race in such issues as energy infrastructure, nuclear arms control, algorithmic accountability, machine learning, artificial intelligence, and synthetic biology. Talks will take a variety of forms, ranging from panel discussions to interviews and lectures. Weekly assignments: read a related article and participate in an online discussion.

Same as: AFRICAAM 51B, BIOE 91B, COMM 51B, CSRE 51B, HUMBIO 71B, STS 51B

CEE 151C. Race in Medicine. 1 Unit.

What are the roles of race and racism in science, technology, and medicine? 3-course sequence; each quarter can be taken independently. Spring quarter focuses on medicine. How do race and racism affect medical research and medical care? What accounts for health disparities among racial groups? What are the history, ethics, legal, and social issues surrounding racialized medical experiments and treatments? Invited speakers will address these and other issues. Talks will take a variety of forms: conversations, interviews, panels, and others. Weekly assignments: read a related article and participate in an online discussion.

Same as: AFRICAAM 51C, BIOE 91C, CSRE 51C, HUMBIO 71C, STS 51C

CEE 154. Data Analytics for Physical Systems. 3-4 Units.

This course introduces practical applications of data analytics and machine learning from understanding sensor data to extracting information and decision making in the context of sensed physical systems. Many civil engineering applications involve complex physical systems, such as buildings, transportation, and infrastructure systems, which are integral to urban systems and human activities. Emerging data science techniques and rapidly growing data about these systems have enabled us to better understand them and make informed decisions. In this course, students will work with real-world data to learn about challenges in analyzing data, applications of statistical analysis and machine learning techniques using MATLAB, and limitations of the outcomes in domain-specific contexts. Topics include data visualization, noise cleansing, frequency domain analysis, forward and inverse modeling, feature extraction, machine learning, and error analysis. Prerequisites: CS106A, CME 100/Math51, Stats110/101, or equivalent.

Same as: CEE 254

CEE 155. Introduction to Sensing Networks for CEE. 3-4 Units.

Introduce the design and implementation of sensor networks for monitoring the built and natural environment. Emphasis on the integration of modern sensor and communication technologies, signal processing and statistical models for network data analysis and interpretation to create practical deployments to enable sustainable systems, in areas such as energy, weather, transportation and buildings. Students will be involved in a practical project that may involve deploying a small sensor system, data models and analysis and signal processing. Limited enrollment.

Same as: CEE 255

CEE 156. Building Systems Design & Analysis. 3-4 Units.

HVAC, lighting, and envelope systems for commercial and institutional buildings, with a focus on energy efficient design. Knowledge and skills required in the development of low-energy buildings that provide high quality environment for occupants.

Same as: CEE 256

CEE 157. Sustainable Finance and Investment Seminar. 1 Unit.

The course aims to equip the Stanford community with the knowledge and networks required to undertake significant future work on sustainable finance and investment. The course will be given in a seminar format, which explores multiple disciplines of sustainable finance with talks by researchers associated with the Stanford Precourt Institute for Energy's Sustainable Finance Initiative and visiting speakers. The course features three highly interactive modules: (1) risk and opportunities of sustainable finance, (2) business and financial innovation toward sustainability, and (3) sustainability assessment and advanced data technologies. The contents covered by this course include but are not limited to systems and theories in sustainable finance and investment such as active ownership, carbon markets and policies, climate finance, environmental disclosure and reporting, divestment, engagement, environmental, social, and governance (ESG), green banks, green bonds, green benchmarks and indices, impact investing, public-private partnerships, responsible investment, stranded assets, and green taxonomies. Seminar meets weekly during the Spring Quarter.

Same as: CEE 257

CEE 161I. Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation. 3 Units.

Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the atmospheric circulation. Topics include the global energy balance, the greenhouse effect, the vertical and meridional structure of the atmosphere, dry and moist convection, the equations of motion for the atmosphere and ocean, including the effects of rotation, and the poleward transport of heat by the large-scale atmospheric circulation and storm systems. Prerequisites: MATH 51 or CME100 and PHYSICS 41.

Same as: CEE 261I, EARTHSYS 146A, ESS 246A

CEE 162A. Mechanics of Fluids. 3 Units.

Course content is the same as CEE 101B but without the Tuesday lecture and lab component. Permission of the instructor is required first to enroll in CEE 162A. Prerequisites: E14, Physics 41 and Math 51.

CEE 162D. Introduction to Physical Oceanography. 4 Units.

The dynamic basis of oceanography. Topics: physical environment; conservation equations for salt, heat, and momentum; geostrophic flows; wind-driven flows; the Gulf Stream; equatorial dynamics and ENSO; thermohaline circulation of the deep oceans; and tides. Prerequisite: PHYSICS 41.

Same as: CEE 262D, EARTHSYS 164, ESS 148

CEE 162E. Rivers, Streams, and Canals. 3 Units.

Introduction to the movement of water through natural and engineered channels, streams, and rivers. Basic equations and theory (mass, momentum, and energy equations) for steady and unsteady descriptions of the flow. Application of theory to the design of flood-control and canal systems. Flow controls such as weirs and sluice gates; gradually varied flow; Saint-Venant equations and flood waves; and method of characteristics. Open channel flow laboratory experiments: controls such as weirs and gates, gradually varied flow, and waves. Limited enrollment in lab section. Prerequisite: CEE 101B or CEE 162A.

Same as: CEE 262E

CEE 162F. Coastal Processes. 3 Units.

Formerly Coastal Engineering. Fluid dynamics and sediment transport processes that govern the physical behavior of the coastal ocean. Topics: waves, coastal sediment transport, tides, storm surge, sea-level rise, estuarine circulation, river plumes, and upwelling. Prerequisite: PHYSICS 41.

CEE 162I. Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation. 3 Units.

Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the large-scale ocean circulation. This course will give an overview of the structure and dynamics of the major ocean current systems that contribute to the meridional overturning circulation, the transport of heat, salt, and biogeochemical tracers, and the regulation of climate. Topics include the tropical ocean circulation, the wind-driven gyres and western boundary currents, the thermohaline circulation, the Antarctic Circumpolar Current, water mass formation, atmosphere-ocean coupling, and climate variability. Prerequisites: MATH 51 or CME100; and PHYSICS 41; and a course that introduces the equations of fluid motion (e.g. ESS 246A, ESS 148, or CEE 101B).

Same as: CEE 262I, EARTHSYS 146B, ESS 246B

CEE 164H. Quantitative methods for marine ecology and conservation. 4 Units.

The goal of this course is to learn the foundations of ecological modelling with a specific (but not exclusive) focus on marine conservation and sustainable exploitation of renewable resources. Students will be introduced to a range of methods ζ from basic to advanced ζ to characterize population structure, conduct demographic analyses, estimate extinction risk, identify temporal trends and spatial patterns, quantify the effect of environmental determinants and anthropogenic pressures on the dynamics of marine populations, describe the potential for adaptation to climate change. This course will emphasize learning by doing, and will rely heavily on practical computer laboratories, in R and/or Python, based on data from our own research activities or peer reviewed publications. Students with a background knowledge of statistics, programming and calculus will be most welcome.

Same as: BIOHOPK 143H, BIOHOPK 243H, CEE 264H, EARTHSYS 143H, EARTHSYS 243H

CEE 165C. Water Resources Management. 3 Units.

Water resources management is studied in the context of increasing population, economic growth, and the effect of climate change on the available water resources. The class examines the question of how to achieve the optimal equilibrium between water supply and water demand, under specific local and regional physical environmental, social and economic constraints. Basic water management principles are reviewed in the context of sustainable development, increasing water scarcity in many parts of the world, and hydrologic uncertainty including that associated with climate change. Specific topics include the management of operations and water quality in reservoirs, river basins, and groundwater systems; non-conventional water sources such as treated wastewater and desalination; demand management options; and the institutional and legal framework of water management.

Same as: CEE 265C

CEE 165H. Big Earth Hackathon Wildland Fire Challenge. 3 Units.

Participate in Stanford's Big Earth Hackathon challenge on wildland fires by finding an innovative solution to wildland fire prediction, prevention, and/or evacuation. Students work in self-organized diverse teams of 2-4 students in weeks 1-8, with a final presentation of the work on Friday May 29. The teams will spend the first few weeks designing their specific team problem/scope/goals under one of three primary areas of focus. Guidance in the design and solution processes will be provided by faculty, industry and/or community leaders. Workshops in data analysis, programming, GIS, and fundamental issues related to wildfires will be provided at the start of the quarter to give students tools and insights to define and tackle problems.

Same as: CEE 265H, EARTH 165H, EARTH 265H

CEE 166A. Watershed Hydrologic Processes and Models. 3 Units.

Introduction to the occurrence and movement of water in the natural environment and its role in creating and maintaining terrestrial, wetland, and aquatic habitat. Hydrologic processes, including precipitation, evaporation, transpiration, snowmelt, infiltration, subsurface flow, runoff, and streamflow. Rivers and lakes, springs and swamps. Emphasis is on observation and measurement, data analysis, modeling, and prediction. Prerequisite: CEE 101B or CEE 162A or equivalent. (Freyberg).

Same as: CEE 266A

CEE 166B. Water Resources and Hazards. 3 Units.

Sociotechnical systems associated with human use of water as a resource and the hazards posed by too much or too little water. Potable and non-potable water use and conservation. Irrigation, hydroelectric power generation, rural and urban water supply systems, storm water management, flood damage mitigation, and water law and institutions. Emphasis is on engineering design. Prerequisite: 166A/266A or equivalent. (Freyberg).

Same as: CEE 266B

CEE 170. Aquatic and Organic Chemistry for Environmental Engineering. 3 Units.

This course provides a solid foundation in the most important aspects of general, aquatic and organic chemistry. Nearly all of aspects environmental engineering apply the chemistry concepts discussed in this course. Given that each of the chemistry subjects to be addressed are standalone classes, this class highlights only the most relevant material to environmental engineering. The class focuses on developing general background skills needed for subsequent classes in environmental engineering focusing on their applications, although certain applications will be discussed for illustration.

Same as: CEE 270M

CEE 171F. New Indicators of Well-Being and Sustainability. 3 Units.

Explore new ways to better measure human development, comprehensive wealth and sustainability beyond standard economic indicators such as income and GDP. Examine how new indicators shape global, national and local policy worldwide. Well-being topics include health, happiness, trust, inequality and governance. Sustainability topics include sustainable development, environmental performance indicators, material flow analysis and decoupling, and inclusive wealth indicators. Students will build their own indicator of well-being and sustainability for a term paper.

CEE 171G. Environmental & Ecological Economics. 3 Units.

Ideas, tools and policy solutions in environmental and ecological economics covering a wide range of topics: biodiversity and ecosystems management, energy and climate change mitigation, environmental health and environmental justice, new indicators of well-being and sustainability beyond GDP and growth and sustainable urban systems.

Same as: CEE 271G

CEE 172. Air Quality Management. 3 Units.

Quantitative introduction to the engineering methods used to study and seek solutions to current air quality problems. Topics: global atmospheric changes, urban sources of air pollution, indoor air quality problems, design and efficiencies of pollution control devices, and engineering strategies for managing air quality. Prerequisites: 70, MATH 51.

CEE 173. Urban Water. 3 Units.

This course explores technical, economic, institutional, social, and policy, and legal aspects of urban water using case studies and discussions around the world. The course will include lectures and discussions. Lectures will provide foundational information on the link between water and human and ecosystem health, drinking water and wastewater treatment methods, as well as policies and guidelines (local, national, and global from the World Health Organization) on water and wastewater, and the role of various stakeholders including institutions and the public, in the outcome of water conflicts. Students will dive into details of nuanced conflicts over water through case studies using discussion and debate. Course themes include (1) scientific uncertainty, (2) institutions, stakeholders, and human behavior matter, and (3) complexity of the coupled human-ecosystem-urban water system.

CEE 173S. Electricity Economics. 3 Units.

This course develops a foundation of economic principles for the electric utility on the topics of regulation, planning, and operation. A particular emphasis is given to emerging electricity sector topics such as renewable planning and integration, distributed energy resources, energy storage, and market design. The course uses these economic principles to assess the effects of existing and proposed policy including the potential for value creation and disruption.

Same as: CEE 273S

CEE 174A. Providing Safe Water for the Developing and Developed World. 3 Units.

This course will cover basic hydraulics and the fundamental processes used to provide and control water, and will introduce the basics of engineering design. In addition to understanding the details behind the fundamental processes, students will learn to feel comfortable developing initial design criteria (30% designs) for fundamental processes. Students should also develop a feel for the typical values of water treatment parameters and the equipment involved. The course should enable students to work competently in environmental engineering firms or on non-profit projects in the developing world such as Engineers without Borders. Pre-requisite: Chem31B/M.

CEE 174B. Wastewater Treatment: From Disposal to Resource Recovery. 3 Units.

This course builds upon CEE 174A, covering basic hydraulics and the fundamental processes used to treat wastewater. In addition to understanding the details behind the fundamental processes, students will learn to feel comfortable developing initial design criteria (30% designs) for fundamental processes. Students should also develop a feel for the typical values of water treatment parameters and the equipment involved. After covering conventional processes, the class addresses newer processes used to meet emerging treatment objectives, including nutrient removal, composting of biosolids and recycling of wastewater for beneficial uses, including potable reuse. Pre-requisites: CEE 174A.

CEE 175A. California Coast: Science, Policy, and Law. 3-4 Units.

This interdisciplinary course integrates the legal, scientific, and policy dimensions of how we characterize and manage resource use and allocation along the California coast. We will use this geographic setting as the vehicle for exploring more generally how agencies, legislatures, and courts resolve resource-use conflicts and the role that scientific information and uncertainty play in the process. Our focus will be on the land-sea interface as we explore contemporary coastal land-use and marine resource decision-making, including coastal pollution, public health, ecosystem management; public access; private development; local community and state infrastructure; natural systems and significant threats; resource extraction; and conservation, mitigation and restoration. Students will learn the fundamental physics, chemistry, and biology of the coastal zone, tools for exploring data collected in the coastal ocean, and the institutional framework that shapes public and private decisions affecting coastal resources. There will be 3 to 4 written assignments addressing policy and science issues during the quarter, as well as a take-home final assignment. Special Instructions: In-class work and discussion is often done in interdisciplinary teams of students from the School of Law, the School of Engineering, the School of Humanities and Sciences, and the School of Earth, Energy, and Environmental Sciences. Students are expected to participate in class discussion and field trips. Elements used in grading: Participation, including class session and field trip attendance, writing and quantitative assignments. Cross-listed with Civil & Environmental Engineering (CEE 175A/275A), Earth Systems (EARTHSYS 175/275), and Law (LAW 2510). Open to graduate students and to advanced undergraduates with instructor consent. Enrollment limited; priority given to CEE majors and Law School students. Same as: CEE 275A

CEE 175Q. Changing Human Behavior: Drivers and Barriers in Environmental Action. 2 Units.

Beyond the scientific and technological challenges of climate change, there are important psychological factors and barriers to individual attitude and behavior change. Students will analyze and identify barriers to individual action; distinguish between targeting individual behaviors vs. attitudes; understand specific psychological challenges and opportunities that climate change raises; develop strategies to address these factors in contexts where behavior change is sought. Students will propose and develop their own ideas for addressing a specific psychological barrier to individual action in an environmental context.

CEE 175S. Environmental Entrepreneurship and Innovation. 3 Units.

Our current infrastructure for provision of critical services—clean water, energy, transportation, environmental protection; requires substantial upgrades. As a complement to the scientific and engineering innovations taking place in the environmental field, this course emphasizes the analysis of economic factors and value propositions that align value chain stakeholder interests.

Same as: CEE 275S

CEE 176A. Energy Efficient Buildings. 3 Units.

Quantitative evaluation of technologies and techniques for reducing energy demand of residential-scale buildings. Heating and cooling load calculations, financial analysis, passive-solar design techniques, water heating systems, photovoltaic system sizing for net-zero-energy all-electric homes.

CEE 176B. 100% Clean, Renewable Energy and Storage for Everything. 3-4 Units.

This course discusses elements of a transition to 100% clean, renewable energy in the electricity, transportation, heating/cooling, and industrial sectors for towns, cities, states, countries, and companies. It examines wind, solar, geothermal, hydroelectric, tidal, and wave characteristics and resources; electricity, heat, cold and hydrogen storage; transmission and distribution; matching power demand with supply on the grid; efficiency; replacing fossil with electric appliances and machines in the buildings and industry; energy, health, and climate costs and savings; land requirements; feedbacks of renewables to the atmosphere; and 100% clean, renewable energy roadmaps to guide transitions.
Same as: CEE 276B

CEE 176C. Energy Storage Integration - Vehicles, Renewables, and the Grid. 3 Units.

This course will provide in-depth introduction to existing energy storage solutions being used on the electric grid and in vehicles with a primary focus on batteries and electrochemical storage. We will discuss the operating characteristics, cost and efficiency of these technologies and how tradeoff decisions can be made. Special attention will be given to system-level integration of new storage technologies, including chargers, inverters, battery management systems and controls, into the existing vehicle and grid infrastructure. Further investigations include issues relating to integration of electric vehicle charging with demand-side management, scheduled renewable energy absorption and local grid balancing. Class format involves regular guest lectures, required lab participation, and field trips to relevant sites. Enrollment is limited; if you are interested in taking the course, please fill out a brief questionnaire at <http://goo.gl/forms/i3YH91Qx05n> Please contact jtaggart@stanford.edu with any questions regarding the application or course information.
Same as: CEE 276C

CEE 176G. Sustainability Design Thinking. 3 Units.

Application design thinking to make sustainability compelling, impactful and realizable. Analysis of contextual, functional and human-centered design thinking techniques to promote sustainable design of products and environments by holistically considering space, form, environment, energy, economics, and health. Includes Studio project work in prototyping, modeling, testing, and realizing sustainable design ideas.
Same as: CEE 276G

CEE 177. Aquatic Chemistry and Biology. 4 Units.

Introduction to chemical and biological processes in the aqueous environment. Basic aqueous equilibria; the structure, behavior, and fate of major classes of chemicals that dissolve in water; redox reactions; the biochemistry of aquatic microbial life; and biogeochemical processes that govern the fate of nutrients and metals in the environment and in engineered systems. Prerequisite: CHEM 31.

CEE 177L. Smart Cities & Communities. 3 Units.

A city is comprised of people and a complex system of systems connected by data. A nexus of forces ζ IoT, open data, analytics, AI, and systems of engagement ζ present new opportunities to increase the efficiency of urban systems, improve the efficacy of public services, and assure the resiliency of the community. Systems studied include: water, energy, transportation, buildings, food production, and social services. The roles of policy and behavior change as well as the risks of smart cities will be discussed. How cities are applying innovation to address the unprecedented challenges of COVID-19 will also be explored.
Same as: CEE 277L

CEE 177Q. Data Analysis, Presentation, and Interpretation in Environmental Engineering. 3 Units.

This class is designed for students interested in pursuing research-based careers. It covers practical aspects of data analysis, presentation, interpretation relevant to the field of environmental engineering. Learning objectives include identifying and refining research questions, choosing appropriate data analysis methods, and applying principles of effective visual and written presentation of proposed research and research findings. Additional topics to be covered include preparing a constructive review, research ethics, and navigating the publication process.
Same as: CEE 277Q

CEE 177S. Engineering and Sustainable Development. 1-3 Unit.

The second of a two-quarter, project-based course sequence that address cultural, political, organizational, technical and business issues at the heart of implementing sustainable engineering projects in the developing world. Students work in interdisciplinary project teams to tackle real-world design challenges in partnership with social entrepreneurs and/or NGOs. This quarter focuses on implementation, evaluation, and deployment of the designs developed in the winter quarter. Designated a Cardinal Course by the Haas Center for Public Service.
Same as: CEE 277S, ENGR 177B, ENGR 277B

CEE 177X. Engineering and Sustainable Development: Toolkit. 1-3 Unit.

The first of a two-quarter, project-based course sequence that address cultural, sociopolitical, organizational, technical, and ethical issues at the heart of implementing sustainable engineering projects in a developing world. Students work in interdisciplinary project teams to tackle real-world design challenges in partnership with social entrepreneurs, local communities, and/or NGOs. While students must have the skills and aptitude necessary to make meaningful contributions to technical product designs, the course is open to all backgrounds and majors. The first quarter focuses on cultural awareness, ethical implications, user requirements, conceptual design, feasibility analysis, and implementation planning. Admission is by application. Students should plan to enroll in CEE 177S/277S (ENGR 177B/277B) Engineering & Sustainable Development: Implementation following successful completion of this course. Designated a Cardinal Course by the Haas Center for Public Service. To satisfy a Ways requirement, students must register for an undergraduate course number (CEE 177S or ENGR 177A) and this course must be taken for at least 3 units. In AY 2020-21, a letter grade or 'CR' grade satisfies the Ways requirement.
Same as: CEE 277X, ENGR 177A, ENGR 277A

CEE 178. Introduction to Human Exposure Analysis. 3 Units.

(Graduate students register for 276.) Scientific and engineering issues involved in quantifying human exposure to toxic chemicals in the environment. Pollutant behavior, inhalation exposure, dermal exposure, and assessment tools. Overview of the complexities, uncertainties, and physical, chemical, and biological issues relevant to risk assessment. Lab projects. Recommended: MATH 51. Apply at first class for admission.
Same as: CEE 276

CEE 178S. Air Pollution Science & Engineering. 3 Units.

Human health and environmental impact of air pollution. Types, sources and production processes of key air pollutants in indoor and outdoor environments. Engineering solutions in air pollution remediation and mitigation. Role of science-informed policy and regulation in air resources protection. Measurement of particulate matter and carbon monoxide. Preparation of a research poster, video short, op-ed, or other media on an air pollution problem.
Same as: CEE 278S

CEE 179A. Water Chemistry Laboratory. 3 Units.

(Graduate students register for 273A.) Laboratory application of techniques for the analysis of natural and contaminated waters, emphasizing instrumental techniques.
Same as: CEE 273A

CEE 179C. Environmental Engineering Design. 5 Units.

Application of engineering fundamentals including environmental engineering, hydrology, and engineering economy to a design problem. Enrollment limited; preference to seniors in Civil and Environmental Engineering.

CEE 179F. Frontiers of Anaerobic Treatment. 1 Unit.

This seminar will present the latest findings on the operation and performance of ground-breaking anaerobic treatment processes for domestic wastewater. Specifically, this seminar will examine the performance of the Staged Anaerobic Fluidized-bed Membrane Bioreactor (SAF-MBR) using results from ongoing operations at the Codiga Resource Recover Center and from previous and parallel research efforts. The seminars will incorporate a description of the fundamentals of anaerobic treatment processes, a discussion of how the SAF-MBR process is different from typical anaerobic processes, and insights from operations along with implications for system design. Course work will include explorations of the costs, benefits, and market potential of this technology.

Same as: CEE 279F

CEE 179S. Seminar: Issues in Environmental Science, Technology and Sustainability. 1-2 Unit.

Invited faculty, researchers and professionals share their insights and perspectives on a broad range of environmental and sustainability issues. Students critique seminar presentations and associated readings.

Same as: CEE 279S, EARTHSYS 179S, ESS 179S

CEE 180. Structural Analysis. 4 Units.

Analysis of beams, trusses, frames; method of indeterminate analysis by consistent displacement, least work, superposition equations, moment distribution. Introduction to matrix methods and computer methods of structural analysis. Prerequisite: 101A and ENGR 14.

CEE 182. Structural Design. 3-4 Units.

Students will learn the principles of structural engineering design including how to design structural components of reinforced concrete (e.g., beams, columns, and slabs) and steel (e.g., beams, columns, tension and compression members, and connections) for various structural systems. Skills will be gained through problem sets and a design project. (Note: this course replaces the combination of CEE 181 and CEE 182 taught separately in previous years). Pre-requisite: CEE 180.

CEE 183. Integrated Civil Engineering Design Project. 4 Units.

Studio format. Design concepts for civil engineering facilities from schematic design through construction, taking into account sustainable engineering issues. Design exercises culminating in the design of a civil engineering facility, emphasizing structural systems and materials and integration with architectural, construction and other project requirements. Prerequisites: CEE 180, 181, 182; CEE 120A (or equivalent background in BIM), civil engineering major; architectural design major with instructor consent.

CEE 192. Properties of Rocks and Geomaterials. 3-4 Units.

Lectures and laboratory experiments. Properties of rocks and geomaterials and how they relate to chemo-mechanical processes in crustal settings, reservoirs, and man-made materials. Focus is on properties such as porosity, permeability, acoustic wave velocity, and electrical resistivity. Students may investigate a scientific problem to support their own research (4 units). Prerequisites: Physics 41 (or equivalent) and CME 100.

Same as: GEOPHYS 259

CEE 198. Directed Reading or Special Studies in Civil Engineering. 1-4 Unit.

Written report or oral presentation required. Students must obtain a faculty sponsor.

CEE 199. Undergraduate Research in Civil and Environmental Engineering. 1-4 Unit.

Written report or oral presentation required. Students must obtain a faculty sponsor.

CEE 199A. Special Projects in Architecture. 1-4 Unit.

Faculty-directed study or internship. May be repeated for credit. Prerequisite: consent of instructor.

CEE 199B. Directed Studies in Architecture. 1-4 Unit.

Projects may include studio-mentoring activities, directed reading and writing on topics in the history and theory of architectural design, or investigations into design methodologies.

CEE 199C. Independent Research in Civil and Environmental Engineering. 1-5 Unit.

Enrollment restricted to CEE students enrolling in classes via SCPD. Directed study of a topic in civil and environmental engineering, under the supervision of a CEE professor. Students enrolling must email Profs. Lepech and Hildemann, cc'ing their research supervisor, to indicate with which CEE faculty member they will be working.

Same as: CEE 299C

CEE 199E. Outreach and Mentoring Program Development in CEE. 1-2 Unit.

Open to undergraduates who are declared majors in Civil Engineering, Environmental Engineering, Atmosphere/Energy, and Architectural Design. Will brainstorm and develop an innovative curriculum and engaging activities for CEE 10 (Intro. to the Civil & Environmental Engineering Professions).

CEE 199H. Undergraduate Honors Thesis. 2-3 Units.

For students who have declared the Civil Engineering B.S. honors major and have obtained approval of a topic for research under the guidance of a CEE faculty adviser. Letter grade only. Written thesis or oral presentation required. (Staff).

CEE 199J. Independent Projects in Environmental & Sustainability Communications. 1 Unit.

Directed independent projects in the communication of environmental and sustainability topics. Selected assignments may explore research, education, mass media, and social media channels. Students will self-research formats, content, and media requirements. Emphasis on design thinking and creativity. Enrollment by Permission Number only. Prerequisite: Consent of Instructor.

Same as: CEE 299J

CEE 199L. Independent Project in Civil and Environmental Engineering. 1-4 Unit.

Prerequisite: Consent of Instructor.

CEE 199S. Undergraduate Summer Research in Civil and Environmental Engineering. 1-6 Unit.

Investigation of a research topic in civil and environmental engineering. For students admitted to the Stanford Summer Session program. Written report or oral presentation required. Students must obtain a faculty or research staff sponsor.

CEE 200A. Teaching of Civil and Environmental Engineering. 1 Unit.

Required of CEE Ph.D. students. Strategies for effective teaching and introduction to engineering pedagogy. Topics: problem solving techniques and learning styles, individual and group instruction, the role of TAs, balancing other demands, grading. Teaching exercises. Register for quarter of teaching assistantship: 200A. Aut; 200B. Win; 200C. Spr.

CEE 200B. Teaching of Civil and Environmental Engineering. 1 Unit.

Required of CEE Ph.D. students. Strategies for effective teaching and introduction to engineering pedagogy. Topics: problem solving techniques and learning styles, individual and group instruction, the role of TAs, balancing other demands, grading. Teaching exercises. Register for quarter of teaching assistantship. May be repeated for credit. 200A. Aut, 200B. Win, 200C. Spr.

CEE 200C. Teaching of Civil and Environmental Engineering. 1 Unit.

Required of CEE Ph.D. students. Strategies for effective teaching and introduction to engineering pedagogy. Topics: problem solving techniques and learning styles, individual and group instruction, the role of TAs, balancing other demands, grading. Teaching exercises. Register for quarter of teaching assistantship. May be repeated for credit. 200A. Aut, 200B. Win, 200C. Spr.

CEE 201D. Computations in Civil and Environmental Engineering. 3 Units.

Computational and visualization methods in the design and analysis of civil and environmental engineering systems. Focus is on applications of MATLAB. How to develop a more lucid and better organized programming style.

Same as: CEE 101D

CEE 201E. Nonlinear Dynamics. 3 Units.

Most real-world systems are to some degree nonlinear, and the addition of nonlinearity can lead to qualitatively different kinds of behavior as compared with linear systems. This course provides an introduction to the analysis of nonlinear dynamical systems, with examples drawn from across the sciences and engineering. In addition to formal analysis, the course will emphasize qualitative and geometric thinking. Topics will include one-dimensional systems; bifurcations; phase-plane analysis; nonlinear oscillators; and chaos, fractals, and strange attractors. Prerequisites: Differential equations at the level of CME 102 and linear algebra at the level of CME 104; some programming experience.

CEE 201S. Science & Engineering Problem-Solving with MatLab.. 3 Units.

Introduction to the application of MATLAB as a powerful tool to solve a variety of science and engineering problems. Exposure to computational and visualization tools available through MATLAB to analyze, solve, and visualize some common problems of interest in science and engineering. Prerequisite: Calculus. Note: students enrolling in CEE 201S must seek the consent of instructor.

Same as: CEE 101S

CEE 202. Construction Law and Claims. 3-4 Units.

Concepts include the preparation and analysis of construction claims, cost overrun and schedule delay analysis, general legal principles, contracts, integrated project delivery, public private partnerships and the resolution of construction disputes through ADR and litigation. Requires attendance of the ten weeks of Monday classes and the first five weeks of Wednesday classes.

CEE 203. Probabilistic Models in Civil Engineering. 3-4 Units.

Introduction to probability modeling and statistical analysis in civil engineering. Emphasis is on the practical issues of model selection, interpretation, and calibration. Application of common probability models used in civil engineering including Poisson processes and extreme value distributions. Parameter estimation. Linear regression.

CEE 203S. Machine Learning: Concepts & Applications in Civil & Environmental Engineering. 3 Units.

Introduction to machine learning concepts, tools and methodologies for incorporating intelligence and smart technology into environmental data applications. Learning algorithms and development of a machine learning pipeline. Set-up of a machine learning platform on an IoT edge sensor device. Prerequisite: CS 106A or equivalent Python programming experience.

Same as: CEE 103S

CEE 204. Structural Reliability. 3-4 Units.

Procedures for evaluating the safety of structural components and systems. First-and second-order estimates of failure probabilities of engineered systems. Sensitivity of failure probabilities to assumed parameter values. Measures of the relative importance of random variables. Reliability of systems with multiple failure modes. Reliability updating. Simulation methods and variance reduction techniques. Prerequisite: 203 or equivalent.

CEE 205A. Structural Materials Testing and Simulation. 3-4 Units.

Hands-on laboratory experience with fabrication, computer simulation, and experimental testing of material and small-scale structural components. Comparison of innovative and traditional structural materials. Behavior and application of high-performance fiber reinforced concrete materials for new design, fiber-reinforced polymeric materials for structural retrofits and introduction to sustainable, bio-based composites. Prerequisites: basic course in reinforced concrete design CEE 182 or equivalent.

CEE 205B. Advanced Topics in Structural Concrete. 3 Units.

Concepts and application of strut and tie modeling including deep beams, design for torsion resistance, beam-column joints, bridge components, and post-tensioned anchor zones. Course project integrating computer simulation and physical experimentation of a structural concrete component. Prerequisites: CEE 285A or equivalent.

CEE 206. Decision Analysis for Civil and Environmental Engineers. 3 Units.

Current challenges in selecting an appropriate site, alternate design, or retrofit strategy based on environmental, economic, and social factors can be best addressed through applications of decision science. Basics of decision theory, including development of decision trees with discrete and continuous random variables, expected value decision making, utility theory value of information, and elementary multi-attribute decision making will be covered in the class. Examples will cover many areas of civil and environmental engineering problems. Prerequisite: CEE 203 or equivalent. (Note: This course will be offered in Fall of 2020).

CEE 207A. Understanding Energy. 3-5 Units.

Energy is the number one contributor to climate change and has significant consequences for our society, political system, economy, and environment. Energy is also a fundamental driver of human development and opportunity. In taking this course, students will not only understand the fundamentals of each energy resource – including significance and potential, conversion processes and technologies, drivers and barriers, policy and regulation, and social, economic, and environmental impacts – students will also be able to put this in the context of the broader energy system. Both depletable and renewable energy resources are covered, including oil, natural gas, coal, nuclear, biomass and biofuel, hydroelectric, wind, solar thermal and photovoltaics (PV), geothermal, and ocean energy, with cross-cutting topics including electricity, storage, climate change and greenhouse gas emissions (GHG), sustainability, green buildings, energy efficiency, transportation, and the developing world. The course is 4 units, which includes lecture and in-class discussion, readings and videos, homework assignments, virtual field trips, and a small-group discussion section once a week for 50 minutes (live participation is required, many different times will be offered). Lectures will be recorded and available on Canvas. No in-person field trips will be offered for AY 2020-2021, but alumni of the class can optionally attend field trips in future quarters. Enroll for 5 units to also attend the Workshop, an interactive discussion section on cross-cutting topics that meets once per week for 80 minutes (timing TBD). The 3-unit option requires instructor approval - please contact Diana Gragg. Open to all: pre-majors and majors, with any background! Website: <https://energy.stanford.edu/understanding-energy>. CEE 107S/207S Understanding Energy: Essentials is a shorter (3 unit) version of this course, offered summer quarter. Students should not take both for credit. Prerequisites: Algebra. Same as: CEE 107A, EARTHSYS 103

CEE 207H. Applied Hope: Whole-Systems Thinking on Energy Solutions. 2 Units.

Whole-systems thinking has yielded transformative insights about prospects for sustainability across a series of energy and environmental challenges. Taught by Amory Lovins, co-founder of Rocky Mountain Institute, this seminar will cover four decades of ground-breaking analysis and validated results that have transformed what is thought to be possible across multiple fields. Topics will include highly efficient buildings, vehicles, and industrial processes; winning the fossil fuel endgames; nuclear power and security; natural capitalism; distributed energy and resilience; and profitable climate protection.
Same as: CEE 107H

CEE 207R. E³: Extreme Energy Efficiency. 3 Units.

Be part of a unique course about extreme energy efficiency and integrative design! We will meet remotely for once a week throughout the winter quarter. E³ will focus on efficiency techniques' design, performance, choice, evolution, integration, barrier-busting, profitable business-led implementation, and implications for energy supply, competitive success, environment, development, security, etc. Examples will span very diverse sectors, applications, issues, and disciplines, covering different energy themes throughout the quarter: buildings, transportation, industry, and implementation and implications, including renewable energy synergy and integration. Solid technical grounding and acquaintance with basic economics and business concepts will both be helpful. The course will be composed of keynote lectures, exercises, and interactive puzzlers synthesizing integrative design principles. Students will be introduced to Factor 10 Engineering, the approach for optimizing the whole system for multiple benefits. Students will work closely and interactively with RMI staff including Amory Lovins, cofounder and Chief Scientist of Rocky Mountain Institute (RMI), and Dr. Holmes Hummel, founder of Clean Energy Works. Exercises will illuminate challenges RMI has faced and solutions it has created in real-world design. Students will explore clean-sheet solutions that meet end-use demands and optimize whole-system resource efficiency, often with expanding rather than diminishing returns to investments, i.e. making big savings cheaper than small ones. All backgrounds and disciplines, both undergraduate and graduate, are welcome to enroll. There is no application this year. Prerequisite - completion of one of the following courses or their equivalent is required: CEE 107A/207A/ Earthsys 103, CEE 107S/ CEE 207S, CEE 176A, CEE 176B. Course details are available at the website: <https://energy.stanford.edu/extreme-energy-efficiency>.
Same as: CEE 107R

CEE 207S. Understanding Energy - Essentials. 3-4 Units.

Energy is the number one contributor to climate change and has significant consequences for our society, political system, economy, and environment. Energy is also a fundamental driver of human development and opportunity. Students will learn the fundamentals of each energy resource – including significance and potential, drivers and barriers, policy and regulation, and social, economic, and environmental impacts – and will be able to put this in the context of the broader energy system. Both depletable and renewable energy resources are covered, including oil, natural gas, coal, nuclear, biomass and biofuel, hydroelectric, wind, solar thermal and photovoltaics (PV), geothermal, and ocean energy, with cross-cutting topics including electricity, storage, climate change and greenhouse gas emissions (GHG), sustainability, green buildings, energy efficiency, transportation, and the developing world. The course is 3 units, which includes lecture, readings and videos, assignments, and one required off-site field trip. Field trip offerings differ each quarter but may include Diablo Canyon nuclear power plant, Shasta dam, Tesla Gigafactory, NextEra wind farm, San Ardo oil field, Geysers geothermal power plants, NEXTracker Solar PV, etc. Enroll for 4 units to also attend the Workshop, an interactive discussion section on cross-cutting topics that meets once per week for 80 minutes (timing TBD). This is a course for all: pre-majors and majors, with any background - no prior energy knowledge necessary. For a course that covers all of this plus goes more in-depth, check out CEE 107A/207A/ EarthSys 103 Understanding Energy offered in the autumn and spring quarters (students should not take both for credit). Website: <http://web.stanford.edu/class/cee207a/>
Prerequisites: Algebra.
Same as: CEE 107S

CEE 209B. Disaster Risk and International Development Seminar. 2 Units.

The human and economic impacts of natural disasters are ever increasing and disproportionately affecting lower-income countries. In fact there is mounting evidence that these ever more frequent shocks threaten to reverse development progress in low-income countries. This seminar course will explore the theory and practice of disaster risk reduction in international development contexts. Weekly readings (and occasional guest lectures) will cover key issues in development theory, a history of "a risk society", participation, human-centered planning, ethics in engineering, and other topics. The seminar will be structured through weekly readings, brief writing responses and group discussion.

CEE 209S. Disaster Resilience Seminar. 1 Unit.

This seminar will present topics associated with quantifying, communicating and improving the resilience of urban areas to disasters. Speakers from a range of disciplines will present current research, application, and thinking on innovations, current best practices and the future of disaster resilience. Guest speakers, supplemental reading, and group discussion will be utilized to teach about the complex nature of natural disasters, the impacts on different regions, and the multi-disciplinary/multi-cultural ways of thinking to prepare communities.

CEE 212A. Industry Applications of Virtual Design & Construction. 2-4 Units.

Building upon the concept of the VDC Scorecard, CEE 112A/212A investigates in the management of Virtual Design and Construction (VDC) programs and projects in the building industry. Interacting with experts and professionals in real estate, architecture, engineering, construction and technology providers, students will learn from the industry applications of Building Information Modeling and its relationship with Integrated Project Delivery, Sustainable Design and Construction, and Virtual Design and Construction. Students will conduct case studies to evaluate the maturity of VDC planning, adoption, technology and performance in practice. Students taking 3 or 4 units will be paired up with independent research or case study projects on the industry applications of VDC. No prerequisite. See CEE 112B/212B in the Winter Quarter and CEE 112C/212C in the Spring Quarter.

CEE 212B. Industry Applications of Virtual Design & Construction. 2-4 Units.

CEE 112B/212B is a practicum on the Industry Applications on Virtual Design and Construction (VDC). Students will gain insights and develop skills that are essential for academic research, internships or industry practice in VDC and Building Information Modeling (BIM). Students can choose between one of the two project topics: [1] Industrialized Construction with Virtual Parts (No Prerequisite) or [2] Industry Benchmarking & Applications of the VDC Management Scorecard (Suggested Prerequisite: CEE 112A/212A).

Same as: CEE 112B

CEE 212C. Industry Applications of Virtual Design & Construction. 2-4 Units.

Following the Autumn- and Winter-quarter course series, CEE 112C/212C is an industry-focused and project-based practicum that focuses on the industry applications of Virtual Design and Construction (VDC). Students will be paired up with industry-based VDC projects with public owners and private developers, such as GSA Public Buildings Service, the Hong Kong Mass Transit Railway, Optima, Walt Disney Imagineering, Microsoft facilities and/or other CIFE International members. Independently, students will conduct case studies and/or develop VDC and building information models (BIM) using off-the-shelf technologies for project analysis, collaboration, communication and optimization. Students will gain insights and develop skills that are essential for academic research, internships or industry practice in VDC. Prerequisite: CEE 112A/212A, CEE 112B/212B, CEE 159C/259C, CEE 159D/259D, or Instructor's Approval.

Same as: CEE 112C

CEE 212D. Industry Applications of Virtual Design and Construction. 2-4 Units.

A continuation of the CEE 112/212 series, CEE 112D/212D is an industry-focused and project-based practicum that focuses on the industry applications of Virtual Design and Construction (VDC). Students will be paired up with industry-based VDC research or application opportunities with public owners and private developers, professional associations, and/or other member organizations of the Center for Integrated Facility Engineering at Stanford. Independently, students will conduct case studies, research activities, and/or develop VDC and building information models (BIM) using off-the-shelf technologies for project analysis, collaboration, communication and optimization. Students will gain insights and develop skills that are essential for academic research, internships or industry practice in VDC. Prerequisite: CEE110/210, CEE 112C/212C, CEE 122B/222B, or Instructor's Approval.

Same as: CEE 112D

CEE 213. Patterns of Sustainability. 1-4 Unit.

This seminar examines the interrelated sustainability of the natural, built and social environments of places in which we live. Several BOSP centers and the home Stanford campus will hold this 1-2 unit seminar simultaneously and collaborate with a shared curriculum, assignments, web conference and a Wiki. The goal of the collaborative arrangement is to expose, share, compare and contrast views of sustainability in different parts of the world. We will look at and assess aspects of sustainability of the places we are living from a theoretical perspective from the literature, from observations and interviews in the countries in which we study.

Same as: CEE 113

CEE 214. Frontier Technology: Understanding and Preparing for Technology in the Next Economy. 2 Units.

The next wave of technological innovation and globalization will affect our countries, our societies, and ourselves. This interdisciplinary course provides an introduction to frontier technology, the intersection where radical forward thinking and real-world implementation meet. Topics covered include artificial intelligence, additive manufacturing and advanced robotics, smart cities and urban mobility, telecommunications with 5G, and other key emerging technologies in society. These technologies have vast potential to address the largest global challenges of the 21st century, ushering in a new era of progress and change.

Limited enrollment, contact instructors for application.

Same as: CEE 114, MED 114, MED 214, PSYC 114

CEE 217. Renewable Energy Infrastructure. 2 Units.

Construction of renewable energy infrastructure: geothermal, solar thermal, solar photovoltaic, wind, biomass. Construction and engineering challenges and related issues and drivers for performance, cost, and environmental impact. Context of renewable energy infrastructure development including comparison of the types of renewable energy, key economic, environmental, and social contextual factors, applicability of a type of renewable energy given a context, related barriers and opportunities. Class project to plan a start-up for developing a type of energy infrastructure based on an engineering innovation.

CEE 218X. Shaping the Future of the Bay Area. 3-5 Units.

The complex urban problems affecting quality of life in the Bay Area, from housing affordability and transportation congestion to economic vitality and social justice, are already perceived by many to be intractable, and will likely be exacerbated by climate change and other emerging environmental and technological forces. Changing urban systems to improve the equity, resilience and sustainability of communities will require new collaborative methods of assessment, goal setting, and problem solving across governments, markets, and communities. It will also require academic institutions to develop new models of co-production of knowledge across research, education, and practice. This XYZ course series is designed to immerse students in co-production for social change. The course sequence covers scientific research and ethical reasoning, skillsets in data-driven and qualitative analysis, and practical experience working with local partners on urban challenges that can empower students to drive responsible systems change in their future careers. The Autumn (X) course is specifically focused on concepts and skills, and completion is a prerequisite for participation in the Winter (Y) and/or Spring (Z) practicum quarters, which engage teams in real-world projects with Bay Area local governments or community groups. X is composed of four modules: (A) participation in two weekly classes which prominently feature experts in research and practice related to urban systems; (B) reading and writing assignments designed to deepen thinking on class topics; (C) fundamental data analysis skills, particularly focused on Excel and ArcGIS, taught in lab sessions through basic exercises; (D) advanced data analysis skills, particularly focused on geocomputation in R, taught through longer and more intensive assignments. X can be taken for 3 units (ABC), 4 units (ACD), or 5 units (ABCD). Open to undergraduate and graduate students in any major. For more information, visit <http://bay.stanford.edu>.

Same as: CEE 118X, ESS 118X, ESS 218X, GEOLSCI 118X, GEOLSCI 218X, GEOPHYS 118X, GEOPHYS 218X, POLISCI 218X, PUBLPOL 118X, PUBLPOL 218X

CEE 218Y. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Y, ESS 118Y, ESS 218Y, GEOLSCI 118Y, GEOLSCI 218Y, GEOPHYS 118Y, GEOPHYS 218Y, POLISCI 218Y, PUBLPOL 118Y, PUBLPOL 218Y

CEE 218Z. Shaping the Future of the Bay Area. 3-5 Units.

Students are placed in small interdisciplinary teams (engineers and non-engineers, undergraduate and graduate level) to work on complex design, engineering, and policy problems presented by external partners in a real urban setting. Multiple projects are offered and may span both Winter and Spring quarters; students are welcome to participate in one or both quarters. Students are expected to interact professionally with government and community stakeholders, conduct independent team work outside of class sessions, and submit deliverables over a series of milestones. Prerequisite: the Autumn (X) skills course or approval of instructors. For information about the projects and application process, visit <http://bay.stanford.edu>.

Same as: CEE 118Z, ESS 118Z, ESS 218Z, GEOLSCI 118Z, GEOLSCI 218Z, GEOPHYS 118Z, GEOPHYS 218Z, POLISCI 218Z

CEE 220A. Building Modeling for Design & Construction. 3 Units.

The foundational Building Information Modeling course introduces techniques for creating, managing, and applying of building information models in the building design and construction process. The course covers processes and tools for creating, organizing, and working with 2D and 3D computer representations of building components and geometries to produce models used in architectural design, construction planning and documentation, rendering and visualization, simulation, and analysis.

Same as: CEE 120A

CEE 220B. Advanced Building Modeling Workshop. 2-4 Units.

This course builds upon the Building Information Model concepts introduced in 120A/220A and illustrates how BIM modeling tools are used to design, analyze, and model building systems including structural, mechanical, electrical, plumbing and fire protection. Course covers the physical principles, design criteria, and design strategies for each system and explores processes and tools for modeling those systems and analyzing their performance. Topics include: building envelopes, access systems, structural systems modeling and analysis, mechanical / HVAC systems, plumbing and fire protection systems, electrical systems, and systems integration/coordination.

Same as: CEE 120B

CEE 220C. Parametric Design and Optimization. 2-4 Units.

This course explores tools and techniques for computational design and parametric modeling as a foundation for design optimization. Class sessions will introduce several parametric design modeling platforms and scripting environments that enable rapid generation of 3D models and enable rapid evaluation of parametrically-driven design alternatives. Topics to be featured include: Principles of parametric design vs. direct modeling; Design exploration using parametric modeling platforms (Revit/FormIt, Rhino); Visual scripting languages and environments (Dynamo, Grasshopper, DesignScript); Single- and multi-dimensional optimization techniques and guidance strategies.

Same as: CEE 120C

CEE 220S. Building Information Modeling Special Study. 2-4 Units.

Special studies of Building Information Modeling strategies and techniques focused on creating, managing, and applying models in the building design and construction process. Processes and tools for creating, organizing, and working with 2D and 3D computer representations of building components to produce models used in design, construction planning, visualization, and analysis. Contact glkatz@stanford.edu for more information.

Same as: CEE 120S

CEE 221A. Planning Tools and Methods in the Power Sector. 3-4 Units.

This course covers the planning methods most commonly used in the power sector today. It covers both the fundamental methods used and their applications to electricity generation, transmission and distribution planning, integrated resource planning using both energy efficiency and renewable resources as well as utility finance and ratemaking. The methods covered will include forecasting (time series, regression and the use of markets), resource assessment (including energy efficiency and demand-side management) optimization (in power markets operation and in expansion planning) and the processes used in decision-making.

CEE 222A. Computer Integrated Architecture/Engineering/Construction (AEC) Global Teamwork. 3 Units.

AEC students engage in a crossdisciplinary, collaborative, geographically distributed, and multicultural project-based teamwork. AEC teams exercise their domain knowledge and information technologies in a multidisciplinary context focusing on the design and construction concept development phase of a comprehensive building project.

Prerequisite: interview with Instructor in Autumn Quarter.

CEE 222B. Computer Integrated Architecture/Engineering/Construction (AEC) Global Teamwork. 2 Units.

Global AEC student teams continue their project activity focusing on the most challenging concept developed in 222A and chosen jointly with their client. Comprehensive team project focusing on design and construction, including: project development and documentation; detailing, 3D and 4D modeling, simulation, sustainable concepts, cost benefit analysis, and life-cycle cost analysis; and final project presentation of product and process. Prerequisite: CEE 222A.

CEE 223. Materials for Sustainable Built Environments. 3 Units.

In this course, students will learn about new and traditional construction materials for use in sustainable building and infrastructure projects. Materials will include cement-based materials, fiber-reinforced polymer composites, and timber for structural and non-structural applications including facades, insulation, and paving. Material properties, their performance over time and their impact on people and the environment will be discussed and students will complete a design project in teams. Pre-requisites: CEE 101A or equivalent. Knowledge of structural design with reinforced concrete and steel recommended.

CEE 223A. Cement-based Materials, Properties and Durability. 2 Units.

Students will develop an understanding of the chemical and physical processes of cement and concrete hydration, strength development, mechanical performance and durability. Students will learn how the properties of materials and admixture combine to create a wide range of cement-based materials used in the built environment. The course will address sustainable construction, including the use of alternative cements, admixtures, and aggregates. Students will apply the principles in this course to various aspects of civil and structural engineering, including innovative mix design specification and review, structural investigations and failure analysis, and cementitious materials research.

CEE 224A. Design and Operation of Integrated Infrastructure Systems. 3 Units.

In the next decade, countries will spend trillions of dollars on built infrastructure, the effect of which is to preserve our isolated infrastructure systems; status quo. Regulatory bodies like Public Utility Commissions (PUC) have unintentionally institutionalized this effect, with sometimes disastrous results, when in fact these isolated systems interact in ways that create new opportunities and new challenges. Infrastructure can be made more flexible and resilient but only when we know how to design, interconnect, and operate urban systems as an integrated whole, and when quality of life is the explicit motivation. These systems include Energy, Transportation, Communication, Water, Air, Green Space and Geophysical systems. This class will introduce the basics of current infrastructure systems and explore in greater depth how these systems can be integrated in design and in operations. During the first half of the quarter, class lectures and guest speakers will develop the principles of infrastructure design and operations. The focus of the second half of the quarter will be directed student research to explore in greater detail the integration of two or more infrastructure systems, concluding with a written paper and class presentation. At the end of this course students will have a framework for understanding integrated infrastructure design from multiple engineering and civic perspectives. Specific topics will be: n- Boundaries and boundary conditions between Built Urban Infrastructure Systems and Natural Urban infrastructure Systems n- Materials and Energy Flows between Built and Natural Urban Systems n- Quantifying and Normalizing Urban Materials and Energy Flows n- Basis of physical control of Infrastructure Systems n- Basis of legal and economic control of Infrastructure systems n- Metrics to evaluate single system and integrated system performance n- Students must submit an application for admission to this course: https://docs.google.com/forms/d/e/1FAIpQLSfxTP9MwxbOMJOYXOA3kK1ZWAPJHCkptxaXfGQ80oNz7d6cA/viewform?usp=sf_link.

CEE 224S. Sustainable Urban Systems Seminar. 1 Unit.

The Sustainable Urban Systems (SUS) Seminar Series will feature speakers from academia, practice, industry, and government who are on the forefront of research and innovation in sustainable urban systems. The SUS Seminar will be open to the public; students will have the option of obtaining 1 unit of course credit based on attendance and completion of writing assignments.
Same as: CEE 124S

CEE 224X. Shaping the Future of the Bay Area. 3-5 Units.

Note to students: please be advised that the course number for this course has been changed to: CEE 218X, which is offered Autumn 2019-20. If you are interested in taking this course, please enroll in CEE 218X instead for Autumn 2019-20.
Same as: CEE 124X

CEE 225. Defining Smart Cities: Visions of Urbanism for the 21st Century. 3-4 Units.

Technological innovations have and will disrupt all domains of urban life, from housing to healthcare to city management to transportation. This seminar is aimed at future technologists, entrepreneurs, policymakers, and urban planners to define and evaluate the smartness of a city through three lenses: technology, equity, and policy. Through readings, seminar discussions, guest speakers, and a final project, we will explore how a smart city can leverage technology for a higher quality of life, less inequality in access to services, and tighter human communities. You will come away with a framework for understanding how to maximize the social good of emerging technologies. Course material is appropriate for students from all disciplines. Students who enroll in the course for 4 units will participate in an off-campus field component during Spring Break.
Same as: CEE 125, URBANST 174

CEE 226. Life Cycle Assessment for Complex Systems. 3-4 Units.

Life cycle modeling of products, industrial processes, and infrastructure/building systems; material and energy balances for large interdependent systems; environmental accounting; and life cycle costing. These methods, based on ISO 14000 standards, are used to examine emerging technologies, such as biobased products, building materials, building integrated photovoltaics, and alternative design strategies, such as remanufacturing, dematerialization, LEED, and Design for Environment: DfE. Student teams complete a life cycle assessment of a product or system chosen from industry.

CEE 226E. Techniques and Methods for Decarbonized and Energy Efficient Building Design. 2-3 Units.

This class explores innovative methods for designing, developing, and financing zero carbon and zero energy buildings. At this pivotal moment, as building codes in California and around the world move towards decarbonization and all electric buildings, this class will ideally position students to enter the field of the built environment with the tools to tackle the quickly changing industry. Students will learn best practices to reduce energy and integrate solar PV generation and battery energy storage in commercial buildings in pursuit of Net Zero Energy and Net Zero Carbon buildings. The class is taught by Peter Rumsey, a widely recognized global leader in energy efficiency and sustainable building design. Lectures include presentations and panels featuring foremost experts and practitioners in the field of green buildings. Optional site visits to the Bay Area's most notable decarbonized and green buildings. CEE 176A and CEE 156/256 or similar courses are recommended prerequisites. All students participate in a group-based, term project focused on the design of a Net Zero Carbon building. Topics covered in this course include: understanding the importance of building envelopes in a successful design, designing a heating system without natural gas, calculating building energy use, optimizing daylighting and electrical lighting, reducing plug load power use, quantifying embodied and lifetime operating carbon emissions from buildings, sizing photovoltaic and battery storage systems, and financing energy efficiency, PV, and battery systems.

CEE 227. Global Project Finance. 3-5 Units.

Public and private sources of finance for large, complex, capital-intensive projects in developed and developing countries. Benefits and disadvantages, major participants, risk sharing, and challenges of project finance in emerging markets. Financial, economic, political, cultural, and technological elements that affect project structures, processes, and outcomes. Case studies. Limited enrollment.

CEE 228. Methods in Urban Systems. 3 Units.

Introduction to quantitative tools and methods for solving problems in urban systems, including geographic information science (GIS), modeling, data analysis, and programming methodologies.

CEE 229A. Reinventing the Design & Construction of Buildings. 2-3 Units.

Challenge to students from all departments -- Making buildings is still painfully laborious and expensive. Can you radically rethink how buildings are designed and constructed? This project-based course balances theory, research, design. We will 1) study why/how Architecture and Construction industry are lagging behind other industries, 2) work with leading professionals to analyze roadblocks preventing them from building cheaper, faster, better, and 3) develop solutions to tackle these problems and advance the industry. You will consider questions such as: Why does it take 6-9 months to build a single family home? Can AI accelerate the architectural design process? How can designers leverage data/IoT? Which new materials offer significant savings and can be adopted for global solutions? Where can the supply chain be optimized? How can we design new technologies that tradesmen and luddites will use? The course is two terms (Winter CEE 229A, Spring CEE 229B).

CEE 229B. Reinventing the Design & Construction of Buildings. 2-3 Units.

Challenge to students from all departments – Making buildings is still painfully laborious and expensive. Can you radically rethink how buildings are designed and constructed? This project-based course balances theory, research, design. We will 1) study why/how Architecture and Construction industry are lagging behind other industries, 2) work with leading professionals to analyze roadblocks preventing them from building cheaper, faster, better, and 3) develop solutions to tackle these problems and advance the industry. You will consider questions such as: Why does it take 6-9 months to build a single family home? Can AI accelerate the architectural design process? How can designers leverage data/IoT? Which new materials offer significant savings and can be adopted for global solutions? Where can the supply chain be optimized? How can we design new technologies that tradesmen and luddites will use? The course is two terms (Winter CEE 229A, Spring CEE 229B).

CEE 229S. Climate Change Adaptation in the Coastal Built Environment. 1 Unit.

How will climate change impact coastal ports and harbors around the world? Leading experts discuss the latest science, policy, and engineering research on this important issue, including the necessary response to protect ports and harbors from significant sea-level rise and storm surge. Focus is on the built environment. Guest speakers. CEE 229/129 for research option. See www.groupspaces.com/seaports2100.

CEE 231. Urban Design. 3 Units.

Introduction to principles of urban design, including buildings, infrastructure, and landscape.

CEE 234B. Intermediate Arch Studio. 5 Units.

This studio offers students experience in working with a real site and a real client program to develop a community facility. Students will develop site analysis, review a program for development and ultimately design their own solutions that meet client and community goals. Sustainability, historic preservation, community needs and materials will all play a part in the development of students final project. Students will also gain an understanding of graphic conventions, verbal and presentation techniques. Course may be repeated for credit.

Same as: CEE 134B

CEE 236. Planning Calif: the Intersection of Climate, Land Use, Transportation & the Economy. 3 Units.

Cities and urban areas have always been transformed by major external changes like pandemics and public health crises. California is both in the midst of its greatest economic recession since the Great Depression and experiencing a pandemic that has the potential to reshape many aspects of life. Planning for cities and regions, however, is a long game that requires follow-through on decisions made sometimes over many decades. How do we balance the shocks to our assumptions from the current Covid world with the need to plan long-term for issues like affordable housing and equitable cities, and perhaps most fundamentally, prepare our cities and communities for the inevitability of climate change and climate impact? This course takes an interdisciplinary view of the key contemporary planning topics in California. It does so from looking at the intersection of climate laws, land use changes, the need for housing, travel patterns and the availability of high quality jobs and employment. This course will give you an understanding of the roles of key levels of government, from the state to the region/metropolitan scale, to the city and county, down to the neighborhood and parcel level. It will give students insight into leading themes and issues of the day in California such as the future of downtowns, the role of high speed rail, the impact of telework, automation in the construction of housing, drawing from examples in San Jose and San Francisco, the Central Valley, the state legislature, Southern California. Within each of these topics we will look at the impact of decisions on equity as well as climate and the economy. The instructors are Kristy Wang, formerly SPUR's Community Planning Policy Director, and Egon Terplan, Senior Advisor for Economic Development and Transportation in the California Governor's Office, formerly SPUR's Regional Planning Director. (Affiliations for identification purposes only).

Same as: CEE 136, PUBLPOL 130, PUBLPOL 230, URBANST 130

CEE 237B. Advanced Architecture Studio. 6 Units.

This course will focus on the topic of interdisciplinary collaboration and its role in the development of design concepts. Specifically, the integration of structural with architectural considerations to produce a unified urban, spatial, tectonic and structural proposition will be our field of investigation. This course is an architecture studio course where class time will be spent primarily in individual or group desk critiques and pin-up sessions. May be repeat for credit. Total completions allowed: 3. Additionally, there will be lectures, case study presentations and a field trip. Prerequisites: required: CEE 31 (or 31Q) Drawing, CEE 120A and CEE 130 Design.

Same as: CEE 137B

CEE 239. Design Portfolio Methods. 4 Units.

The portfolio is an essential creative tool used to communicate academic work, design philosophies, and professional intent. This course will explore elements of graphic design, presentation, communication, binding, printing, and construction, yielding a final portfolio (physical and digital) for professional, academic or personal purposes. Limited enrollment. Prerequisites: two Art, Design, or Architecture studio courses, or consent of instructor. Note: CEE139 will run M/W from 10:30am-12:20pm, Autumn 2020-21.

Same as: CEE 139

CEE 240. Project Assessment and Budgeting. 3 Units.

Course objectives: 1) learn the processes of determining the quantities of permanent materials required and the associated construction quantities; 2) learn the capabilities of construction equipment; 3) be introduced to the make-up of construction crews; 4) design concrete form systems; 5) utilize the historic productivity of a crew to estimate the cost of construction; 6) write construction logic to create a critical path project schedule; 7) distribute the cost of construction over schedule activities to generate a cash flow curve and monthly payment schedule for the project. Construction engineering: A construction project that has reached final design must be quantified, a delivery schedule developed, its final total price determined and the month by month demand for cash payments established. Each student will perform these activities to satisfy a "Course Project" requirement utilizing actual project design drawings obtained from the companies of the Guest Lectures and others. Guest Lecturers from: Disney Construction, Pankow Construction, Granite Construction, Stacy & Witbeck Incorporated.

CEE 241. Managing Fabrication and Construction. 4 Units.

Methods to manage the physical production of construction projects; design, analysis, and optimization of the fabricate-assemble process including performance metrics. Project management techniques and production system design including: push versus pull methods; master scheduling and look-ahead scheduling; scope, cost, and schedule control; earned value analysis; critical path method; location-based scheduling; 4D modeling; workflow; trade coordination; methods to understand uncertainty and reduce process variability; and supply chain systems including made-to-stock, engineered-to-order, and made-to-order. Prerequisite: 100 or consent of instructor.

CEE 241A. Infrastructure Project Development. 3 Units.

Infrastructure is critical to the economy, global competitiveness and quality of life. Topics include energy, transportation, water, public facilities, and communications sectors. Analysis of the condition of the nation's infrastructure and how projects are planned and financed. Focus is on public works in the U.S. The role of public and private sectors through a step-by-step study of the project development process. Case studies of real infrastructure projects. Industry guest speakers. Student teams prepare project environmental impact statements. Same as: CEE 141A

CEE 241B. Infrastructure Project Delivery. 3 Units.

Infrastructure is critical to the economy, global competitiveness and quality of life. Topics include energy, transportation, water, public facilities, and communications sectors. Analysis of how projects are designed, constructed, operated, and maintained. Focus is on public works projects in the U.S. Alternative project delivery approaches and organizational strategies. Case studies of real infrastructure projects. Industry guest speakers. Student teams prepare finance/design/build/operate/maintain project proposals. Same as: CEE 141B

CEE 241C. Global Infrastructure Projects Seminar. 1-2 Unit.

Nine current global infrastructure projects presented by top project executives or company leaders from industry. Water, transportation, energy and communication projects are featured. Course provides comparisons of project development, win and delivery approaches for mega-projects around the world. Alternative project delivery methods, the role of public and private sector, different project management and construction strategies, and lessons learned. The course also includes field trips to local mega-projects. Grade (one unit) is based on attending all 9 lectures and at least 2 field trips. Same as: CEE 141C

CEE 241P. Integrated Management of Fabrication and Construction. 3-4 Units.

Application of the fundamental fabrication and construction management concepts covered in CEE 241T to an actual project; integrated software environments; integration of scope, schedule, and cost information for scheduling, estimating, and progress control; scope management with BIM; off-site fabrication vs. on-site construction and supply chain coordination; group project; project permitting, potential for a joint project with CEE 242P. Prerequisites: CEE 210, CEE 241T.

CEE 242. Organization Design for Projects and Companies. 3-4 Units.

Introduction to organizational behavior and organizational design for construction projects and companies. Class incorporates readings, individual, small group and large group case study assignments. Students use computer simulation to design real-world project organizations.

CEE 242P. Designing Project Organizations. 2 Units.

Sequel to CEE 242T. Course develops information-processing approach for designing project and project-based company organizations to deliver sustainable construction projects; includes design of organizations and work processes for integrated project delivery and public-private partnership concession project delivery. Term project applies computer-based organization simulation to optimize design of project organization for a participating company.

CEE 242R. Project Risk Analysis. 3 Units.

Teaches principles and methods for quantitative modeling and mitigation of risks in project planning, design, construction and operation, using new MS Excel capabilities and standardized probability distributions. Several case studies will be covered, including ongoing work with PG&E to roll up operational risks.

CEE 242T. Organizational Behavior and Design for Construction. 2 Units.

Introduction to organizational behavior and organizational design for Architecture, Engineering and Construction projects and companies. Class incorporates readings, individual and group case study assignments. Students use computer simulation to analyze project organizations and predict schedule, cost and quality risks. This class is a prerequisite for CEE 242P.

CEE 243. Intro to Urban Sys Engrg. 3 Units.

This course is an introduction to the interdisciplinary domain of urban systems engineering. It will provide you with a high-level understanding of the motivation for studying sustainable cities and urban systems, systems-based modeling approaches and the social actor theories embedded in the urban sustainability decision making process. Coursework will be comprised of three group mini-projects corresponding to course modules.

CEE 244. Accounting, Finance & Valuation for Engineers & Constructors. 3 Units.

Concepts of financial accounting and economics emphasizing the construction industry. Financial statements, accounting concepts, project accounting methods, and the nature of project costs. Case study of major construction contractor. Ownership structure, working capital, and the sources and uses of funds.

CEE 246. Venture Creation for the Real Economy. 3-4 Units.

A project-based course where teams of 4 prepare their entrepreneurial venture for fundraising and launch. Students acquire the experience of an early-stage entrepreneur as they progress through stages of team building, opportunity assessment, product-market fit analysis, business model architecture, go-to market strategy, product planning, financial modelling, and fundraising planning. The course structure includes weekly workshops, guest presentations from seasoned entrepreneurs, weekly meetings with the teaching team, and one-on-one support from a dedicated industry mentor. The experience culminates in three pitches to panels of VCs and other industry experts. By the end of the class, successful students will be equipped with the knowledge and network to create impactful business ideas, many of which have been launched from this class. Open to all Stanford students. No prerequisites. For more information, visit the course website: <https://web.stanford.edu/class/msande273>. Enrolment by application: <https://web.stanford.edu/class/msande273/apply>. Same as: MS&E 273

CEE 246B. Real Estate Development and Finance. 3 Units.

Introduction to the Real Estate Development Process from conception, feasibility analysis, due diligence, entitlements, planning, financing, market analysis, contract negotiation, construction, marketing, asset management and disposition. Pro-forma and Financial modeling in Real Estate. Financing options for different types of Real Estate projects and products. Redevelopment projects. Affordable Housing. The class will combine lectures, case studies, field work (Group Project) and guest speakers. Recommended knowledge of spreadsheets. Prerequisites: highly recommended Engineering Economy (CEE 246A or ENGR 60) or any Introduction to Finance class (concepts of Present Worth and IRR). Attendance to the first class is mandatory.

CEE 246S. Real Estate Finance Seminar or Real Estate Career Development Seminar. 1 Unit.

Real Estate Development and Finance presented by industry guest speakers. Executives from different Real Estate companies will give an overview of their business and projects. (Residential, Retail, Commercial, Mixed Used, REITs, Redevelopment Projects, Affordable Housing, public and private real estate companies, real estate funds, etc.). Short Real Estate Case Studies will be given as homework. Two optional field trips. Attendance to the first class is mandatory. (Please note that the classroom is Y2E2 111 for Spring 2019-20).

CEE 247A. Network Governance. 3-4 Units.

This course aims at providing students with insights, concepts and skills needed to understand the dynamics of multi-actor interaction processes in uncertain and often highly politicized contexts and to be able to cope with technological and strategic uncertainties and risks including the unpredictable behavior of actors. They will develop knowledge, skills and competences about how to manage divergent and conflicting interests of different actors including principles of integrative negotiation, communication and mediation.

CEE 248. Introduction to Real Estate Development. 2 Units.

This course will offer students an introduction to Real Estate Development. Senior Principals from Sares Regis, a regional commercial and residential real estate development company, will cover topics on all aspects of the development process. Guest speakers from the fields of architecture and engineering, finance and marketing will participate in some of the classes. They will offer the students a window into the world of how houses, apartments, office buildings and public facilities are conceived of, brought through the design and approval process, financed, marketed and then sold and/or rented. There will be nine 1.5-hour lectures (robust class discussion encouraged). Throughout the quarter, the students will work on a group case study assignment about one local project that is currently being built or was recently completed. This assignment will be due in the form of a presentation during the final exam period. No prior knowledge of real estate is required. Classes commence on April 1st and complete on June 3rd. Number of students is limited to 30. Undergraduates must apply by submitting a one-page essay explaining their interest in taking the class to mradyk@srgnc.com by March 8, 2021.

CEE 250. Product Management Fundamentals for the Real Economy. 3 Units.

This course teaches students how to apply product management skills to create products and services for the "real economy." Students will learn the basics of product management and the product lifecycle and design a product in a team setting. They will also learn iterative product development with an eye towards applying those skills towards products that produce real economic value for society as well as the entrepreneurs. This course includes instruction from seasoned industry veterans and guest speakers. Students will be guided through identifying an opportunity, designing a solution, launching a product, and building a roadmap. The content is tailored to students interested in developing real products and delivering solutions within startups, established companies, non-profits, governments, and non-governmental organizations. The goal is to teach students the fundamentals of product management and equip them with the knowledge to make meaningful progress on some of the biggest challenges facing society. This course requires an application due to limited enrollment. Application link: <https://forms.gle/3f9RRpgF9zjpXkfq8>. Application deadline: Sunday, September 13, 9PM PST.

CEE 251. Negotiation. 3 Units.

Students learn to prepare for and conduct negotiations in a variety of arenas including getting a job, managing workplace conflict, negotiating transactions, and managing personal relationships. Interactive class. The internationally travelled instructor who has mediated cases in over 75 countries will require students to negotiate real life case studies and discuss their results in class. Application required before first day of class; students should enroll on Axess and complete the application on Canvas before March 20, 2020. Note: there is a class fee of \$130 for access to case files and readings. Same as: CEE 151, EARTH 251, PUBLPOL 152

CEE 252. Construction Methods for Concrete and Steel Structures. 3 Units.

Providing technical support for concrete and steel construction operations on buildings or infrastructure projects. Concrete materials, construction properties of fresh concrete. Resources and operations for batching, transporting, placing, finishing, and curing concrete. Design, fabrication, and use of formwork. Special operations and formwork systems. Detailing, fabricating, erecting, and connecting structural steel. Lifting equipment and lift planning. Welding processes, operations, and quality control. Readings, exercises and course projects.

CEE 252Q. Construction Engineering Fundamentals. 2 Units.

Construction engineering is a series of technical activities to meet project objectives related to cost and schedule, safety, quality, and sustainability. These activities include: 1) designing temporary works and construction work processes; 2) providing the required temporary and permanent resources; and 3) integrating activities to consider construction during all project phases and between projects. The objectives of CEE 252Q are to learn about the technical fundamentals, resources, and field operations required to complete construction engineering activities and to develop a foundation for continued related learning. The course requires reviewing recorded presentations and other online resources, completing queries, participating in class sessions with guest speakers and in field trips, and completing group exercises and projects. The exercises, completed by all of the student groups, include construction engineering activities for earthwork, concrete construction, and steel erection. Each group will also complete a project to analyze one of the following types of systems or facilities: building electrical systems, lighting systems, HVAC systems, control systems, solar photovoltaic power plant, and wind turbine power plant.

CEE 254. Data Analytics for Physical Systems. 3-4 Units.

This course introduces practical applications of data analytics and machine learning from understanding sensor data to extracting information and decision making in the context of sensed physical systems. Many civil engineering applications involve complex physical systems, such as buildings, transportation, and infrastructure systems, which are integral to urban systems and human activities. Emerging data science techniques and rapidly growing data about these systems have enabled us to better understand them and make informed decisions. In this course, students will work with real-world data to learn about challenges in analyzing data, applications of statistical analysis and machine learning techniques using MATLAB, and limitations of the outcomes in domain-specific contexts. Topics include data visualization, noise cleansing, frequency domain analysis, forward and inverse modeling, feature extraction, machine learning, and error analysis. Prerequisites: CS106A, CME 100/Math51, Stats110/101, or equivalent. Same as: CEE 154

CEE 255. Introduction to Sensing Networks for CEE. 3-4 Units.

Introduce the design and implementation of sensor networks for monitoring the built and natural environment. Emphasis on the integration of modern sensor and communication technologies, signal processing and statistical models for network data analysis and interpretation to create practical deployments to enable sustainable systems, in areas such as energy, weather, transportation and buildings. Students will be involved in a practical project that may involve deploying a small sensor system, data models and analysis and signal processing. Limited enrollment. Same as: CEE 155

CEE 256. Building Systems Design & Analysis. 3-4 Units.

HVAC, lighting, and envelope systems for commercial and institutional buildings, with a focus on energy efficient design. Knowledge and skills required in the development of low-energy buildings that provide high quality environment for occupants. Same as: CEE 156

CEE 257. Sustainable Finance and Investment Seminar. 1 Unit.

The course aims to equip the Stanford community with the knowledge and networks required to undertake significant future work on sustainable finance and investment. The course will be given in a seminar format, which explores multiple disciplines of sustainable finance with talks by researchers associated with the Stanford Precourt Institute for Energy's Sustainable Finance Initiative and visiting speakers. The course features three highly interactive modules: (1) risk and opportunities of sustainable finance, (2) business and financial innovation toward sustainability, and (3) sustainability assessment and advanced data technologies. The contents covered by this course include but are not limited to systems and theories in sustainable finance and investment such as active ownership, carbon markets and policies, climate finance, environmental disclosure and reporting, divestment, engagement, environmental, social, and governance (ESG), green banks, green bonds, green benchmarks and indices, impact investing, public-private partnerships, responsible investment, stranded assets, and green taxonomies. Seminar meets weekly during the Spring Quarter. Same as: CEE 157

CEE 258. Donald R. Watson Seminar in Construction Engineering and Management. 1 Unit.

Presentations from construction industry leaders. Discussions with speakers from various segments of industry regarding career options. During Autumn 2020, this course will be offered "remote-only" and "synchronous." Students interested in taking CEE 258 with an in-person component should enroll in CEE 258C.

CEE 258B. Donald R. Watson Seminar in Construction Engineering and Management. 1 Unit.

Weekly seminars and field trips focusing on technical aspects of concrete and steel construction. Submission of abstract and paper required.

CEE 258C. Donald R. Watson Seminar in Construction Engineering and Management. 1 Unit.

Presentations from construction industry leaders. Discussions with speakers from various segments of industry regarding career options. During Autumn 2020, this course will be offered 'remote + in-person' and 'synchronous.' Students interested in taking CEE 258C must submit an online application found here; <https://forms.gle/dLADjwGeYNU7ppcp7>. Students interested in taking CEE 258C without an in-person component should enroll in CEE 258.

CEE 259A. Construction Problems. 1-3 Unit.

Group-selected problems in construction techniques, equipment, or management; preparation of oral and written reports. Guest specialists from the construction industry. See 299 for individual studies. Prerequisites: graduate standing in CEM program and consent of instructor.

CEE 259B. Construction Problems. 1-3 Unit.

Group-selected problems in construction techniques, equipment, or management; preparation of oral and written reports. Guest specialists from the construction industry. See 299 for individual studies. Prerequisites: graduate standing in CEM program and consent of instructor.

CEE 260A. Physical Hydrogeology. 4 Units.

(Formerly GES 230.) Theory of underground water occurrence and flow, analysis of field data and aquifer tests, geologic groundwater environments, solution of field problems, and groundwater modeling. Introduction to groundwater contaminant transport and unsaturated flow. Lab. Prerequisite: elementary calculus. Same as: ESS 220

CEE 260C. Contaminant Hydrogeology and Reactive Transport. 3 Units.

Decades of industrial activity have released vast quantities of contaminants to groundwater, threatening water resources, ecosystems and human health. What processes control the fate and transport of contaminants in the subsurface? What remediation strategies are effective and what are the tradeoffs among them? How are these processes represented in models used for regulatory and decision-making purposes? This course will address these and related issues by focusing on the conceptual and quantitative treatment of advective-dispersive transport with reacting solutes, including modern methods of contaminant transport simulation. Some Matlab programming / program modification required. Prerequisite: Physical Hydrogeology ESS 220 / CEE 260A (Gorelick) or equivalent and college-level course work in chemistry. Same as: ESS 221

CEE 260D. Remote Sensing of Hydrology. 3 Units.

This class discusses the methods available for remote sensing of the components of the terrestrial hydrologic cycle and how to use them. Topics include the hydrologic cycle, relevant sensor types and the electromagnetic spectrum, active/passive microwave remote sensing (snow, soil moisture, canopy water content, rainfall), thermal sensing of evapotranspiration, gravity and hyperspectral methods, as well as an introduction to data assimilation and calibration/validation approaches for hydrologic variables. Pre-requisite: programming experience. Same as: ESS 224

CEE 261A. Physics of Wind. 3 Units.

An introduction to the Atmospheric Boundary Layer (ABL), including measurements and simulations of ABL flows. Wind and flow, turbulent transport, buoyancy and virtual potential temperature, the diurnal cycle. Derivation of the governing equations, simplifications and assumptions. Turbulence kinetic energy and its budget, ABL stability, the Richardson number and the Obukhov length. Analysis of boundary layer turbulence. Overview of field and wind tunnel measurement techniques, and of computational models from meso- to micro-scale. a Discussion of micro-scale applications, including pedestrian wind comfort, pollutant dispersion and wind loading, and an introduction to uncertainty quantification for ABL flows. Prerequisites: Knowledge of fluid mechanics.

CEE 261B. Physics of Wind Energy. 3 Units.

Formerly CEE 261. An introduction to the analysis and modeling of wind energy resources and their extraction. Topics include the physical origins of atmospheric winds; vertical profiles of wind speed and turbulence over land and sea; the wind energy spectrum and its modification by natural topography and built environments; theoretical limits on wind energy extraction by wind turbines and wind farms; modeling of wind turbine aerodynamics and wind farm performance. Final project will focus on development of a new wind energy technology concept. Prerequisites: CEE 262A or ME 351A.

Same as: ENERGY 262, ME 262

CEE 261C. Wind Engineering for Sustainable Cities. 3 Units.

An introduction to structural and environmental wind engineering for the design of sustainable buildings and cities, covering the physics and analysis of wind loading, urban flow and dispersion, and natural ventilation. Topics include: the atmospheric boundary layer and design wind speeds; bluff body aerodynamics; calculating design wind loads from building codes, wind tunnel experiments or computational fluid dynamics; analyzing pedestrian wind comfort and pollutant dispersion; and the design and analysis of natural ventilation systems using envelope models, scale modeling, full-scale measurements, and computational fluid dynamics. Measurement and simulation data of the flow on Stanford's Engineering Quad and in the Y2E2 building will be used throughout the course to illustrate the different concepts and methods.

CEE 261I. Atmosphere, Ocean, and Climate Dynamics: The Atmospheric Circulation. 3 Units.

Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the atmospheric circulation. Topics include the global energy balance, the greenhouse effect, the vertical and meridional structure of the atmosphere, dry and moist convection, the equations of motion for the atmosphere and ocean, including the effects of rotation, and the poleward transport of heat by the large-scale atmospheric circulation and storm systems. Prerequisites: MATH 51 or CME100 and PHYSICS 41.

Same as: CEE 161I, EARTHSYS 146A, ESS 246A

CEE 262A. Hydrodynamics. 3-4 Units.

The flow of incompressible viscous fluid; emphasis is on developing an understanding of fluid dynamics that can be applied to environmental flows. Topics: kinematics of fluid flow; equations of mass and momentum conservation (including density variations); some exact solutions to the Navier-Stokes equations; appropriate analysis of fluid flows including Stokes flows, potential flows, and laminar boundary layers; and an introduction to the effects of rotation and stratification through scaling analysis of fluid flows. Prerequisites: 101B or consent of instructor; and some knowledge of vector calculus and differential equations.

CEE 262B. Transport and Mixing in Surface Water Flows. 3-4 Units.

Application of fluid mechanics to problems of pollutant transport and mixing in the water environment. Mathematical models of advection, diffusion, and dispersion. Application of theory to problems of transport and mixing in rivers, estuaries, and lakes and reservoirs. Recommended: 262A and CME 102 (formerly ENGR 155A), or equivalents.

CEE 262C. Coastal Ocean Modeling. 3 Units.

Introduction to numerical methods for modeling flows in the coastal ocean and estuaries that are influenced by river flows, tides, winds and gravity waves. Topics include stability and accuracy analysis, curvilinear and unstructured grids, implicit/explicit methods, transport and diffusion, shallow water equations, nonhydrostatic equations, Navier-Stokes solvers, turbulence modeling, and wave modeling. Prerequisites: CEE 262A, CME 206, or equivalent.

CEE 262D. Introduction to Physical Oceanography. 4 Units.

The dynamic basis of oceanography. Topics: physical environment; conservation equations for salt, heat, and momentum; geostrophic flows; wind-driven flows; the Gulf Stream; equatorial dynamics and ENSO; thermohaline circulation of the deep oceans; and tides. Prerequisite: PHYSICS 41.

Same as: CEE 162D, EARTHSYS 164, ESS 148

CEE 262E. Rivers, Streams, and Canals. 3 Units.

Introduction to the movement of water through natural and engineered channels, streams, and rivers. Basic equations and theory (mass, momentum, and energy equations) for steady and unsteady descriptions of the flow. Application of theory to the design of flood-control and canal systems. Flow controls such as weirs and sluice gates; gradually varied flow; Saint-Venant equations and flood waves; and method of characteristics. Open channel flow laboratory experiments: controls such as weirs and gates, gradually varied flow, and waves. Limited enrollment in lab section. Prerequisite: CEE 101B or CEE 162A.

Same as: CEE 162E

CEE 262F. Ocean Waves. 3 Units.

The fluid mechanics of surface gravity waves in the ocean of relevance to engineers and oceanographers. Topics include irrotational waves, wave dispersion, wave spectra, effects of bathymetry (shoaling), mass transport, effects of viscosity, and mean currents driven by radiation stresses. Prerequisite: CEE 262A or a graduate class in fluid mechanics.

CEE 262G. Sediment Transport Physics and Modeling. 3 Units.

Mechanics of sediment transport in rivers, estuaries and coastal oceans, with an emphasis on development of models and application of three-dimensional software tools. Topics include bottom boundary layers in steady and wave-driven flows, bedform dynamics, suspended and bedload transport, cohesive sediments. Prerequisites: CEE262A, CEE 262C or consent of instructor.

CEE 262H. Observational Methods in Coastal Oceanography. 3 Units.

TBA.

CEE 262I. Atmosphere, Ocean, and Climate Dynamics: the Ocean Circulation. 3 Units.

Introduction to the physics governing the circulation of the atmosphere and ocean and their control on climate with emphasis on the large-scale ocean circulation. This course will give an overview of the structure and dynamics of the major ocean current systems that contribute to the meridional overturning circulation, the transport of heat, salt, and biogeochemical tracers, and the regulation of climate. Topics include the tropical ocean circulation, the wind-driven gyres and western boundary currents, the thermohaline circulation, the Antarctic Circumpolar Current, water mass formation, atmosphere-ocean coupling, and climate variability. Prerequisites: MATH 51 or CME100; and PHYSICS 41; and a course that introduces the equations of fluid motion (e.g. ESS 246A, ESS 148, or CEE 101B).

Same as: CEE 162I, EARTHSYS 146B, ESS 246B

CEE 263A. Air Pollution Modeling. 3-4 Units.

The numerical modeling of urban, regional, and global air pollution focusing on gas chemistry and radiative transfer. Stratospheric, free-tropospheric, and urban chemistry. Methods for solving stiff systems of chemical ordinary differential, including the multistep implicit-explicit method, Gear's method with sparse-matrix techniques, and the family method. Numerical methods of solving radiative transfer, coagulation, condensation, and chemical equilibrium problems. Project involves developing a basic chemical ordinary differential equation solver. Prerequisite: CS 106A or equivalent.

CEE 263B. Numerical Weather Prediction. 3-4 Units.

Numerical weather prediction. Continuity equations for air and water vapor, the thermodynamic energy equation, and momentum equations derived for the atmosphere. Numerical methods of solving partial differential equations, including finite-difference, finite-element, semi-Lagrangian, and pseudospectral methods. Time-stepping schemes: the forward-Euler, backward-Euler, Crank-Nicolson, Heun, Matsuno, leapfrog, and Adams-Bashforth schemes. Boundary-layer turbulence parameterizations, soil moisture, and cloud modeling. Project developing a basic weather prediction model. Prerequisite: CS 106A or equivalent.

CEE 263C. Weather and Storms. 3 Units.

Daily and severe weather and global climate. Topics: structure and composition of the atmosphere, fog and cloud formation, rainfall, local winds, wind energy, global circulation, jet streams, high and low pressure systems, inversions, el Niño, la Niña, atmosphere/ocean interactions, fronts, cyclones, thunderstorms, lightning, tornadoes, hurricanes, pollutant transport, global climate and atmospheric optics.

Same as: CEE 63

CEE 263D. Air Pollution and Global Warming: History, Science, and Solutions. 3 Units.

Survey of Survey of air pollution and global warming and their renewable energy solutions. Topics: evolution of the Earth's atmosphere, history of discovery of chemicals in the air, bases and particles in urban smog, visibility, indoor air pollution, acid rain, stratospheric and Antarctic ozone loss, the historic climate record, causes and effects of global warming, impacts of energy systems on pollution and climate, renewable energy solutions to air pollution and global warming. UG Reqs: GER: DBNatSci.

Same as: CEE 64

CEE 263G. Energy Policy in California and the West. 1 Unit.

This seminar provides an in-depth analysis of the role of California state agencies and Western energy organizations in driving energy policy development, technology innovation, and market structures, in California, the West and internationally. The course covers three areas: 1) roles and responsibilities of key state agencies and Western energy organizations; 2) current and evolving energy and climate policies; and 3) development of the 21st century electricity system in California and the West. The seminar will also provide students a guideline of what to expect in professional working environment.

Same as: ENERGY 73, POLISCI 73, PUBLPOL 73

CEE 263H. Introduction to Quantitative Methods for Energy Decisions. 3 Units.

This course provides students from various backgrounds with knowledge of the principles and quantitative methods of decision analysis and policy analysis to tackle interdisciplinary questions in the context of sustainable energy systems. We consider engineering analysis, decision analysis and economic analysis in the formulation of answers to address energy system problems. We will use methods such as life-cycle assessment, benefit-cost and cost-effectiveness analysis, microeconomics, distributional metrics, risk analysis methods, sensitivity and uncertainty analysis, multi-attribute utility theory, and simulation and optimization. The integration of uncertainty into formal methods is a fundamental component of the course.

Same as: ENERGY 263

CEE 263S. Atmosphere/Energy Seminar. 1 Unit.

Interdisciplinary seminar with talks by researchers and practitioners in the fields of atmospheric science and renewable energy engineering. Addresses the causes of climate, air pollution, and weather problems and methods of addressing these problems through renewable and efficient energy systems. May be repeated for credit.

CEE 264H. Quantitative methods for marine ecology and conservation. 4 Units.

The goal of this course is to learn the foundations of ecological modelling with a specific (but not exclusive) focus on marine conservation and sustainable exploitation of renewable resources. Students will be introduced to a range of methods ζ from basic to advanced ζ to characterize population structure, conduct demographic analyses, estimate extinction risk, identify temporal trends and spatial patterns, quantify the effect of environmental determinants and anthropogenic pressures on the dynamics of marine populations, describe the potential for adaptation to climate change. This course will emphasize learning by doing, and will rely heavily on practical computer laboratories, in R and/or Python, based on data from our own research activities or peer reviewed publications. Students with a background knowledge of statistics, programming and calculus will be most welcome.

Same as: BIOHOPK 143H, BIOHOPK 243H, CEE 164H, EARTHSYS 143H, EARTHSYS 243H

CEE 265A. Resilience, Sustainability and Water Resources Development. 3 Units.

"Sustainability" has been part of the vocabulary of water engineers since the 1990s, and in the past decade, "resilience" has appeared with increasing frequency in combination with sustainability in the water resources literature. In this course, students learn about sustainability and resilience as cultural ideals and, at times, sources of confusion. They will also investigate how these concepts are influencing the development and management of water resources. Sustainability and resilience concepts are illustrated using cases studies involving water development agencies in the US and other countries. These studies illustrate the role of political, social, economic, and environmental factors in decision making. Topics include multipurpose dams, structural and non-structural flood control measures, and drought management strategies. The course also examines the work of international aid organizations and NGOs in promoting sustainability and resilience in water resources development. Students will have many opportunities to sharpen their oral communication and writing abilities. Enrollment limited to 25 students. This is a Remote-Synchronous course. If you are interested in taking this course, please attend the first class regardless of your formal enrollment status. (See Zoom link on the CEE 265A Canvas site.) If more than 25 students wish to take the class, decisions on final enrollment will be based on completion of an admissions essay described on the first day of class. Intended for juniors, seniors and graduate students. No prerequisites.

CEE 265C. Water Resources Management. 3 Units.

Water resources management is studied in the context of increasing population, economic growth, and the effect of climate change on the available water resources. The class examines the question of how to achieve the optimal equilibrium between water supply and water demand, under specific local and regional physical environmental, social and economic constraints. Basic water management principles are reviewed in the context of sustainable development, increasing water scarcity in many parts of the world, and hydrologic uncertainty including that associated with climate change. Specific topics include the management of operations and water quality in reservoirs, river basins, and groundwater systems; non-conventional water sources such as treated wastewater and desalination; demand management options; and the institutional and legal framework of water management.

Same as: CEE 165C

CEE 265D. Water and Sanitation in Developing Countries. 1-3 Unit.

Economic, social, political, and technical aspects of sustainable water supply and sanitation service provision in developing countries. Service pricing, alternative institutional structures including privatization, and the role of consumer demand and community participation in the planning process. Environmental and public health considerations, and strategies for serving low-income households. Limited enrollment. Prerequisite: consent of instructor, see jennadavis.stanford.edu for application.

CEE 265E. Adaptation to Sea Level Rise and Extreme Weather Events. 3 Units.

Students are introduced to basic aspects of climate change in the context of sea level rise and the intensity and frequency of extreme-weather events, including floods, droughts and wildfires. Climate change adaptations are adjustments in behaviors, plans and projects to reduce society's vulnerability to climate change impacts. Major adaptation approaches relevant to civil and environmental engineers are emphasized. Adaptation measures considered include structural and ecologically-based measures for dealing with sea level rise, storm surges, floods and wildfires. In the context of coastal flooding, consideration is also given to *managed retreat* (i.e., deliberately altering flood defenses to allow flooding of presently protected areas). Influence of climate change on migration is also considered. Additional measures to reduce vulnerability include emergency preparedness and disaster response management systems. Illustrations of innovative adaptation measures taken by cities around the world are featured. Common barriers to climate change adaptation are also reviewed. Limited enrollment. Students from all departments and programs are welcome, with some admission preference given to students in CEE graduate programs followed by CEE Department seniors.

CEE 265F. Environmental Governance and Climate Resilience. 3 Units.

Adaptation to climate change will not only require new infrastructure and policies, but it will also challenge our local, state and national governments to collaborate across jurisdictional lines in ways that include many different types of private and nonprofit organizations and individual actors. The course explores what it means for communities to be resilient and how they can reach that goal in an equitable and effective way. Using wildfires in California as a case study, the course assesses specific strategies, such as controlled burns and building codes, and a range of planning and policy measures that can be used to enhance climate resilience. In addition, it considers how climate change and development of forested exurban areas (among other factors) have influenced the size and severity of wildfires. The course also examines the obstacles communities face in selecting and implementing adaptation measures (e.g., resource constraints, incentives to develop in forested areas, inadequate policy enforcement, and weak inter-agency coordination). Officials from various Bay Area organizations contribute to aspects of the course; and students will present final papers to local government officials. Limited enrollment. Students will be asked to prepare application essays on the first day of class. Course is intended for seniors and graduate students.

Same as: POLISCI 227B, PUBLPOL 265F

CEE 265H. Big Earth Hackathon Wildland Fire Challenge. 3 Units.

Participate in Stanford's Big Earth Hackathon challenge on wildland fires by finding an innovative solution to wildland fire prediction, prevention, and/or evacuation. Students work in self-organized diverse teams of 2-4 students in weeks 1-8, with a final presentation of the work on Friday May 29. The teams will spend the first few weeks designing their specific team problem/scope/goals under one of three primary areas of focus. Guidance in the design and solution processes will be provided by faculty, industry and/or community leaders. Workshops in data analysis, programming, GIS, and fundamental issues related to wildfires will be provided at the start of the quarter to give students tools and insights to define and tackle problems.

Same as: CEE 165H, EARTH 165H, EARTH 265H

CEE 265I. Poverty, Infrastructure and Climate. 2-3 Units.

Lack of access to physical infrastructure such as roads, water supply and electricity is a key element of how 'poverty' is often defined. At the same time, the causal pathways that link infrastructure and economic development are not well understood, and are likely being re-shaped by a changing climate. Students in this course will contribute to a new initiative on poverty, infrastructure and climate change by (1) reviewing and synthesizing literature from relevant scholarly communities, (2) co-creating a conceptual causal model of the ways in which infrastructure (particularly roads and water assets) contributes to poverty alleviation, and (3) contributing to the design of applied research effort on these topics in sub-Saharan Africa. Students who opt for the 3-unit enrollment will have an additional supervised project that could take the form of a review paper, research proposal, or analysis of secondary data. There are no formal pre-requisites for the class; students from all schools and departments are welcome. Enrollment requires permission of the instructors. Interested students are invited to submit an application at <https://tiny.cc/EPIC-Stanford>.

Same as: ESS 264

CEE 266A. Watershed Hydrologic Processes and Models. 3 Units.

Introduction to the occurrence and movement of water in the natural environment and its role in creating and maintaining terrestrial, wetland, and aquatic habitat. Hydrologic processes, including precipitation, evaporation, transpiration, snowmelt, infiltration, subsurface flow, runoff, and streamflow. Rivers and lakes, springs and swamps. Emphasis is on observation and measurement, data analysis, modeling, and prediction. Prerequisite: CEE 101B or CEE 162A or equivalent. (Freyberg).

Same as: CEE 166A

CEE 266B. Water Resources and Hazards. 3 Units.

Sociotechnical systems associated with human use of water as a resource and the hazards posed by too much or too little water. Potable and non-potable water use and conservation. Irrigation, hydroelectric power generation, rural and urban water supply systems, storm water management, flood damage mitigation, and water law and institutions. Emphasis is on engineering design. Prerequisite: 166A/266A or equivalent. (Freyberg).

Same as: CEE 166B

CEE 266C. Dams, Reservoirs, and their Sustainability. 3 Units.

An investigation of dams and reservoirs and their short- and long-term costs, benefits, and impacts. Dam safety, operating rules and reoperation in response to change, fish passage, reservoir sediment management, fish passage and habitat, dam removal. Heavy reliance on case studies, technical literature, and discussion. Enrollment limited. Graduate status or permission of the instructor. Prerequisite: CEE 266A, 266B, or equivalents.

CEE 266E. California's Water Policy and Management: Toward A Sustainable Future. 1 Unit.

This seminar series focuses on the dramatic changes in recent decades in California water policy and management and how water researchers can help forge modern, collaborative solutions that will allow the state to adapt to an uncertain and challenging future. The seminar will meet six times during the Spring Quarter. The heart of the series will include four seminars with panels of outside experts covering the following topics: 1) The diversification of California's water supply portfolio; 2) The rise of the coequal goals of ecosystem restoration and water supply reliability; 3) The ongoing tension between collaborative and adversarial decision-making processes; and 4) Implications for water researchers seeking to help define pathways to meaningful solutions. In addition to these four seminar sessions, there will be an introductory California Water 101 session for students and a closing session on what we have learned. Students will be assigned readings and required to develop questions for discussion. Lead instructor for the seminar will be Landreth Visiting Fellow Dr. Timothy Quinn. Dr. Quinn spent more than ten years as the executive director of the Association of California Water Agencies, and more than twenty years as the Deputy General Manager of the Metropolitan Water District of Southern California. Over the course of that career, he was at the center of every major water management issue facing the state of California, including the state's use of Colorado River water, management of the Bay Delta, and sustainable groundwater management. This class will meet the first five weeks of the quarter. Elements used in grading: Attendance, Class Participation, Written Assignments. Cross-listed with Law 2521.

CEE 266F. Stochastic Hydrology. 3 Units.

Hydrological processes like precipitation, streamflow, and groundwater flow are highly variable over time and across locations. Quantifying the uncertainty in hydrological models and simulating future conditions is critical for informing the development and management of civil infrastructure systems. This course introduces students to statistical methods used in hydrology for data analysis, risk and uncertainty analysis, and simulation. Topics include: flood and drought frequency, time series analysis, rainfall-runoff modeling, and lake water quality. Methods include: applied probability theory, extreme value theory, parameter estimation, regression, time series analysis, transfer functions, Bayesian methods. Prerequisites: CEE 266A or equivalent and a class in probability and/or statistics.

CEE 266G. Water Resources Systems Analysis. 3 Units.

Water resources planners use computational systems engineering models to inform decisions about operations, infrastructure development, and policy. Systems models evaluate alternative decisions against performance metrics like water reliability, access, cost, electricity production, and ecosystem services under a range of hydrological and social conditions. This course will introduce computational methods used in decision-support and common applications in water resources. Focus is on applied optimization methods such as linear programming, dynamic programming, and evolutionary algorithms as well as stochastic simulation. Application areas may include: reservoir operation, environmental flow alteration, hydropower, and flood control. Attention will be given to multi-objective analysis and climate change adaptation. Assignments will involve programming in Python; some Python tutorials will be provided, but prior programming experience is recommended. Prerequisites: CEE 166A or equivalent.

CEE 267. Applied Data Analysis and Uncertainty Quantification. 3 Units.

Probabilistic and statistical methods with emphasis on basic concepts and tools, illustrated with applications from environmental and water studies. Topics: exploratory data analysis; probability theory; classical statistics; Bayesian statistics; geostatistics; and inverse problems.

CEE 269A. Environmental Engineering Seminar. 1 Unit.

Presentations on current research in environmental engineering by Civil & Environmental Engineering faculty.

CEE 269B. Environmental Engineering Seminar. 1 Unit.

Presentations on current research, practice and thinking in environmental engineering by visiting academics and practitioners.

CEE 269C. Environmental Engineering Seminar. 1 Unit.

Presentations on current research, practice and thinking in environmental engineering by visiting academics and practitioners.

CEE 270. Movement and Fate of Organic Contaminants in Waters. 3 Units.

Transport of chemical constituents in surface and groundwater including advection, dispersion, sorption, interphase mass transfer, and transformation; impacts on water quality. Emphasis is on physicochemical processes and the behavior of hazardous waste contaminants. Prerequisites: undergraduate chemistry and calculus. Recommended: 101B.

CEE 270B. Environmental Organic Reaction Chemistry. 2-3 Units.

With over 70,000 chemicals now in production worldwide, predicting their fate in the environment is a difficult task. The course focuses on developing two key skills. First, students should develop the ability to derive mass balance equations used to quantify the fate of chemicals in the environment. With so many chemicals having been introduced in the past ~60 years, many of the key parameters needed for mass balance models have not been measured experimentally. The class builds on CEE 270, which developed methods of predicting equilibrium partitioning coefficients. For many situations involving reactions of target contaminants, equilibrium is not attained. The course develops methods of predicting the reactivity of chemicals based upon their chemical structures both qualitatively and quantitatively. natural reaction processes covered include acid-base speciation, nucleophilic substitution, oxidation/reduction reactions, and photochemical reactions. Key treatment reactions (ozone, UV treatment and advanced oxidation) are also covered. Prerequisites: CEE 270, Chem 31B/M.

CEE 270M. Aquatic and Organic Chemistry for Environmental Engineering. 3 Units.

This course provides a solid foundation in the most important aspects of general, aquatic and organic chemistry. Nearly all of aspects environmental engineering apply the chemistry concepts discussed in this course. Given that each of the chemistry subjects to be addressed are standalone classes, this class highlights only the most relevant material to environmental engineering. The class focuses on developing general background skills needed for subsequent classes in environmental engineering focusing on their applications, although certain applications will be discussed for illustration. Same as: CEE 170

CEE 270S. Environmental Disasters. 2 Units.

Mining and critical review of scientific literature for environmental impacts, especially chemical contamination caused by natural and anthropogenic disasters. Focus is on the development of research review skills, critical thinking and discussion of findings.

CEE 271A. Physical and Chemical Treatment Processes. 3 Units.

Physical and chemical unit operations for water treatment, emphasizing process combinations for drinking water supply. Application of the principles of chemistry, rate processes, fluid dynamics, and process engineering to define and solve water treatment problems by flocculation, sedimentation, filtration, disinfection, oxidation, aeration, and adsorption. Investigative paper on water supply and treatment. Prerequisites: CEE 101B (or CEE 162A); CEE 270. Recommended: 273.

CEE 271B. Environmental Biotechnology. 4 Units.

Stoichiometry, kinetics, and thermodynamics of microbial processes for the transformation of environmental contaminants. Design of dispersed growth and biofilm-based processes. Applications include treatment of municipal and industrial waste waters, detoxification of hazardous chemicals, and groundwater remediation. Prerequisites: 270; 177 or 274A or equivalents.

CEE 271D. Introduction to Wastewater Treatment Process Modeling. 2 Units.

The course will present a structured protocol for simulator application comprising project definition, data collection and reconciliation, model set-up, calibration and validation, and simulation and result interpretation. This course will include a series of guided simulation exercises evaluating resource consumption (e.g., electrical energy, natural gas, chemicals) and resource recovery (e.g., biogas, struvite, biosolids, recycled water) from a variety of treatment plant configurations. Coursework will consist of guided simulation exercises, an end-of-the-quarter project evaluating an assigned plant configuration, and presenting model results to the class. Enrollment will be limited, with preference to CEE graduate students.

CEE 271G. Environmental & Ecological Economics. 3 Units.

Ideas, tools and policy solutions in environmental and ecological economics covering a wide range of topics: biodiversity and ecosystems management, energy and climate change mitigation, environmental health and environmental justice, new indicators of well-being and sustainability beyond GDP and growth and sustainable urban systems. Same as: CEE 171G

CEE 271M. Transport Phenomena: Momentum, heat and mass transport. 3 Units.

Heat, mass and momentum transfer theory from the viewpoint of basic transport equations. Steady and unsteady state; laminar and turbulent flow; boundary layer theory. Prerequisites: fluid mechanics, ordinary differential equations.

Same as: CEE 371M

CEE 272. Coastal Contaminants. 3-4 Units.

Coastal pollution and its effects on ecosystems and human health. The sources, fate, and transport of human pathogens and nutrients. Background on coastal ecosystems and coastal transport phenomena including tides, waves, and cross shelf transport. Introduction to time series analysis with MATLAB. Undergraduates require consent of instructor.

CEE 272R. Modern Power Systems Engineering. 3 Units.

Focus is on Power Engineering from a systems point of view. Topics covered may include modeling of generation, transmission and distribution systems, load flow analysis, transient and steady-state stability analysis. Special emphasis given to modern market operations and dispatch, modeling intermittent controllable power sources, storage technologies, mechanisms for demand response, sensing the grid and the role of market mechanisms for deep integration. Course content may vary year to year.

CEE 272T. SmartGrids and Advanced Power Systems Seminar. 1-2 Unit.

A series of seminar and lectures focused on power engineering. Renowned researchers from universities and national labs will deliver bi-weekly seminars on the state of the art of power system engineering. Seminar topics may include: power system analysis and simulation, control and stability, new market mechanisms, computation challenges and solutions, detection and estimation, and the role of communications in the grid. The instructors will cover relevant background materials in the in-between weeks. The seminars are planned to continue throughout the next academic year, so the course may be repeated for credit.

Same as: EE 292T

CEE 273A. Water Chemistry Laboratory. 3 Units.

(Graduate students register for 273A.) Laboratory application of techniques for the analysis of natural and contaminated waters, emphasizing instrumental techniques.

Same as: CEE 179A

CEE 273B. The Business of Water. 1-2 Unit.

One of the fastest growing economic sectors is the water field, and private water companies are playing an increasingly important role in improving water management around the world. In some cases, however, the involvement of private companies in the water sector has also proven controversial (e.g., when private companies have taken over public water supply systems in developing countries such as Bolivia). This course will look at established or emerging businesses in the water sector and the legal, economic, and social issues that they generate. These businesses include investor-owned water utilities, water technology companies (e.g., companies investing in new desalination or water recycling technologies), water-right funds (who directly buy and sell water rights), social impact funds, innovative agricultural operations, water concessionaires, and infrastructure construction companies and investors. Each week will focus on a different business and company. Company executives will attend the class session and discuss their business with the class. In most classes, we will examine (1) the viability and efficacy of the company's business plan, (2) the legal and/or social issues arising from the business' work, and (3) how the business might contribute to improved water management and policy. Each student will be expected to write (1) two short reflection papers during the course of the quarter on businesses that present to the class, and (2) a 15-page paper at the conclusion of the class on either a water company of the student's choice or a policy initiative that can improve the role that business plays in improving water management (either in a particular sector or more generally). Elements used in grading: Attendance, Class Participation, Written Assignments, Final Paper.

CEE 273C. Environmental Engineering Applications of Membrane Technology. 3 Units.

Introduction to membrane technology and processes with applications in R&D, water/wastewater treatment, and renewable energy. Membrane separation principles, reverse osmosis, nanofiltration, membrane characterization techniques, mass transport phenomena, fouling processes, rejection of salts and trace organics, brine disposal system design, energy and cost considerations, and pre- and post-treatment procedures. Case studies in environmental sustainability issues related to full scale treatment engineering.

CEE 273F. Urban Water Use Efficiency and Conservation. 2 Units.

Introduction to water reuse, including membrane treatment, groundwater infiltration, artificial turf, and runoff collection and use.

CEE 273M. Desalination for a Circular Water Economy. 3 Units.

This course will explore the technological innovations required to support a circular water economy in which nontraditional water is treated to fit-for-purpose standards and reused locally. The first part of this course will review the key constituents present in nontraditional source waters and the state-of-the-art pretreatment, desalination, and concentrate disposal technologies for their removal. Attention will be given to the thermodynamic and operational barriers to improving the efficiency and cost-effectiveness of current technologies. The second part of this course will identify opportunities for next generation autonomous, precise, resilient, process-intensified, modular, and electrically powered desalination alternatives to lower the cost and energy intensity of water reuse. Finally, we will conclude by assessing the scale of the opportunity for water reuse and the technical, policy, and legal barriers to doing so. Over the duration of the course, students will form teams to perform an in-depth review of a single nontraditional source water treatment train, research the state-of-technology relative that required for reuse, and perform a quantitative estimate of life cycle capex and opex costs. Course structure: This course combines a lecture-based introduction to critical material with extensive in-class discussion of daily readings from the peer reviewed literature. As such, it is designed for graduate students across the university with a solid knowledge of physicochemical processes and a basic understanding of traditional water treatment technologies. Assessment elements will include class participation, responses on 4 written assignments, and a final project. Class sessions will include occasional field trips to manufacturers and end users of desalination components, special seminars by invited guests, and presentations of final projects. Enrollment limited to 10. Prospective students must submit an application and be accepted into the course prior to enrolling. Weblink to application: <https://forms.gle/SAm7EZJbdvItPzpA6n> CEE 271A is a prerequisite for CEE 273M.

CEE 273S. Electricity Economics. 3 Units.

This course develops a foundation of economic principles for the electric utility on the topics of regulation, planning, and operation. A particular emphasis is given to emerging electricity sector topics such as renewable planning and integration, distributed energy resources, energy storage, and market design. The course uses these economic principles to assess the effects of existing and proposed policy including the potential for value creation and disruption.

Same as: CEE 173S

CEE 274A. Environmental Microbiology I. 3 Units.

Basics of microbiology and biochemistry. The biochemical and biophysical principles of biochemical reactions, energetics, and mechanisms of energy conservation. Diversity of microbial catabolism, flow of organic matter in nature: the carbon cycle, and biogeochemical cycles. Bacterial physiology, phylogeny, and the ecology of microbes in soil and marine sediments, bacterial adhesion, and biofilm formation. Microbes in the degradation of pollutants. Prerequisites: CHEM 33, CHEM 121 (formerly CHEM 35), and BIOSCI 83, CHEMENG 181, or equivalents. Same as: BIO 273A, CHEMENG 174, CHEMENG 274

CEE 274B. Microbial Bioenergy Systems. 3 Units.

Introduction to microbial metabolic pathways and to the pathway logic with a special focus on microbial bioenergy systems. The first part of the course emphasizes the metabolic and biochemical principles of pathways, whereas the second part is more specifically directed toward using this knowledge to understand existing systems and to design innovative microbial bioenergy systems for biofuel, biorefinery, and environmental applications. There also is an emphasis on the implications of rerouting of energy and reducing equivalents for the fitness and ecology of the organism. Prerequisites: CHEMENG 174 or 181 and organic chemistry, or equivalents.

Same as: BIO 273B, CHEMENG 456

CEE 274D. Pathogens and Disinfection. 3 Units.

Introduction to epidemiology, major pathogens and infectious diseases, the immune system, movement and survival of pathogens in the environment, transfer of virulence and antibiotic resistance genes, and pathogen control, with an emphasis on public health engineering measures (disinfection). Prerequisite: 274A.

CEE 274P. Environmental Health Microbiology Lab. 3-4 Units.

Microbiology skills including culture-, microscope-, and molecular-based detection techniques. Focus is on standard and EPA-approved methods to enumerate and isolate organisms used to assess risk of enteric illnesses, such as coliforms, enterococci, and coliphage, in drinking and recreational waters including lakes, streams, and coastal waters. Student project to assess the microbial water quality of a natural water. Limited enrollment; priority to CEE graduate students. An application form must be filed and approved before admission to the class.

CEE 274S. Hopkins Microbiology Course. 3-12 Units.

(Formerly GES 274S.) Four-week, intensive. The interplay between molecular, physiological, ecological, evolutionary, and geochemical processes that constitute, cause, and maintain microbial diversity. How to isolate key microorganisms driving marine biological and geochemical diversity, interpret culture-independent molecular characterization of microbial species, and predict causes and consequences. Laboratory component: what constitutes physiological and metabolic microbial diversity; how evolutionary and ecological processes diversify individual cells into physiologically heterogeneous populations; and the principles of interactions between individuals, their population, and other biological entities in a dynamically changing microbial ecosystem. Prerequisites: CEE 274A and CEE 274B, or equivalents. Same as: BIO 274S, BIOHOPK 274, ESS 253S

CEE 275A. California Coast: Science, Policy, and Law. 3-4 Units.

This interdisciplinary course integrates the legal, scientific, and policy dimensions of how we characterize and manage resource use and allocation along the California coast. We will use this geographic setting as the vehicle for exploring more generally how agencies, legislatures, and courts resolve resource-use conflicts and the role that scientific information and uncertainty play in the process. Our focus will be on the land-sea interface as we explore contemporary coastal land-use and marine resource decision-making, including coastal pollution, public health, ecosystem management; public access; private development; local community and state infrastructure; natural systems and significant threats; resource extraction; and conservation, mitigation and restoration. Students will learn the fundamental physics, chemistry, and biology of the coastal zone, tools for exploring data collected in the coastal ocean, and the institutional framework that shapes public and private decisions affecting coastal resources. There will be 3 to 4 written assignments addressing policy and science issues during the quarter, as well as a take-home final assignment. Special Instructions: In-class work and discussion is often done in interdisciplinary teams of students from the School of Law, the School of Engineering, the School of Humanities and Sciences, and the School of Earth, Energy, and Environmental Sciences. Students are expected to participate in class discussion and field trips. Elements used in grading: Participation, including class session and field trip attendance, writing and quantitative assignments. Cross-listed with Civil & Environmental Engineering (CEE 175A/275A), Earth Systems (EARTHSYS 175/275), and Law (LAW 2510). Open to graduate students and to advanced undergraduates with instructor consent. Enrollment limited; priority given to CEE majors and Law School students. Same as: CEE 175A

CEE 275B. Process Design for Environmental Biotechnology. 3 Units.

Use of microbial bioreactors for degradation of contaminants and recovery of clean water, clean energy and/or green materials. Student teams design, operate, and analyze bioreactors and learn to write consulting style reports. Limited enrollment. Prerequisites: 271B.

CEE 275C. Water, Sanitation and Health. 1-4 Unit.

Students acquire basic knowledge to participate in a dialogue on water, sanitation and health issues in developing and developed countries. The focus is on enteric pathogenic pollutants. Material includes: Important pathogens, their modes of transmission and the diseases they cause, their fate and transport in the environment, and the means by which they are measured; statistical methods for processing and interpreting waterborne pollutant concentrations, and interpreting data from epidemiology studies; microbial source tracking; epidemiology and quantitative microbial risk assessment; reduction of pathogens in water and sludge; and non-experimental water, sanitation, and hygiene research. Several laboratory sessions will allow students to measure indicator bacteria and viruses using culture-based techniques and expose students to molecular methods for measuring health-relevant targets in water.

CEE 275D. Environmental Policy Analysis. 3-4 Units.

Environmental policy formation is a complex process involving a large number of actors making value laden interpretations of scientifically complex phenomena. This course explores the origins of this complexity and its implications for the future of environmental decision making and policy-directed environmental engineering. We will begin by asking what good environmental policy looks like, including how we set policy for groups of individuals with diverse preferences, how we value preferences across space and time, and how we account for the deep uncertainty that permeates environmental systems. We then turn to how environmental policies are actually developed, exploring the technical, cognitive, organizational, and systemic barriers to implementing "good" policy. Finally, will explore the role of scientific evidence in shaping environmental policy and the mechanisms by which policy shapes engineering and science research. Students will gain familiarity with the existing theories, methods, and strategies used to set environmental policy; critically examine the embedded assumptions and inherent shortcomings of these approaches; and practice their thoughtful and ethical application to timely environmental challenges. Course Structure: This course combines a lecture-based introduction to critical material with extensive in-class discussion of daily readings from the policy analysis canon. As such, it is designed for PhD and Masters students across the university with an interest in exploring the effective role of science in setting public policy and comfort in reading primary literature. Upper level undergraduates are welcome with instructor consent. Assessment elements will include class participation, responses on 4 to 5 written assignments, and a take-home final. Occasional Friday recitation sessions will provide guidance on the application of policy analysis methods.

CEE 275K. The Practice of Environmental Consulting. 2 Units.

Class consists of eight interactive two-hour seminars with discussions, and will cover the evolution of the environmental consulting business, strategic choices and alternative business models for private and public firms, a review of the key operational issues in managing firm, organizational strategies, knowledge management and innovation, and ethical issues in providing professional services. Case studies will be used to illustrate key concepts. Selected reading materials drawn from the technical and business literature on the consulting business. Student groups will prepare and present an abbreviated business plan for an environmental based business. Enrollment limited to CEE MS and PHD students.

CEE 275P. Persuasive Communication for Environmental Scientists, Practitioners, and Entrepreneurs. 2 Units.

Achieving environmental goals depends not only on innovative ideas and great science but also persuasive communication. What makes communication persuasive? The ability of the communicator to create value for his or her audience. This course will teach students how to: 1) focus on their audience and 2) create value for their audience using research-proven communication techniques. Students will master these techniques through oral and written exercises so that, after taking this course, they will speak and write more persuasively.

CEE 275S. Environmental Entrepreneurship and Innovation. 3 Units.

Our current infrastructure for provision of critical services—clean water, energy, transportation, environmental protection; requires substantial upgrades. As a complement to the scientific and engineering innovations taking place in the environmental field, this course emphasizes the analysis of economic factors and value propositions that align value chain stakeholder interests.

Same as: CEE 175S

CEE 276. Introduction to Human Exposure Analysis. 3 Units.

(Graduate students register for 276.) Scientific and engineering issues involved in quantifying human exposure to toxic chemicals in the environment. Pollutant behavior, inhalation exposure, dermal exposure, and assessment tools. Overview of the complexities, uncertainties, and physical, chemical, and biological issues relevant to risk assessment. Lab projects. Recommended: MATH 51. Apply at first class for admission.

Same as: CEE 178

CEE 276B. 100% Clean, Renewable Energy and Storage for Everything. 3-4 Units.

This course discusses elements of a transition to 100% clean, renewable energy in the electricity, transportation, heating/cooling, and industrial sectors for towns, cities, states, countries, and companies. It examines wind, solar, geothermal, hydroelectric, tidal, and wave characteristics and resources; electricity, heat, cold and hydrogen storage; transmission and distribution; matching power demand with supply on the grid: efficiency; replacing fossil with electric appliances and machines in the buildings and industry; energy, health, and climate costs and savings; land requirements; feedbacks of renewables to the atmosphere; and 100% clean, renewable energy roadmaps to guide transitions.

Same as: CEE 176B

CEE 276C. Energy Storage Integration - Vehicles, Renewables, and the Grid. 3 Units.

This course will provide in-depth introduction to existing energy storage solutions being used on the electric grid and in vehicles with a primary focus on batteries and electrochemical storage. We will discuss the operating characteristics, cost and efficiency of these technologies and how tradeoff decisions can be made. Special attention will be given to system-level integration of new storage technologies, including chargers, inverters, battery management systems and controls, into the existing vehicle and grid infrastructure. Further investigations include issues relating to integration of electric vehicle charging with demand-side management, scheduled renewable energy absorption and local grid balancing. Class format involves regular guest lectures, required lab participation, and field trips to relevant sites. Enrollment is limited; if you are interested in taking the course, please fill out a brief questionnaire at <http://goo.gl/forms/i3YH91Qx05n> Please contact jtaggart@stanford.edu with any questions regarding the application or course information.

Same as: CEE 176C

CEE 276G. Sustainability Design Thinking. 3 Units.

Application design thinking to make sustainability compelling, impactful and realizable. Analysis of contextual, functional and human-centered design thinking techniques to promote sustainable design of products and environments by holistically considering space, form, environment, energy, economics, and health. Includes Studio project work in prototyping, modeling, testing, and realizing sustainable design ideas.

Same as: CEE 176G

CEE 277A. An Introduction to fuzzy set QCA. 2-3 Units.

This course provides an introduction to the theory and practice of fuzzy set qualitative comparative analysis (fsQCA). It is designed for students with an interest in using fsQCA in their research. We will review the development of this analytical approach and identify the types of research question for which fsQCA is more and less appropriate. Through lectures and exercises that use fsQCA software, students will master key concepts underlying the methodology, including set theory, Boolean algebra, fuzzy versus crisp set analysis, principles of coding causal conditions and outcomes, and interpreting consistency and coverage metrics. There are no pre-requisites for the course; however, enrollment is capped, and permission of the instructor is required to enroll. Please visit <http://jennadavis.stanford.edu/courses-taught-jenna-davis> to complete an application.

CEE 277F. Advanced Field Methods in Water, Health and Development. 1-10 Unit.

Field methods for assessing household stored water quality, hand contamination, behaviors, and knowledge related to water, sanitation and health. Limited enrollment. Instructor consent required.

CEE 277L. Smart Cities & Communities. 3 Units.

A city is comprised of people and a complex system of systems connected by data. A nexus of forces ζ IoT, open data, analytics, AI, and systems of engagement ζ present new opportunities to increase the efficiency of urban systems, improve the efficacy of public services, and assure the resiliency of the community. Systems studied include: water, energy, transportation, buildings, food production, and social services. The roles of policy and behavior change as well as the risks of smart cities will be discussed. How cities are applying innovation to address the unprecedented challenges of COVID-19 will also be explored.

Same as: CEE 177L

CEE 277Q. Data Analysis, Presentation, and Interpretation in Environmental Engineering. 3 Units.

This class is designed for students interested in pursuing research-based careers. It covers practical aspects of data analysis, presentation, interpretation relevant to the field of environmental engineering. Learning objectives include identifying and refining research questions, choosing appropriate data analysis methods, and applying principles of effective visual and written presentation of proposed research and research findings. Additional topics to be covered include preparing a constructive review, research ethics, and navigating the publication process.

Same as: CEE 177Q

CEE 277S. Engineering and Sustainable Development. 1-3 Unit.

The second of a two-quarter, project-based course sequence that address cultural, political, organizational, technical and business issues at the heart of implementing sustainable engineering projects in the developing world. Students work in interdisciplinary project teams to tackle real-world design challenges in partnership with social entrepreneurs and/or NGOs. This quarter focuses on implementation, evaluation, and deployment of the designs developed in the winter quarter. Designated a Cardinal Course by the Haas Center for Public Service.

Same as: CEE 177S, ENGR 177B, ENGR 277B

CEE 277X. Engineering and Sustainable Development: Toolkit. 1-3 Unit.

The first of a two-quarter, project-based course sequence that address cultural, sociopolitical, organizational, technical, and ethical issues at the heart of implementing sustainable engineering projects in a developing world. Students work in interdisciplinary project teams to tackle real-world design challenges in partnership with social entrepreneurs, local communities, and/or NGOs. While students must have the skills and aptitude necessary to make meaningful contributions to technical product designs, the course is open to all backgrounds and majors. The first quarter focuses on cultural awareness, ethical implications, user requirements, conceptual design, feasibility analysis, and implementation planning. Admission is by application. Students should plan to enroll in CEE 177S/277S (ENGR 177B/277B) Engineering & Sustainable Development: Implementation following successful completion of this course. Designated a Cardinal Course by the Haas Center for Public Service. To satisfy a Ways requirement, students must register for an undergraduate course number (CEE 177S or ENGR 177A) and this course must be taken for at least 3 units. In AY 2020-21, a letter grade or 'CR' grade satisfies the Ways requirement.

Same as: CEE 177X, ENGR 177A, ENGR 277A

CEE 278A. Air Pollution Fundamentals. 3 Units.

The sources and health effects of gaseous and particulate air pollutants. The influence of meteorology on pollution: temperature profiles, stability classes, inversion layers, turbulence. Atmospheric diffusion equations, downwind dispersion of emissions from point and line sources. Removal of air pollutants via settling, diffusion, coagulation, precipitation, Mechanisms for ozone formation, in the troposphere versus in the stratosphere. Effects of airborne particle size and composition on light scattering/absorption, and on visual range. Prerequisites: MATH 51 or equivalent. Recommended: 101B, CHEM 31A, or equivalents.

CEE 278C. Indoor Air Quality. 2-3 Units.

Factors affecting the levels of air pollutants in the built indoor environment. The influence of ventilation, office equipment, floor coverings, furnishings, cleaning practices, and human activities on air quality including carbon dioxide, VOCs, resuspended dust, and airborne molds and fungi. Limited enrollment, preference to CEE students. Prerequisites: Math 21 and CEE 70, or equivalents.

CEE 278S. Air Pollution Science & Engineering. 3 Units.

Human health and environmental impact of air pollution. Types, sources and production processes of key air pollutants in indoor and outdoor environments. Engineering solutions in air pollution remediation and mitigation. Role of science-informed policy and regulation in air resources protection. Measurement of particulate matter and carbon monoxide. Preparation of a research poster, video short, op-ed, or other media on an air pollution problem.

Same as: CEE 178S

CEE 279F. Frontiers of Anaerobic Treatment. 1 Unit.

This seminar will present the latest findings on the operation and performance of ground-breaking anaerobic treatment processes for domestic wastewater. Specifically, this seminar will examine the performance of the Staged Anaerobic Fluidized-bed Membrane Bioreactor (SAF-MBR) using results from ongoing operations at the Codiga Resource Recover Center and from previous and parallel research efforts. The seminars will incorporate a description of the fundamentals of anaerobic treatment processes, a discussion of how the SAF-MBR process is different from typical anaerobic processes, and insights from operations along with implications for system design. Course work will include explorations of the costs, benefits, and market potential of this technology.

Same as: CEE 179F

CEE 279S. Seminar: Issues in Environmental Science, Technology and Sustainability. 1-2 Unit.

Invited faculty, researchers and professionals share their insights and perspectives on a broad range of environmental and sustainability issues. Students critique seminar presentations and associated readings.

Same as: CEE 179S, EARTHSYS 179S, ESS 179S

CEE 280. Advanced Structural Analysis. 3-4 Units.

Theoretical development and computer implementation of direct stiffness method of structural analysis; virtual work principles; computation of element stiffness matrices and load vectors; direct assembly procedures; equation solution techniques. Analysis of two- and three-dimensional truss and frame structures, thermal loads, and substructuring and condensation techniques for large systems. Practical modeling techniques and programming assignments. Introduction to nonlinear analysis concepts. Prerequisites: elementary structural analysis and matrix algebra.

CEE 281. Mechanics and Finite Elements. 3 Units.

Fluid conduction and solid deformation; conservation laws: balance of mass and balance of momentum; generalized Darcy's law and Hooke's law in 3D; the use of tensors in mechanics; finite element formulation of boundary-value problems; variational equations and Galerkin approximations; basic shape functions, numerical integration, and assembly operations.

CEE 282. Nonlinear Structural Analysis. 3-4 Units.

Introduction to methods of geometric and material nonlinear analysis, emphasizing modeling approaches for framed structures. Large-displacement analysis, concentrated and distributed plasticity models, and nonlinear solution methods. Applications to frame stability and performance-based seismic design. Assignments emphasize computer implementation and applications. Prerequisites: 280 and an advanced course in structural behavior (e.g., 285A, 285B or equivalent).

CEE 283. Structural Dynamics. 3-4 Units.

Vibrations and dynamic response of simple structures under time dependent loads; dynamic analysis of single and multiple degrees of freedom systems; support motion; response spectra.

CEE 284. Finite Element Methods in Structural Dynamics. 3-4 Units.

Computational methods for structural dynamics analysis of discrete and continuous systems in free and forced vibration; finite element formulation; modal analysis; numerical methods; introduction to nonlinear dynamics; advanced topics. Prerequisites: 280, 283.

CEE 285A. Advanced Structural Concrete Behavior and Design. 3-4 Units.

Behavior and design of reinforced and prestressed concrete for building and bridge design. Topics will include flexural behavior, prestressed concrete design, and two-way slab design & analysis, among others.

CEE 285B. Advanced Structural Steel Behavior and Design. 3-4 Units.

Advanced topics in structural steel design. Topics include composite floor systems; bolted and welded connections; beam-column connections; innovative lateral load resisting systems. As part of this course students design a 15-story steel building. Prerequisite: basic course in structural steel design CEE181 or equivalent.

CEE 285C. Strut-and-Tie-Modeling for Structural Concrete. 2 Units.

This course presents the concepts and application of strut-and-tie modeling (STM) for structural concrete elements. Students will identify regions within structures where STM can be used for design, apply the methodology to locate and detail reinforcement, and check the capacity of their model. Applications of the method will be illustrated for deep beams, corbels, post-tensioned anchorage zones, torsion resistance, and bridge components. Various strut-and-tie models will be evaluated based on efficiency, economy, and performance.

CEE 286. Structural Monitoring. 3-4 Units.

Introduction to structural monitoring systems that enable us to understand the states of structures and excitations. Theoretical background on linear time-invariant systems, time-series modeling, frequency analysis, and features extractions in the context of structural systems. Damage diagnosis algorithms and excitation characterization using both physics- and data-based methods for civil structures. Emphasis on the underlying physical interpretations and their practical usage. Prerequisites: CEE 203/CEE 254, CEE 283, CS 106A/X or equivalent.

CEE 287. Earthquake Resistant Design and Construction. 3-4 Units.

Evaluation, design, and construction of structures in seismic regions. Factors influencing earthquake ground motions, design spectra, design of linear and nonlinear single- and multiple-degree-of-freedom-system structures, force-based and displacement-based design methods, capacity design, detailing and construction of steel and reinforced concrete structures, introduction to performance-based design, seismic isolation, and energy dissipation. Prerequisites: 283 and either 285A or 285B.

CEE 288. Introduction to Performance Based Earthquake Engineering. 3-4 Units.

Earthquake phenomena, faulting, ground motion, earthquake hazard formulation, effects of earthquakes on manmade structures, response spectra, Fourier spectra, soil effects on ground motion and structural damage, methods for structural damage evaluation, and formulation of the performance-based earthquake engineering problems. Prerequisite: CEE 203; and co-requisite: CEE 283.

CEE 289. Random Vibrations. 3-4 Units.

Introduction to random processes. Correlation and power spectral density functions. Stochastic dynamic analysis of multi-degree-of-freedom structures subjected to stationary and non-stationary random excitations. Crossing rates, first-excursion probability, and distributions of peaks and extremes. Applications in earthquake, wind, and ocean engineering. Prerequisite: 203 or equivalent.

CEE 290. Structural Performance and Failures. 2 Units.

Basic concepts in the definition of satisfactory structural performance; key elements in structural performance; types of failures, ranging from reduced serviceability to total collapse; failure sources and their root cause allocation, emphasizing design/construction process failures; failure prevention mechanisms; illustration with real life examples.

CEE 291. Solid Mechanics. 3 Units.

Vector and tensor algebra; vector and tensor analysis; kinetics, basic physical quantities, global and local balance laws, representative material models of 1D and 3D continua at small strains; thermodynamics of general internal variable formulations of inelasticity; integration algorithms for inelastic 1D and 3D materials; basic solution techniques for boundary value problems in 1D and 3D.

CEE 292X. Battery Systems for Transportation and Grid Services. 1-3 Unit.

Driven by high-capacity battery systems, electrification is transforming mobility solutions and the grid that powers them. This course provides an introduction to battery systems for transportation and grid services: cell technologies, topology selection, thermal and aging management, safety monitoring, AC and DC charging, and operation control/optimization. Invited experts introduce students to the state of the heart of each topic. The course is aimed at mezzanine and graduate levels students who wish to design battery systems, model them from data, integrate them into applications, or just learn about them. It can be taken for 1 unit (Credit/no Credit) for attending seminars, or for 3 units (letter grade only) for also doing an optional project. Prerequisites: No prerequisites needed for taking the course for 1 unit. Relevant background in selected project area is recommended, for example, CEE 272R for grid applications; EE 253 for AC or DC charging and battery controller design; CEE 322, CS 229 or EE 104 for data-based projects. Same as: EE 292X

CEE 293. Foundations and Earth Structures. 2-3 Units.

Types, characteristics, analysis, and design of shallow and deep foundations; rigid and flexible retaining walls; braced excavations; settlement of footings in sands and clays; slope stability analysis by method of slices including search algorithms for the critical slip surface. Prerequisite: 101C or equivalent.

CEE 296. Regional Seismic Risk Analysis and Risk Management. 3 Units.

This course is aimed at students who are interested in rigorous modeling of earthquake impacts at regional scale and data-driven design of risk management strategies. The first half of the course will focus on building computational tools for simulation of earthquake shaking, damage to buildings and infrastructure, and the resulting social and economic losses. The second half of the course will explore how impact modeling relates to disaster recovery policy, infrastructure investment planning, and other aspects of disaster risk management. The class will include guest speakers from government institutions, private sector, and academia who work at the intersection of risk modeling and planning/policy. The students will also conduct a regional seismic risk analysis tailored to a specific risk management objective, as part of a final project.

CEE 297M. Managing Critical Infrastructure. 2 Units.

Safe and effective performance of infrastructure systems is critical to our economy, quality of life and safety. This course will present topics associated with risk analysis and management of critical civil infrastructure systems, tolerable risk and community resilience. Methods of risk analysis including systems analysis, reliability analysis, expert elicitation and systems analysis for spatially distributed infrastructure systems will be presented. Aspects of seismic and flood risk analysis will also be discussed. Case histories and lessons learned from Hurricane Katrina, Tohoku earthquake, among others will be presented. The evolution of change in the risk management of civil infrastructure systems; how they are analyzed, designed and operated is discussed. Guest speakers. Student presentations. (Prerequisite: CEE 203 or equivalent).

CEE 298. Structural Engineering and Geomechanics Seminar. 1 Unit.

Recommended for all graduate students. Lectures on topics of current interest in professional practice and research.

CEE 298C. Structural Engineering Professional Practice and Research. 1 Unit.

Recommended for all graduate students. Lectures on topics of current interest in professional practice and research. Hybrid; limited enrollment, application required - see cee.stanford.edu/cee-courses-offered-ay-2020-21.

CEE 299. Independent Study in Civil Engineering for CEE-MS Students. 1-5 Unit.

Directed study for CEE-MS students on subjects of mutual interest to students and faculty. Student must obtain faculty sponsor.

CEE 299C. Independent Research in Civil and Environmental Engineering. 1-5 Unit.

Enrollment restricted to CEE students enrolling in classes via SCPD. Directed study of a topic in civil and environmental engineering, under the supervision of a CEE professor. Students enrolling must email Profs. Lepech and Hildemann, cc'ing their research supervisor, to indicate with which CEE faculty member they will be working. Same as: CEE 199C

CEE 299E. Graduate Summer Research in CEE. 1-6 Unit.

Investigation of a research topic in civil and environmental engineering. For students admitted to the Stanford Summer Session program. Written report or oral presentation required. Students must obtain a faculty or research staff sponsor.

CEE 299I. Independent Study in CEE for Grad Students. 1-5 Unit.

CEE 299I - Independent Study in CEE for Graduate Students Directed study of a topic in civil and environmental engineering, under the supervision of a CEE professor. Students wishing to enroll must email Prof Hildemann to request a permission code, cc'ing their independent study supervisor. The email must indicate with which CEE faculty member they will be working, and for how many units. Course is hybrid; some in-person meetings required.

CEE 299J. Independent Projects in Environmental & Sustainability Communications. 1 Unit.

Directed independent projects in the communication of environmental and sustainability topics. Selected assignments may explore research, education, mass media, and social media channels. Students will self-research formats, content, and media requirements. Emphasis on design thinking and creativity. Enrollment by Permission Number only. Prerequisite: Consent of Instructor.

Same as: CEE 199J

CEE 299L. Independent Project in Civil and Environmental Engineering. 1-4 Unit.

Prerequisite: Consent of Instructor.

CEE 300. Thesis. 1-15 Unit.

Research by Engineer candidates.

Same as: Engineer Degree

CEE 301. The Energy Seminar. 1 Unit.

Interdisciplinary exploration of current energy challenges and opportunities, with talks by faculty, visitors, and students. May be repeated for credit.

Same as: ENERGY 301, MS&E 494

CEE 305. Damage and Failure Mechanics of Structural Systems. 3-4 Units.

Examine the mechanics and failure mechanisms of structural deterioration mechanisms and hazards. Overview of fracture mechanics concepts as a general basis for analyzing brittle failure modes in steel and concrete structures. Analysis and design theory for corrosion, fatigue, fire and other damage mechanisms in steel and concrete structures. New methods for mitigation of these failure modes and hazards will be introduced, including new construction materials, structural designs and protection methods.

CEE 306. Computational Fracture Mechanics. 3 Units.

Review of solid mechanics at small strains; energy principles of mechanics; introduction to fracture mechanics; constrained problems; advanced finite element concepts like mixed, assumed, and enhanced strain methods; computational fracture strategies like cohesive finite elements, embedded and extended finite element methods, and phase field approaches to fracture. Prerequisite: CEE 281, CEE 291, or equivalent.

CEE 308. Topics in Disaster Resilience Research. 1 Unit.

This seminar will explore past and current research on disaster risk and resilience, towards the development of new frontiers in resilience engineering science research. Designed for graduate students engaged in the topic of risk and resilience research, the seminar will be organized around weekly readings and discussion groups. May be repeat for credit. Same as: GEOPHYS 308

CEE 310. Computational Solid Mechanics. 3 Units.

Review of tensor algebra and analysis; kinematics of solids at finite deformation; basic mechanical principles; formulation and algorithmic implementation of finite elasticity, finite viscoelasticity, and finite plasticity; discrete variational formulation and non-linear finite element implementation in a C++ environment. Prerequisite: CEE 281, CEE 291, or equivalent.

CEE 314. Computational Poromechanics. 3 Units.

Continuum and finite element formulations of steady-state and transient fluid conduction problems; elliptic, parabolic, and hyperbolic systems; time integration - stability, accuracy, high-frequency numerical damping; coupled solid deformation/fluid flow; thermodynamically consistent effective stress; mixed finite element formulation; inf-sup condition; stabilized mixed finite elements; unsaturated flow in geomechanics. Computing assignments. Prerequisite: CEE 281 or equivalent.

CEE 315. Plasticity Modeling and Computation. 3 Units.

Rate-independent elastoplasticity; classical plasticity models for metals and cohesive-frictional materials; cap plasticity models for porous materials; return-mapping algorithm; shear bands, faults, and other discontinuities; Lagrange multipliers, penalty, and augmented Lagrangian methods for frictional contact; extended finite element and strong discontinuity methods; rate-dependent viscoplasticity; Duvaut-Lions and Perzyna models; creep and stress relaxation. Prerequisite: CEE 281 or equivalent.

CEE 316. Sustainable Built Environment Research. 3 Units.

Intended for early stage Ph.D. students in Sustainable Design and Construction (SDC). Covers dominant methodological approaches at the intersection of engineering, social management science and computer science. Overviews an array of methods available for research, focusing on methods commonly used in SDC. Publications using various methods will be analyzed, and journal review processes will be discussed. Major deliverable is research proposal using one or more of the methods discussed. Students will gain familiarity with the array of methods available for SDC research, know how to apply the methods in their own research area, and receive guidance on publishing their research in scientific journals.

CEE 320. Integrated Facility Engineering. 1 Unit.

Individual and group presentations on goals, research, and state-of-practice of virtual design and construction in support of integrated facility engineering, including objectives for the application and further development of virtual design and construction technologies. May be repeated for credit.

CEE 322. Data Analytics for Urban Systems. 3 Units.

TBA.

CEE 323A. Infrastructure Finance and Governance. 1 Unit.

Presentation and discussion of early stage or more mature research on a variety of topics related to financing, governance and sustainability of civil infrastructure projects by researchers associated with the Global Projects Center and visiting speakers. To obtain one unit of credit, students must attend and participate in all seminars, with up to two excused absences. Seminar meets weekly during Autumn, Winter and Spring Quarters.

CEE 323B. Infrastructure Finance and Governance. 1 Unit.

Presentation and discussion of early stage or more mature research on a variety of topics related to financing, governance and sustainability of civil infrastructure projects by researchers associated with the Global Projects Center and visiting speakers. To obtain one unit of credit, students must attend and participate in all seminars, with up to two excused absences. Seminar meets weekly during Autumn, Winter, and Spring quarters.

CEE 323C. Reinventing Disruptive Innovation for Civil Engineering. 1 Unit.

Reinventing Disruptive Innovation explores how we should approach early stage disruptive technologies for civil engineering. It takes into consideration fundamental market shifts in where technology is being developed and shift in funding. Today, \$300B is invested annually in venture backed technology development versus \$200B in corporate R&D dedicated to new innovation out of a total spend of \$2 Trillion. This fundamental shift has altered the landscape on how innovation is done and how we need to develop new strategies to be effective in integrating appropriate technology for civil engineering. The course will train students in new methods on innovation, and also present real world case examples of new startup technologies crossing every category from advanced material sciences to behavioral technologies.

CEE 324. Industrialized Construction. 1-2 Unit.

The course will present driving forces, comprehensive concepts, technologies, and managerial aspects of Industrialized Construction. Further a series of case studies of successful and failed industry implementations in Sweden, North America and Japan will be presented, showcasing process and technology platforms; use of renewable resources and other sustainable design and construction practices. The contrast between industrialized construction practices in Sweden, the U.S. and other countries is highlighted. Project-orientated vs. product-oriented approaches are essential, along with business models and strategies for industrialized construction companies and their opportunities for innovations. The course includes lectures, case studies, and course group-project assignments with leading companies in the industry. Visiting lecturer Dr Jerker Lessing, one of Sweden's leading experts on industrialized construction with more than 15 years of experience in this field, is giving this course. This is a unique opportunity to learn about this comprehensive, emerging construction concept. Dr Lessing's research at Lund University has pioneered the area of industrialized construction and established models and strategic perspectives that are widely adopted throughout academia and industry. Dr Lessing has published articles and books and he frequently lectures on the topic in Sweden and internationally. He is the Director and General manager of Research and Development at BoKlok, an industrialized house-building company which is a joint venture of the construction company SKANSKA and furniture giant IKEA. The class will be taught as a condensed two week course. Readings and discussions will be organized in the weeks before the lecture component of the class, a group project after. During weeks 1-5, class will not meet regularly and only meet a few times for reading discussions and guest speakers. When they occur, these meetings will be held either Tuesday or Thursday 8-9am in Y2E2 292A. A detailed class schedule will be available before the start of the quarter. Attendance mandatory. No exam. Case and problem discussion. Auditing not allowed. Eligible for SDC Building & Infrastructure Development concentration area requirement. Number of students limited to 20. Prerequisite: CEE 100 or equivalent. Direct questions to jerker.lessing@boklok.se.

CEE 325. CapaCity Design Studio. 5 Units.

Silicon Valley's rapid expansion has created explosive urban development in a fragile and under-prepared natural context. Delicate coastal ecology and rapid urbanization (expanding technology headquarters, new residential housing, parking, services, etc.) are competing for space. The same land also serves the regional functions of transport, open space, recreation, water supply, flood protection and wastewater treatment. Compounding the problems between these competing factors are global climate change instabilities increasing the certainty of catastrophic flooding, infrastructure collapse, and other urban resilience challenges. Students will be immersed in a process that allows them to understand and spatially identify these risks, develop a vocabulary and an understanding of innovative tools to respond to them, and then work with expert practitioners to create unique design responses. Students will be provided with urban design frameworks (for planning, site development, and conservation) combined with advanced sustainable design concepts (such as resource co-optimization, adaptable infrastructure platforms, and high performance urban ecology) by working with expert lecturers and in small groups. Students will ultimately develop a series of visual and technical presentations to propose a final thesis for a local intervention that could be replicated in other coastal contexts globally. This course has been designed to develop student learning through a project-based format. Students will be organized into design teams of 3 or 4 and will have the semester to collaborate with partners on an interdisciplinary proposal including policy and design recommendations.

CEE 326. Autonomous Vehicles Studio. 2-3 Units.

Autonomous vehicles have been a fast-growing area of interest for research, development, and commercialization. This interdisciplinary research-based class explores the design and development of autonomous vehicles. Research teams will study the interaction of the human driver and autonomous driving system, particularly in dangerous situations of autonomous systems failures. Collaborate with national and international experts. Independent and team projects will contribute to ongoing research. May be repeated for credit.

CEE 327. Construction Robotics. 3 Units.

Advances in technologies, such as sensing, positioning, and computing, combined with Building Information Models (BIM) enable the use of robots in unstructured environments like construction. Class sessions contrast the development of construction robots with manufacturing robots, showcase the application of construction robots to at least ten tasks, such as drilling, painting, layout, bricklaying, etc., and introduce the Robotics Evaluation Framework (REF). The small-group class project carried out with industry partners applies the REF to compare the health and safety, quality, schedule, and cost performance of robotic and traditional construction methods.

CEE 328A. Multidisciplinary Design and Simulation of Building Envelopes. 3 Units.

Curtain walls are a manufactured product ubiquitous in the world of architecture and engineering that must meet structural, thermal, acoustic, environmental, and economic performance requirements. This course focuses on design strategies for building envelopes and explores new design approaches including parametric 3D modeling, simulation, and Multidisciplinary Design Optimization (MDO) methods that leverage computation to augment human abilities to identify novel, high performing solutions. Prerequisite: CEE 220A or equivalent. Limited to 16 students.

CEE 329. Artificial Intelligence Applications in the AEC Industry. 2 Units.

Through weekly lectures given by prominent researchers, practicing professionals, and entrepreneurs, this class will examine important industry problems and critically assess corresponding AI directions in both academia and industry. Students will gain an understanding of how AI can be used to provide solutions in the architecture, engineering, and construction industry and assess the technology, feasibility, and corresponding implementation effort. Students are expected to participate actively in the lectures and discussions, submit triweekly reflection writings, and present their own evaluation of existing solutions. Enrollment limited to 12 students.

CEE 329S. Seminar on Artificial Intelligence Applications in the AEC Industry. 1 Unit.

Through weekly lectures given by prominent researchers, practicing professionals, and entrepreneurs, this class will examine important industry problems and critically assess corresponding AI directions in both academia and industry. Students will gain an understanding of how AI can be used to provide solutions in the architecture, engineering, and construction industry and assess the technology, feasibility, and corresponding implementation effort. Students are expected to actively prepare for and participate in all lectures and corresponding discussions.

CEE 330. Racial Equity in Energy. 2-3 Units.

The built environment and the energy systems that meet its requirements is a product of decisions forged in a context of historical inequity produced by cultural, political, and economic forces expressed through decisions at individual and institutional levels. This interdisciplinary course will examine the imprint of systemic racial inequity in the U.S. that has produced a clean energy divide and a heritage of environmental injustice. Drawing on current events, students will also explore contemporary strategies that center equity in the quest for rapid technology transitions in the energy sector to address climate change, public health, national security, and community resilience. Prerequisites: By permission of the instructor. Preferable to have completed Understanding Energy (CEE 107A/207A/EarthSys 103/CEE 107S/207S) or a similar course at another institution if a graduate student.

Same as: CEE 130R

CEE 330B. Quest for an Inclusive Clean Energy Economy. 3 Units.

Building bridges across the clean energy divide involves addressing barriers to participation. These barriers affect the pace of investment, especially for distributed energy solutions such as building energy upgrades, on-site solar, and transportation electrification. This course will explore innovative business models that are responsive to calls for equity and inclusion, and it will give special attention to California's ongoing clean energy finance rulemaking in the utility sector to open the clean energy economy for all.

Same as: CEE 130B

CEE 341. Virtual Design and Construction. 3 Units.

Virtual Design and Construction (VDC) starts by understanding the client's objectives for building performance and the translation of these objectives into measurable project and production objectives. Based on a culture of proactive and constructive engagement, three mutually supportive strategies are essential to achieve these objectives: (1) the knowledge of the many disciplines contributing to the design and construction of a buildable, usable, operable, and sustainable building needs to be orchestrated concurrently, (2) the information supporting the project team must be integrated and be accessible seamlessly, and (3) the workflow carried out by the project team must enable the creation of integrated knowledge and information and lead to decisions that stick. This course will teach all the essential elements of VDC. This is an online course. Prerequisite: 100 or consent of instructor. Recommended: CEE 240, CEE 241.

CEE 345. Network Analysis for Urban Systems. 3 Units.

The objectives of this course are to: 1) introduce you to the mathematical theory of networks and common metrics of networks; 2) develop an understanding of how to utilize network models to study urban systems; 3) provide an opportunity to apply network models to analyze a real urban system. Students are expected to have a strong background in calculus and linear algebra before taking this course and should be comfortable with the calculation and manipulation of matrices. Experience in a numerical scripting language (preferably Python, R or Matlab) is necessary for the final project. Coursework will consist of graded problem sets pertaining to both theory of networks and applications to urban systems. There will be a final project where students will be required to apply network based methods to the analysis of real data of an urban system. (subject to change).

CEE 350. Engineering Writing, Reviewing and Presentations. 3 Units.

This class will cover key skills for future professors including how to write journal articles suitable for Environmental Science & Technology, 2) how to review articles for such journals, and how to deliver an effective presentation. The class is organized to provide criticism between peers on these topics.

CEE 361. Turbulence Modeling for Environmental Fluid Mechanics. 2-4 Units.

An introduction to turbulence and its modeling, including Reynolds-averaged and large-eddy simulation models. Derivation of closure approximations and models. Impact of numerical code truncation error on turbulence model value and accuracy. Discussion of typical models and their applications to turbulent flows in rivers, estuaries, the coastal ocean and the atmospheric boundary layer (e.g., wind turbines and weather models). Prerequisites: knowledge of hydrodynamics or atmosphere dynamics and the basics of transport and mixing in the environment; consent of instructor.

CEE 362. Numerical Modeling of Subsurface Processes. 3-4 Units.

Numerical modeling including: problem formulation, PDEs and weak formulations, and choice of boundary conditions; solution using the finite-element code COMSOL Multiphysics with a variety of solvers and pre- and postprocessing of data; and interpretation of results. Problems include: flow in saturated porous media with complex boundaries and heterogeneities; solute transport with common reaction models; effects of heterogeneity on dispersion, dilution, and mixing of solutes; variable-density flow and seawater intrusion; upscaling or coarsening of scale; and biofilm modeling. Enrollment limited to 5.

CEE 362A. Uncertainty Quantification. 3 Units.

Uncertainty is an unavoidable component of engineering practice and decision making. Representing a lack of knowledge, uncertainty stymies our attempts to draw scientific conclusions, and to confidently design engineering solutions. Failing to account for uncertainty can lead to false discoveries, while inaccurate assessment of uncertainties can lead to overbuilt engineering designs. Overcoming these issues requires identifying, quantifying, and managing uncertainties through a combination of technical skills and an appropriate mindset. This class will introduce modern techniques for quantifying and propagating uncertainty and current challenges. Emphasis will be on applying techniques in genuine applications, through assignments, case studies, and student-defined projects. Prerequisite: Basic probability and statistics at the level of CME 106 or equivalent.

Same as: ME 470

CEE 362G. Imaging with Incomplete Information. 3-4 Units.

Statistical and computational methods for inferring images from incomplete data. Bayesian inference methods are used to combine data and quantify uncertainty in the estimate. Fast linear algebra tools are used to solve problems with many pixels and many observations. Applications from several fields but mainly in earth sciences. Prerequisites: Linear algebra and probability theory.

Same as: CME 262

CEE 363A. Mechanics of Stratified Flows. 3 Units.

The effects of density stratification on flows in the natural environment. Basic properties of linear internal waves in layered and continuous stratification. Flows established by internal waves. Internal hydraulics and gravity currents. Turbulence in stratified fluids. Prerequisites: 262A,B, CME 204.

CEE 363B. Chaos and Turbulence. 3 Units.

An overview of the statistical analysis of unsteady flows, with a focus on chaos and turbulence. Topics will include random variables and statistical analysis; self-similarity, scaling, and symmetries; the turbulent energy cascade and the Kolmogorov similarity hypotheses; intermittency, refined similarity, and multifractal analysis; mixing and transport in chaotic and turbulent flows; and an overview of the effects of additional conservation laws on flow statistics. Prerequisites: CEE 262A or ME 351A, or permission of instructor.

CEE 363C. Ocean and Estuarine Modeling. 3 Units.

Advanced topics in modeling for ocean and estuarine environments, including methods for shallow water, primitive, and nonhydrostatic equations on Cartesian, curvilinear, and unstructured finite-volume grid systems. Topics include accuracy and stability analyses, free-surface methods, nonhydrostatic solvers, turbulence modeling, vertical coordinate systems, and advanced Eulerian and Lagrangian advection techniques. Prerequisites: CEE262A or ME351A, CME 200, 206, or equivalents.

CEE 363D. Topics in Fundamental Turbulence. 2 Units.

A seminar-style class exploring the fundamental nature of turbulence via the primary literature, including both classical and contemporary papers. Students will be expected to present papers and lead discussions over the course of the quarter. Enrollment is limited and requires the consent of the instructor. Prior graduate coursework in fluid mechanics and turbulence is expected.

CEE 363F. Geophysical Fluid Dynamics. 3 Units.

The fundamental dynamics of rotating stratified fluids. Topics include inertia-gravity waves, geostrophic and cyclogeostrophic balance, vorticity and potential vorticity dynamics, quasi-geostrophic motions, planetary and topographic Rossby waves, inertial, symmetric, barotropic, and baroclinic instability, Ekman layers, and the frictional spin-down of geostrophic flows. Prerequisites: CEE 262A or a graduate class in fluid mechanics. Recommended math background: vector calculus, ordinary differential equations, and partial differential equations. Same as: ESS 363F

CEE 363G. Field Techniques in Coastal Oceanography. 3 Units.

This course focuses on the design and implementation of coastal oceanographic field studies from implementation through analysis. A wide range of field instrumentation and techniques, including AUVs and scientific diving is covered. Field studies. Data collection and analysis under instructor guidance.

CEE 363H. Topics in Stratified Turbulence. 2 Units.

An exploration of classical and current papers dealing with the behavior of turbulence in stratified environments. This is a seminar-style class where each student will be expected to make presentations and lead discussions during the course of the quarter. Enrollment is limited and is based on the consent of the instructor. Prerequisites – graduate coursework in turbulence and stratified flows.

CEE 363I. Coral Reefs of the Western Pacific: Interdisciplinary Perspectives, Emerging Crises, and Solutions. 1 Unit.

This new graduate-level course focusses on the complex interplay of biology, physics, chemistry, and human activities that both promotes and limits the development of coral reefs. We will examine the ecology of these biodiverse systems as well as the service they provide in terms of rapid nutrient recycling, coastal protection, and maintenance of large populations of fish. New advances in our understanding of coral reefs will be highlighted, including the role of climate variability and micro- and mesoscale fluid flow in controlling reef growth and persistence, the physiology, genomics, and physics underpinning thermal resilience in corals, contributing and mitigating factors involved in the current decline of coral reefs, ocean acidification, fishing, reef-scale trophic modeling, ecological interactions and trophic cascades, and reefs as part of complex seascapes and linkages with other marine ecosystems. The course will conclude with an analysis of science to policy case studies and future opportunities. The faculty leaders collectively have over 100 years of field experience working in coral reefs of the Pacific and despite our forced online teaching and learning format will endeavor to bring the coral reef field experience to life for this class.

Same as: BIO 355, BIOHOPK 355, ESS 355

CEE 365A. Advanced Topics in Environmental Fluid Mechanics and Hydrology. 2-6 Units.

Students must obtain a faculty sponsor.

CEE 365B. Advanced Topics in Environmental Fluid Mechanics and Hydrology. 2-6 Units.

Students must obtain a faculty sponsor.

CEE 365C. Advanced Topics in Environmental Fluid Mechanics and Hydrology. 2-6 Units.

Students must obtain a faculty sponsor.

CEE 365D. Advanced Topics in Environmental Fluid Mechanics and Hydrology. 2-6 Units.

Students must obtain a faculty sponsor.

CEE 370A. Environmental Research. 5-6 Units.

Introductory research experience for first-year Ph.D. students in the Environmental Engineering and Science program. 15-18 hours/week on research over three quarters. 370A requires written literature survey on a research topic; 370B requires oral presentation on experimental techniques and research progress; 370C requires written or oral presentation of preliminary doctoral research proposal. Students must obtain a faculty sponsor.

CEE 370B. Environmental Research. 5-6 Units.

Introductory research experience for first-year Ph.D. students in the Environmental Engineering and Science program. 15-18 hours/week on research over three quarters. 370A requires written literature survey on a research topic; 370B requires oral presentation on experimental techniques and research progress; 370C requires written or oral presentation of preliminary doctoral research proposal. Students must obtain a faculty sponsor.

CEE 370C. Environmental Research. 5-6 Units.

Introductory research experience for first-year Ph.D. students in the Environmental Engineering and Science program. 15-18 hours/week on research over three quarters. 370A requires written literature survey on a research topic; 370B requires oral presentation on experimental techniques and research progress; 370C requires written or oral presentation of preliminary doctoral research proposal. Students must obtain a faculty sponsor.

CEE 370D. Environmental Research. 3-6 Units.

Introductory research experience for first-year Ph.D. students in the Environmental Engineering and Science program. 15-18 hours/week on research over three quarters. 370A requires written literature survey on a research topic; 370B requires oral presentation on experimental techniques and research progress; 370C requires written or oral presentation of preliminary doctoral research proposal. Students must obtain a faculty sponsor.

CEE 370M. Independent Study in Environmental Chemistry Research. 3 Units.

Environmental chemistry laboratory research. Summer Quarter only. For doctoral students in the Mitch research group. May be repeated for credit.

CEE 371L. Helminthic Disease Monitoring and Control.. 5 Units.

Assessment will be based upon weekly written and/or oral reports, with a final written critical review due at the end of the quarter.

CEE 371M. Transport Phenomena: Momentum, heat and mass transport. 3 Units.

Heat, mass and momentum transfer theory from the viewpoint of basic transport equations. Steady and unsteady state; laminar and turbulent flow; boundary layer theory. Prerequisites: fluid mechanics, ordinary differential equations.

Same as: CEE 271M

CEE 372. Sustainable Energy Interdisciplinary Graduate Seminar. 1 Unit.

Graduate students will present their ongoing research to an audience of faculty and graduate students with a diversity of disciplinary perspectives regarding sustainable energy.

Same as: ENERGY 309, MS&E 495

CEE 374A. Introduction to Physiology of Microbes in Biofilms. 1-6 Unit.

Diversification of biofilm populations, control of gene expression in biofilm environments, and evolution of novel genetic traits in biofilms.

CEE 374B. Introduction to Physiology of Microbes in Biofilms. 1-6 Unit.

Diversification of biofilm populations, control of gene expression in biofilm environments, and evolution of novel genetic traits in biofilms.

CEE 374C. Introduction to Physiology of Microbes in Biofilms. 1-6 Unit.

Diversification of biofilm populations, control of gene expression in biofilm environments, and evolution of novel genetic traits in biofilms.

CEE 374D. Introduction to Physiology of Microbes in Biofilms. 1-6 Unit.

Diversification of biofilm populations, control of gene expression in biofilm environments, and evolution of novel genetic traits in biofilms.

CEE 374M. Advanced Topics in Watershed Systems Modeling. 4 Units.

Basic principles of watershed systems analysis is required for water resources evaluation, watershed-scale water quality issues, and watershed-scale pollutant transport problems. The dynamics of watershed-scale processes and the human impact on natural systems, and for developing remediation strategies are studied, including terrain analysis and surface and subsurface characterization procedures and analysis.

CEE 374S. Advanced Topics in Microbial Pollution. 1-5 Unit.

May be repeated for credit. Prerequisite: consent of instructor.

CEE 374W. Advanced Topics in Water, Health and Development. 1-18 Unit.

Advanced topics in water, health and development. Emphasis on low-and-middle-income countries. Class content varies according to interests of students. Instructor consent required.

CEE 374X. Advanced Topics in Multivariate Statistical Analysis. 1-6 Unit.

Analysis of experimental and non-experimental data using multivariate modeling approaches. May be repeated for credit. Permission of instructor required for enrollment.

CEE 374Z. Urban Water Conflicts. 3 Units.

Students in this course will review and discuss current literature on urban water conflicts using a case-study approach. We will consider the technical, economic, social, policy, and law aspects of the conflicts. Each student will take responsibility for leading 1-2 class sessions (depending on the final number of students enrolled in the course), and will write a description of the case study as well as a short proposal describing novel research on urban water conflicts. Course enrollment is capped. Permission to enroll must be obtained from the instructor through an application process.

CEE 377. Research Proposal Writing in Environmental Engineering and Science. 1-3 Unit.

For first- and second-year post-master's students preparing for thesis defense. Students develop progress reports and agency-style research proposals, and present a proposal in oral form. Prerequisite: consent of thesis adviser.

CEE 378D. Seminar of Statistical Analysis of Multidisciplinary Primary Data. 1-3 Unit.

Practical management and analysis techniques for primary data collected in multidisciplinary projects. Selection of appropriate statistical tests, interpretation of results, and effective communication of findings to lay audiences. Univariate, bivariate and multivariate techniques, including hypothesis testing, nonparametric statistics, regression analysis and matching. Use of SPSS statistical package. Limited enrollment. Prerequisite: consent of instructor.

CEE 379. Introduction to PHD Studies in Civil and Environmental Engineering. 1 Unit.

This seminar course will cover important topics for students considering a PhD in Civil and Environmental Engineering. Sessions will include presentations and discussions on career development, exploring research and adviser options, and the mechanics of PhD studies, including General Qualifying Exam requirements for all CEE PHD Students. In addition, CEE faculty will give presentations on their research. This seminar is required for CEE students considering a PHD or preparing to sit for the General Qualifying Exam in Civil and Environmental Engineering. Students may only receive credit for one of CEE 379 or CEE 379C.

CEE 379C. Introduction to CEE Graduate Studies. 1 Unit.

This course will cover important topics for students starting graduate studies in Civil and Environmental Engineering. Sessions will include presentations and discussions on career development, exploring research and adviser options, and the mechanics of PhD studies, including General Qualifying Exam requirements for all CEE PHD Students. In addition, CEE faculty will give presentations on their research. This seminar is only open to graduate students in CEE; it has required synchronous remote lectures has required in-person discussion sections. Students can only receive credit for one of CEE379 (remote only; open to all) or CEE379C (hybrid; limited enrollment, application required - see cee.stanford.edu/cee-courses-offered-ay-2020-21).

CEE 381. Advanced Engineering Informatics. 1-4 Unit.**CEE 385. Performance-Based Earthquake Engineering. 3-4 Units.**

Synthesis and application of approaches to performance-based design and assessment that recently have been developed or are under development. Emphasis is on quantitative decision making based on life-cycle considerations that incorporate direct losses, downtime losses, and collapse, and the associated uncertainties. Hazard analysis, response simulation, damage and loss estimation, collapse prediction. Case studies. Prerequisites: 282, 287, and 288.

CEE 398. Report on Civil Engineering Training. 1 Unit.

On-the-job training under the guidance of experienced, on-site supervisors; meets the requirements for Curricular Practical Training for students on F-1 visas. Students submit a concise report detailing work activities, problems worked on, and key results. Prerequisite: qualified offer of employment and consent of adviser as per I-Center procedures.

CEE 399. Advanced Engineering Problems. 1-10 Unit.

Individual graduate work under the direction of a faculty member on a subject of mutual interest. For Engineer Degree students and Pre-quals Doctoral students. Student must have faculty sponsor. May be repeated for credit.

CEE 400. Thesis. 1-15 Unit.

For students who have successfully completed the department general qualifying examination. Research and dissertation for the Ph.D. degree. Same as: Ph.D. Degree

CEE 707. Hacking for Urban Resilience: Expecting the Unexpected with a Lean Launchpad Mindset. 3-4 Units.

People, businesses and the built environment constituting major urban centers are fragile by their very nature. Aging infrastructure built on land subject to earthquake, flood and drought risks, neighborhood housing inequality, quality food, water, air, transportation and energy allocated based on ability to pay, jobs restructured by the global economy, and local political forces, cyber risks and data malfeasance creeping into digital lifestyles and urban systems. The cascading risks of failure from urban fragility play out in multiple scenarios, endangering local and regional economic, environmental and social systems. In the heat of urban emergency, rapid problem definition, innovative solution design and prototyping are unleashed and take control of the situational dynamics. Lean startup methodologies that have successfully driven Silicon Valley's pace of innovation can improve governments' ability to respond to the same dynamics. In this class student teams will take actual urban resilience problems working with governmental organizations will apply lean startup principles to discover and validate beneficiary needs and to continually build iterative prototypes to validate the original the problem and build solution pathways. Teams take a hands-on approach, and are mentored by close engagement with actual Chief Resilience Officers, emergency responders, business and utility continuity executives, national and international response agencies, technology companies and nonprofits. Team applications required by [_____]. Limited enrollment.

CEE 801. TGR Project. 0 Units.

Same as: Engineer Degree

CEE 802. TGR Dissertation. 0 Units.

Same as: PhD degree