ENVIRONMENTAL ENGINEERING

Director of undergraduate studies: John Fortner (john.fortner@yale.edu); seas.yale.edu/departments/chemical-and-environmental-engineering

Environmental engineering encompasses the scientific assessment and development of engineering solutions to environmental problems affecting land, water, and air (the biosphere). The field addresses broad environmental issues, including the safety of drinking water, groundwater protection and remediation, wastewater treatment, indoor and outdoor air pollution, climate change, solid and hazardous waste disposal, cleanup of contaminated sites, the prevention of pollution through product and process design, and strategies for sustainable water and energy use and production.

Environmental engineers must balance competing technical, social, and legal issues concerning the use of environmental resources. Because of the complexity of these challenges, environmental engineers need a broad understanding not only of engineering disciplines but also of chemistry, biology, geology, and economics. Accordingly, the program allows students in the major to select an emphasis on environmental engineering technology, sustainability, global health, economics, or energy and climate change. The program prepares students for leadership positions in industry and government agencies or for further studies in engineering, science, business, law, and medicine.

Two degree programs are offered: the B.S. in Environmental Engineering, and the B.A. in Engineering Sciences (Environmental). The B.S. degree program in Environmental Engineering is designed for students who desire a strong background in environmental engineering leading to a career in the field. The B.A. degree program in Engineering Sciences (Environmental) is intended for students whose careers will involve, but not be dominated by, the skills of environmental engineering. The B.A. program is appropriate for those contemplating a career in which scientific and technological problems can play an important role, as is often the case in law, business, medicine, or public service.

Students in the Class of 2024 and 2025 With approval from the director of undergraduate studies (DUS), the following changes to the prerequisites and the major requirements of the B.S. degree program may be fulfilled by students who declared their major under previous requirements.

Students in the Class of 2026 and subsequent classes follow the prerequisite and the major requirements for the B.S. degree program as indicated below.

PREREQUISITES

B.A. degree program in Engineering Sciences (Environmental) The B.A. degree program requires MATH 112 and 115; a two-term lecture sequence in chemistry; and PHYS 170, 171.

B.S. degree program in Environmental Engineering The B.S. degree program has the following prerequisites in mathematics and basic sciences: MATH 112, 115; MATH 120 or ENAS 151; ENAS 194; ENAS 130 or S&DS 230; a two-term lecture sequence in

chemistry, with corresponding labs; PHYS 180, 181; BIOL 101 and 102 or BIOL 103 and 104.

REQUIREMENTS OF THE MAJOR

B.A. degree program The B.A. degree program requires nine term course credits beyond the prerequisites, including the senior requirement. Students take ENVE 120, 360, and either ENVE 373 or 377. Five electives must be chosen in consultation with the director of undergraduate studies (DUS). Elective courses may build toward an optional concentrated area of emphasis, including (a) Climate and Energy, (b) Environmental Science and Technology, (c) Sustainability and Policy, and (d) Self-designed.

B.S. degree program The B.S. degree program requires at least thirteen term course credits beyond the prerequisites, including the senior requirement. Students take CENG 300 or MENG 211; ENVE 120; ENVE 360; ENVE 373; ENVE 314 or 448; EVST 444 or ENVE 438; ENVE 441; and ENAS 642. At least four electives must be chosen in consultation with the DUS; of these, three must be technical electives. Elective courses may build toward an optional concentrated area of emphasis, including (a) Climate and Energy, (b) Environmental Science and Technology, (c) Sustainability and Policy, and (d) Self-designed.

Credit/D/Fail No course taken Credit/D/Fail may count toward the major, including prerequisites.

SENIOR REQUIREMENT

B.A. degree program Students in the B.A. program must pass ENVE 416 or ENVE 490 in their senior year.

B.S. degree program Students in the B.S. program must pass ENVE 416 or ENVE 490 in their senior year.

SUMMARY OF MAJOR REQUIREMENTS

ENGINEERING SCIENCES (ENVIRONMENTAL), B.A.

Prerequisites MATH 112, 115; two-term lecture sequence in chemistry; PHYS 170, 171

Number of courses 9 term courses beyond prereqs (incl senior req)

Specific courses required ENVE 120; ENVE 360; and ENVE 373 or 377

Distribution of courses 5 electives approved by DUS

Senior requirement ENVE 416 or ENVE 490

ENVIRONMENTAL ENGINEERING, B.S.

Prerequisites MATH 112, 115; MATH 120 or ENAS 151; ENAS 194; ENAS 130 or S&DS 230; two-term lecture sequence in chemistry, with labs; PHYS 180, 181; BIOL 101 and 102 or BIOL 103 and 104

Number of courses 13 term courses beyond prereqs (incl senior req)

Specific courses required CENG 300 or MENG 211; ENVE 120; ENVE 360; ENVE 373; ENVE 314 or 448; EVST 444 or ENVE 438; ENVE 441; ENAS 642

Distribution of courses 4 electives approved by DUS, three of which must be technical electives

Senior requirement ENVE 416 or ENVE 490

Environmental engineers are involved with many aspects of society's interaction with the environment. The field embraces broad environmental concerns, including the safety of drinking water, groundwater protection and remediation, wastewater treatment, indoor and outdoor air pollution, solid and hazardous waste disposal, cleanup of contaminated sites, preservation of sensitive wetlands, energy and the environment, and prevention of pollution through product and process design. Environmental engineers must balance technical, social, economic, and legal issues concerning the use of environmental resources. Consequently, they need a broad understanding not only of engineering disciplines but also of chemistry, biology, geology, economics, and management.

Students majoring in Environmental Engineering select an emphasis on environmental engineering technology, sustainability, global health, energy and climate change, or economics. The major prepares students for leadership positions in industry and government agencies. Graduates may also continue with further studies in engineering, science, business, law, and medicine.

Students interested in the major should take the following course during the first year:

- ENVE 120, Introduction to Environmental Engineering

One of the following math courses:

- MATH 112, Calculus of Functions of One Variable I
- MATH 115, Calculus of Functions of One Variable II
- MATH 120, Calculus of Functions of Several Variables

One of the following chemistry sequences:

- CHEM 161, General Chemistry I and CHEM 165, General Chemistry II
- CHEM 163, Advanced University Chemistry I and CHEM 167, Advanced University Chemistry II

Information can be found on the Chemical and Environmental Engineering website. The director of undergraduate studies (DUS) welcomes consultation with students about the program at any time.

FACULTY ASSOCIATED WITH THE PROGRAM IN ENVIRONMENTAL ENGINEERING

Professors Paul Anastas (*Forestry & Environmental Studies*), Michelle Bell (*Forestry & Environmental Studies*), Ruth Blake (*Geology & Geophysics*), Menachem Elimelech (*Chemical & Environmental Engineering*), Edgar Hertwich (*Forestry & Environmental Studies*), Edward Kaplan (*School of Management*), Jaehong Kim (*Chemical & Environmental Engineering*), Jordan Peccia (*Chemical & Environmental Engineering*), Lisa Pfefferle (*Chemical & Environmental Engineering*), Julie Zimmerman (*Chemical & Environmental Engineering*)

Associate Professors John Fortner (*Chemical & Environmental Engineering*), Drew Gentner (*Chemical & Environmental Engineering*)

View Courses

Courses

*** ENVE 120a / CENG 120a / ENAS 120a, Introduction to Environmental Engineering** John Fortner

Introduction to engineering principles related to the environment, with emphasis on causes of problems and technologies for abatement. Topics include air and water pollution, global climate change, hazardous chemical and emerging environmental technologies. Prerequisites: high school calculus and chemistry or CHEM 161, 165 or CHEM 163, 167 (may be taken concurrently) or permission of instructor. QR, SC

ENVE 210a / CENG 210a, Principles of Chemical Engineering and Process Modeling Peijun Guo

Analysis of the transport and reactions of chemical species as applied to problems in chemical, biochemical, and environmental systems. Emphasis on the interpretation of laboratory experiments, mathematical modeling, and dimensional analysis. Lectures include classroom demonstrations. Prerequisite: MATH 120 or permission of instructor. QR, SC RP

ENVE 215b, Environmental Engineering Practice Jaehong Kim

Focus on the technical tools of environmental engineering and science, with emphasis on data acquisition and integration, experimental project design and problem solving, and science and engineering communication. Students emerge competent in the skills needed for environmental exploration and communication and armed with the tools of discovery. Prerequisite: ENVE 120.

ENVE 314a / CENG 314a, Transport Phenomena I Kyle Vanderlick

First of a two-semester sequence. Unified treatment of momentum, energy, and chemical species transport including conservation laws, flux relations, and boundary conditions. Topics include convective and diffusive transport, transport with homogeneous and heterogeneous chemical reactions and/or phase change, and interfacial transport phenomena. Emphasis on problem analysis and mathematical modeling, including problem formulation, scaling arguments, analytical methods, approximation techniques, and numerical solutions. Prerequisite: ENAS 194 or permission of the instructor. QR, SC RP

ENVE 315b / CENG 315b, Transport Phenomena II Amir Haji-Akbari

Unified treatment of momentum, energy, and chemical species transport including conservation laws, flux relations, and boundary conditions. Topics include convective and diffusive transport, transport with homogeneous and heterogeneous chemical reactions and/or phase change, and interfacial transport phenomena. Emphasis on problem analysis and mathematical modeling, including problem formulation, scaling arguments, analytical methods, approximation techniques, and numerical solutions. Prerequisite: ENAS 194 or permission of instructor. QR, SC

*** ENVE 320a / ENRG 320a / MENG 320a, Energy, Engines, and Climate** Alessandro Gomez

The course aims to cover the fundamentals of a field that is central to the future of the world. The field is rapidly evolving and, although an effort will be made to keep abreast

of the latest developments, the course emphasis is on timeless fundamentals, especially from a physics perspective. Topics under consideration include: key concepts of climate change as a result of global warming, which is the primary motivator of a shift in energy supply and technologies to wean humanity off fossil fuels; carbon-free energy sources, with primary focus on solar, wind and associated needs for energy storage and grid upgrade; and, traditional power plants and engines using fossil fuels, that are currently involved in 85% of energy conversion worldwide and will remain dominant for at least a few decades. Elements of thermodynamics are covered throughout the course as needed, including the definition of various forms of energy, work and heat as energy transfer, the principle of conservation of energy, first law and second law, and rudiments of heat engines. We conclude with some considerations on energy policy and with the "big picture" on how to tackle future energy needs. The course is designed for juniors and seniors in science and engineering. Prerequisite: MENG 211 or permission from the instructor. SC

ENVE 360b / ENAS 360b, Green Engineering and Sustainable Design Julie Zimmerman

Study of green engineering, focusing on key approaches to advancing sustainability through engineering design. Topics include current design, manufacturing, and disposal processes; toxicity and benign alternatives; policy implications; pollution prevention and source reduction; separations and disassembly; material and energy efficiencies and flows; systems analysis; biomimicry; and life cycle design, management, and analysis. Prerequisites: CHEM 161, 165 or 163, 167 (or CHEM 112, 113, or 114, 115), or permission of instructor.

ENVE 373a / CENG 373a, Air Pollution Control Drew Gentner

An overview of air quality problems worldwide with a focus on emissions, chemistry, transport, and other processes that govern dynamic behavior in the atmosphere. Quantitative assessment of the determining factors of air pollution (e.g., transportation and other combustion–related sources, chemical transformations), climate change, photochemical “smog,” pollutant measurement techniques, and air quality management strategies. Prerequisite: ENVE 120. QR, SC RP

*** ENVE 377b / CENG 377b, Water-Energy Nexus** Lea Winter

This course explores processes and technologies at the water-energy nexus. We utilize chemical and environmental engineering fundamentals to explore the links between maintaining clean water supply and energy security globally, as well as implications for environmental contamination and climate change. We develop a quantitative understanding of water chemistry and energy considerations for topics including traditional water and wastewater treatment, energy recovery from wastewater, membrane processes, water electrolysis for energy storage and electrochemical contaminant conversion, industrial water consumption and wastewater production, underground water sources and water for oil and gas, opportunities for reuse of nontraditional source waters and contaminant valorization, and considerations for decentralization, resilience, and electrification. Quantitative understanding of these processes will be attained based on mass and energy balances, systems engineering, thermodynamics, and kinetics. Prerequisite: ENVE 120 or permission of instructor. The course is primarily designed for juniors and seniors majoring in environmental engineering, but students in other engineering majors are welcome. Students in non-engineering majors are also welcome but are encouraged to communicate with

the instructor to make sure they have sufficient background knowledge in required mathematics. QR, SC

ENVE 416b / CENG 416b, Chemical Engineering Process Design Yehia Khalil
Study of the techniques for and the design of chemical processes and plants, applying the principles of chemical engineering and economics. Emphasis on flowsheet development and equipment selection, cost estimation and economic analysis, design strategy and optimization, safety and hazards analysis, and environmental and ethical considerations. Enrollment limited to seniors majoring in Chemical Engineering or Environmental Engineering. QR, SC RP

ENVE 438b, Environmental Organic Chemistry John Fortner
This course examines major physical and chemical attributes and processes affecting the behavior of organic compounds in environmental systems, including volatilization, sorption/attachment, diffusion, and reactivity. Emphasis is placed on legacy pollutants (e.g. TCE, PCBs, DDT) and along with emerging contaminants of concern (e.g. pharmaceuticals, explosives, etc). The course reviews basic concepts from physical chemistry and examines the relationships between chemical structure, properties, and environmental behavior of organic compounds. Physical and chemical processes important to the fate, treatment, and transformation of specific organic compounds are addressed including solubility, volatilization, partitioning, sorption/attachment, bioaccumulation, and bulk environmental transformation pathways. Equilibrium and kinetic models based on these principles are used to predict the fate and transport of organic contaminants in the environment. Priority given to seniors or permission of instructor. QR, SC

ENVE 448a, Environmental Transport Processes Menachem Elimelech
Analysis of transport phenomena governing the fate of chemical and biological contaminants in environmental systems. Emphasis on quantifying contaminant transport rates and distributions in natural and engineered environments. Topics include distribution of chemicals between phases; diffusive and convective transport; interfacial mass transfer; contaminant transport in groundwater, lakes, and rivers; analysis of transport phenomena involving particulate and microbial contaminants. Prerequisite: ENVE 120 or permission of instructor. QR, SC

[ENVE 473, Air Quality and Energy]

* **ENVE 490a or b, Senior Project** John Fortner
Individual research and design projects supervised by a faculty member in Environmental Engineering, or in a related field with permission of the director of undergraduate studies.