

# 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.

## 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; a two-term lecture sequence in chemistry, with corresponding labs; PHYS 180, 181; and 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 courses 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).

**B.S. degree program** The B.S. degree program requires at least twelve term courses beyond the prerequisites, including the senior requirement. Students take CENG 300 or MENG 211; ENVE 120, 360, 373, 377; ENVE 315 or 448; EVST 444 or ENVE 438; and MENG 361 or ENAS 646. At least three technical electives must be chosen in consultation with the DUS.

**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.

## REQUIREMENTS OF THE MAJOR

### 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; 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; two-term lecture sequence in chemistry, with labs; PHYS 180, 181; BIOL 101 and 102 or BIOL 103 and 104

**Number of courses** 12 term courses beyond prereqs (incl senior req)

**Specific courses required** CENG 300 or MENG 211; ENVE 120, 360, 373, 377; ENVE 315 or 448; EVST 444 or ENVE 438, and MENG 361 or ENAS 646

**Distribution of courses** 3 technical electives approved by DUS

**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 120b / CENG 120b / ENAS 120b, 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 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** Michael Loewenberg

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; traditional fossil-fuel power plants and engines,

that are currently involved in 85% of energy conversion worldwide and we can't "turn on a dime". 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. Designed for juniors and seniors in science and engineering. Prerequisite: MENG 211 or permission from the instructor. QR, 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 377a / CENG 377a, 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 438a, 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 441a, Biological Processes in Environmental Engineering** Jordan Peccia

Fundamental aspects of microbiology and biochemistry, including stoichiometry, kinetics, and energetics of biochemical reactions, microbial growth, and microbial ecology, as they pertain to biological processes for the transformation of environmental contaminants; principles for analysis and design of aerobic and anaerobic processes, including suspended- and attached-growth systems, for treatment of conventional and hazardous pollutants in municipal and industrial wastewaters and in groundwater. Prerequisites: CHEM 161, 165, or 163, 167 (or CHEM 112, 113, or 114, 115, or 118); MCDB 290 or equivalent; or with permission of instructor. SC

**[ ENVE 448, Environmental Transport Processes ]**

**ENVE 473b, Air Quality and Energy** Drew Gentner

The production and use of energy explored as a source of air pollution worldwide. Assessment of emissions and physical/chemical processes; the effects of emissions from energy sources; the behavior of pollutants in energy systems and in the atmosphere. Topics include traditional and emerging energy technology, climate change, atmospheric aerosols, tropospheric ozone, and transport/modeling/mitigation. Prerequisite: ENVE 373 or equivalent. SC

**\* 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.