

INTRODUCTION

Since the dawn of civilization, humans have transformed the environment to accommodate and satisfy their needs. Advances in agriculture, mining, manufacturing, transportation, and energy production, for example, have dramatically improved standards of living over the centuries. However, this progress has been achieved at a cost to Earth's natural systems and has yet to be more equitably distributed to all. Human impacts on the environment accelerated with the advent of the Industrial Age and the subsequent rapid growth of the human population, creating significant areas of friction between human societies and the environment. At its worst, the human presence is manifest in pollution hanging over cities; sprawling development in place of forests; hazardous chemicals permeating rivers, lakes, and soil; vanishing species; and a changing climate.

The field of environmental engineering emerged to support human and environmental needs while mitigating adverse impacts associated with human activities. Propelled by public sentiment in support of protecting natural resources and human health and by laws aimed at curtailing some of the most egregious forms of environmental damage, the field has achieved remarkable successes over the past several decades. However, the solutions of the past will not be sufficient to address the problems of the future. As humanity faces mounting and diverse challenges, the field of environmental engineering must build on its unique strengths, inspire and implement visionary solutions, and continue to evolve in order to serve the best interests of people and the planet.

What Is Environmental Engineering?

Environmental engineering is best characterized by the vast array of issues that its practitioners address. Broadly, environmental engineers design systems and solutions at the interface between humans and the environment. Historically, this work focused on the provision of water and treatment of wastewater, drawing upon the field's roots in sanitation system design and public health protection. In the 1970s the term environmental engineering replaced the previous term, sanitary engineering, as the field's focus broadened to include the mitigation of pollution in air, water, and soil. Around the same time, the field's approach to design shifted from a focus on engineered treatment systems toward a greater emphasis on ecological principles and processes. More recently, the field has expanded further to address emerging contaminants, chemical exposures from goods and materials, and endeavors such as green manufacturing and sustainable urban design.

To support these activities, many environmental engineers have acquired expertise in a wide variety of domains, including hydrology, microbiology, chemistry, systems design, and civic infrastructure. About half of practicing environmental engineers have graduate degrees; practitioners apply their craft to a wide range of



areas in industry, government, nonprofits, and academia. Trained to take a systems-level approach to problems, environmental engineers often act as a bridge among scientists, other engineers, decision makers, and communities to assess options, weigh trade-offs, and design cost-effective, pragmatic solutions.

The discipline of environmental engineering has no single, widely agreed-upon definition. This report does not focus on defining the field as it is, but rather seeks to outline a vision for the ways in which environmental engineering expertise, skills, and areas of focus can help address future challenges. Fulfilling this vision will require a new model for environmental engineering practice, education, and research—

building on and complementary with the field's traditional core competencies—as outlined in the report's final chapter.

New Pressures in the 21st Century

In this century, human pressure on the environment will accelerate. Life expectancy has increased substantially across the globe over the past several decades as living conditions have improved and is projected to continue to increase.⁵ The United Nations predicts that by 2050 the world's population will reach roughly 9.8 billion people, an increase of approximately 30 percent from today.⁶ As human

BUILDING ON A REMARKABLE LEGACY

Although the term environmental engineering has been in use for only a few decades, the field's roots reach back centuries. Romans built sophisticated sewage disposal and water supply systems, some of which still deliver water to Rome today. In the new world, the Inca and the Maya developed innovative systems to distribute clean water to great cities such as Cusco and Tikal. The beginnings of modern-day environmental engineering are typically traced to the creation of the first municipal drinking water filtration systems, the first continuously pressurized drinking water supply, and the first large-scale municipal sanitary sewer in 19th century London. These and subsequent advancements markedly improved people's quality of life by curbing the spread of disease. In the early 20th century, chlorine-based disinfection for water treatment and advances in wastewater treatment contributed to a drastic decline in urban mortality rates.¹

Environmental engineering continued to evolve throughout the 20th century as a series of environmental

crises sparked the creation of new laws aimed at preventing and mitigating pollution in air, water, and soil. After London's Great Smog of 1952 killed thousands of people, the Parliament of the United Kingdom passed the first major legislation aimed at limiting emissions from households and industries. In the United States, debilitating smog over Los Angeles and other



populations grow, so too will humanity's demand for natural resources and impacts on natural systems. These impacts will play out in different ways in different areas. At least two-thirds of the population in 2050 will live in cities, compounding pressures on urban systems that provide clean water, food, energy, and sanitation. Rapid economic and population growth in lower-income countries threatens to overwhelm basic infrastructure and drive sharp increases in pollution, just as the developed world experienced in the early 20th century. At the same time, countries of all income levels face new types of challenges—many driven by climate change—that existing policies, technologies, and infrastructures are not equipped to handle.

Most environmental engineering expertise is concentrated in developed countries, but some of the most vexing challenges are concentrated in the world's poorer regions. More than 10 percent of humanity continue to live off less than \$1.90 per day and lack access to basic services and economic opportunity.⁷ More than 2 billion people still lack access to basic sanitation services,⁸ more than 1 billion are without electricity,⁹ and more than 3 billion people rely on household energy sources that produce dangerous indoor air pollutants.¹⁰ Unsafe air and water rank among the major contributors to disease and death worldwide.¹¹ Despite economic progress, meeting the basic human needs of the large swath of the world's population who live in extreme poverty will remain a monumental task in the decades ahead.

At the same time, many more people are experiencing an improved standard of living. The proportion of people living in extreme poverty has been reduced by half since 1990.¹² Recent economic growth in China, Brazil, and India has been lifting about 150 million people out of poverty and into the middle class each year.¹³ Although undoubtedly positive for people's well-being and quality of life, this growth also has the potential to create or exacerbate some of the same types

U.S. cities from vehicle emissions led to the passage of the Clean Air Act of 1970. Environmental engineers, working with atmospheric chemists and other scientists, responded by developing models of pollution and its sources, monitoring emissions, helping ensure compliance with regulations, and designing and implementing technologies to improve air quality. Such efforts resulted in a two-thirds drop in U.S. emissions of common air pollutants between 1970 and 2017.²

The same period saw a major movement to reduce water pollution. After the 1969 fire on Ohio's Cuyahoga River called public attention to the widespread practice of dumping industrial and household wastes into rivers and streams, the U.S. Clean Water Act of 1972 banned the discharge of pollutants from pipes and other point sources into navigable waters without a permit. In 1974, Congress passed the Safe Drinking Water Act establishing standards for public water systems. Environmental engineers work to support the enforcement of these laws by developing water treatment technologies along

with new analytical methods and modeling tools to quantify and reduce contamination of rivers and streams.

Another infamous episode focused the public and environmental engineers on contamination of soils and groundwater. More than 21,000 tons of hazardous chemicals dumped into a 70-acre industrial landfill near Love Canal, New York, during the 1950s and 1960s seeped into waterways and soil, affecting the health of hundreds of residents.³ Responding to the disaster, Congress in 1980 passed a law launching the Superfund program, which called on the U.S. Environmental Protection Agency to develop remedial actions and treatment technologies to reduce pollutants at designated sites.⁴ Environmental engineers today play a crucial role in carrying out this charge by providing technical expertise to assess and remediate existing contaminants and by designing new processes and disposal methods to prevent future contamination.

SUSTAINABLE DEVELOPMENT GOALS

A vision for responsibly improving quality of life in the world's poorer regions is embodied in the United Nations' 2030 Agenda for Sustainable Development, which articulates 17 strategic goals designed "to end poverty, protect the planet, and ensure prosperity for all."¹⁴ While environmental quality has the potential to contribute to all of these goals, at least 10 of them relate directly or indirectly to the work of environmental engineers:

Goal 2: Zero Hunger

Goal 3: Good Health and Well-Being

Goal 6: Clean Water and Sanitation

Goal 7: Affordable and Clean Energy

Goal 9: Industry, Innovation, and Infrastructure

Goal 11: Sustainable Cities and Communities

Goal 12: Responsible Consumption and Production

Goal 13: Climate Action

Goal 14: Life Below Water

Goal 15: Life on Land

of environmental problems that wealthier countries have grappled with in the past. Some mistakes of the past may be avoided with the benefit of hindsight, public awareness, and new technology. Nonetheless, it is expected that increased purchasing power and consumption preferences of the world's growing middle class will generally lead to increases in resource and energy use, with negative implications for ecosystems, biodiversity, and human health. The United Nations' Sustainable Development Goals offer a framework to guide economic development while minimizing its potential downsides (see sidebar). The grand challenges for environmental engineers outlined in this report align closely with many of these goals.

In addition to drivers related to population growth, urbanization, poverty, and economic development, climate change adds new complexity to nearly every environmental challenge. Expected increases in extreme weather, including heat waves, drought, hurricanes, wildfires, and floods place enormous strain on water supplies, agriculture, and the built environment. Global warming is already contributing to the reemergence of pathogens and spread of insect-borne diseases to new regions. For the increasing number of people living near a coast, sea-level rise combined with storm surge has become a threat to life and property. These trends pose urgent threats in developing and developed countries alike.

A New Vision for Environmental Engineering

Environmental engineers were instrumental in pulling the United States and other countries out of the depths of environmental crises such as Love Canal and urban smog. Rivers in Ohio no longer catch fire. Cholera and other once-prevalent waterborne diseases are now so rare in the United States that lightning strikes pose a greater threat. These successes, worthy of celebration, reflect the value of the field's approach to creating systems and solutions that are grounded in sound scientific, ecological, and engineering principles while being cost-effective, feasible, and acceptable for the many stakeholders that environmental engineers serve.

But these battles are not over. Pollution and waterborne diseases persist around the globe. Rivers are still catching fire. Billions of people suffer from inadequate access to clean water, food, sanitation, and energy. As the human population continues to grow, demands intensify and humanity's mark on the planet deepens. In short, the challenges ahead are of a different nature and a larger scale than those faced in the past.

Today's environmental engineers also operate in a different policy context than the one that fueled past achievements. The types of sweeping laws that directed public attention and funding toward large-scale infrastructure expansion, basic research, and technology development for environmental remediation in the 1970s-1990s have not emerged to address today's national and global challenges. Legislation may not be the primary drivers of future innovation.

As we face this period of dramatic growth and change, it is time to step back and consider new roles that environmental engineers might play in meeting human and environmental needs. Although efforts to characterize, manage, and remediate existing environmental problems are still essential, environmental engineers must also turn their skills and knowledge toward the design, development, and communication of innovative solutions that avoid or reduce environmental problems. The core competencies of environmental engineering, which emphasize not only specific goals related to human needs and the condition of the environment but holistic consideration of the consequences of our actions, are uniquely valuable in developing the solutions that will be needed in the coming decades.



The report identifies five pressing challenges for the 21st century that environmental engineers are uniquely poised to help advance:

- 1: Sustainably supply food, water, and energy**
- 2: Curb climate change and adapt to its impacts**
- 3: Design a future without pollution and waste**
- 4: Create efficient, healthy, resilient cities**
- 5: Foster informed decisions and actions**



These grand challenges stem from a vision of a future world where humans and ecosystems thrive together. Although this is unquestionably an ambitious vision, it is feasible—and imperative—to achieve significant steps toward these challenges in both the near and long term.

The challenges provide focal points for evolving environmental engineering education, research, and practice toward increased contributions and a greater impact. Implementing this new model will require modifications in the educational curriculum and creative approaches to foster interdisciplinary research on complex social and environmental problems. It will also require broader coalitions of scholars and practitioners from different disciplines and backgrounds, as well as true partnerships with communities and stakeholders. Greater collaboration with economists, policy scholars, and businesses and entrepreneurs is needed to understand and manage issues that cut across sectors. Finally, this work must be carried out with a keen awareness of the needs of people who have historically been excluded from environmental decision making, such as those who are socioeconomically disadvantaged, members of underrepresented groups, or those otherwise marginalized.



