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Environmental Engineering for the 21st Century: Addressing Grand Challenges

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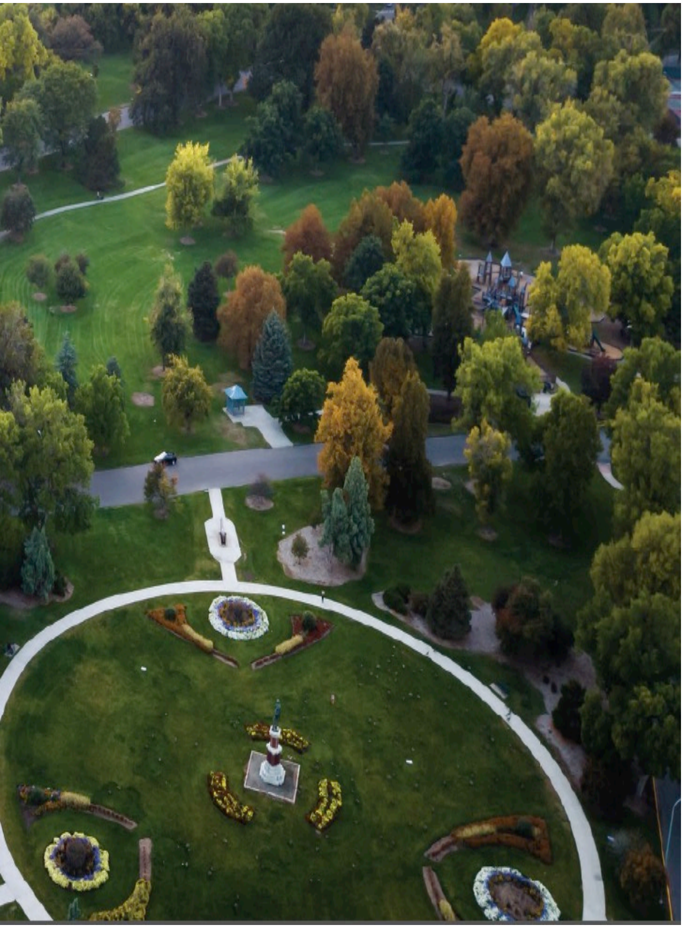
Environmental Engineering's Legacy



- Successes and ongoing work in:
  - Wastewater and sanitation
  - Air pollution controls
  - Industrial pollution controls
  - Cleanup of contaminants
- 20th century work was regulation-driven
- 21st century pressures will be challenge-driven

Motivation: 21st Century Pressures

Study Committee

- **Domenico Grasso**, *Chair*, University of Michigan, Dearborn
- **Craig H. Benson** (NAE), University of Virginia, Charlottesville
- **Amanda Carrico**, University of Colorado, Boulder
- **Kartik Chandran**, Columbia University, New York City
- **G. Wayne Clough** (NAE), Georgia Institute of Technology, Atlanta
- **John C. Crittenden** (NAE), Georgia Institute of Technology, Atlanta
- **Daniel S. Greenbaum**, Health Effects Institute, Boston, MA
- **Steven P. Hamburg**, Environmental Defense Fund, Belmont, MA
- **Thomas C. Harmon**, University of California, Merced
- **James M. Hughes** (NAM), Emory University, Atlanta, GA
- **Kimberly L. Jones**, Howard University, Washington DC
- **Linsey C. Marr**, Virginia Polytechnic Institute and State University, Blacksburg
- **Robert Perciasepe**, Center for Climate and Energy Solutions, Arlington, VA
- **Stephen Polasky** (NAS), University of Minnesota, St. Paul
- **Maxine L. Savitz** (NAE), Honeywell, Inc. (*retired*), Los Angeles, CA
- **Norman R. Scott** (NAE), Cornell University, Ithaca, NY
- **R. Rhodes Trussell** (NAE), Trussell Technologies, Inc., Pasadena, CA
- **Julie B. Zimmerman**, Yale University, New Haven, CT

The Committee's Work

- Identified the most pressing challenges of the 21st century for which the expertise of environmental engineering will be needed to help resolve or manage.
  - Used input from the scientific community, NGOs, public
  - Benefitted from 4 prior Association of Environmental Engineering & Science Professors (AEESP) "grand challenges" workshops.
- Identified ways the field might evolve with regard to research, education, and practice
- Sponsored by: National Science Foundation, U.S. Department of Energy, and Delta Stewardship Council

Five Interconnected Grand Challenges

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

Skills Environmental Engineers Bring

- Broad understanding of Earth systems
- Experience working with aligned sciences
- Application of holistic systems thinking
- Use of life-cycle analysis and similar tools

GRAND CHALLENGE 1:

Sustainably Supply Food, Water, and Energy

Context for this Challenge

- Many still under-served
  - Nearly 800 million undernourished
  - 844 million without safe drinking water
  - 2.3 billion without sanitation
  - 1 in 7 without electricity
- Growing population, more in the middle class
- 2.6 billion more people to feed by 2050; global water use growing

Food, water and energy are linked

Sustainably Feeding a Growing Population

- Increase yields without impacts on water, soil, and climate
  - Utilize sensor technology
  - Innovations in farming and aquaculture
- Reduce food waste (globally 30% wasted)
  - Protective films
  - Consumer education
- Changing diets could feed 30 percent more people

Overcoming Water Scarcity

- Create new water supplies
  - Low-cost, reliable reuse, desalination, groundwater recharge
- Increase water-use efficiency
  - Process and technology improvements (e.g., waterless toilets)
  - Changing behavior
- Redesigning and revitalizing distribution systems

Supplying Sustainable Energy to All

- Switch to low-carbon energy sources
  - Conduct life-cycle assessments of alternatives
  - Develop emerging source (e.g., anaerobic digesters)
- Getting energy to remote areas
  - Sustainable microgrids

GRAND CHALLENGE 2:

Curb Climate Change and Adapt to Its Impacts

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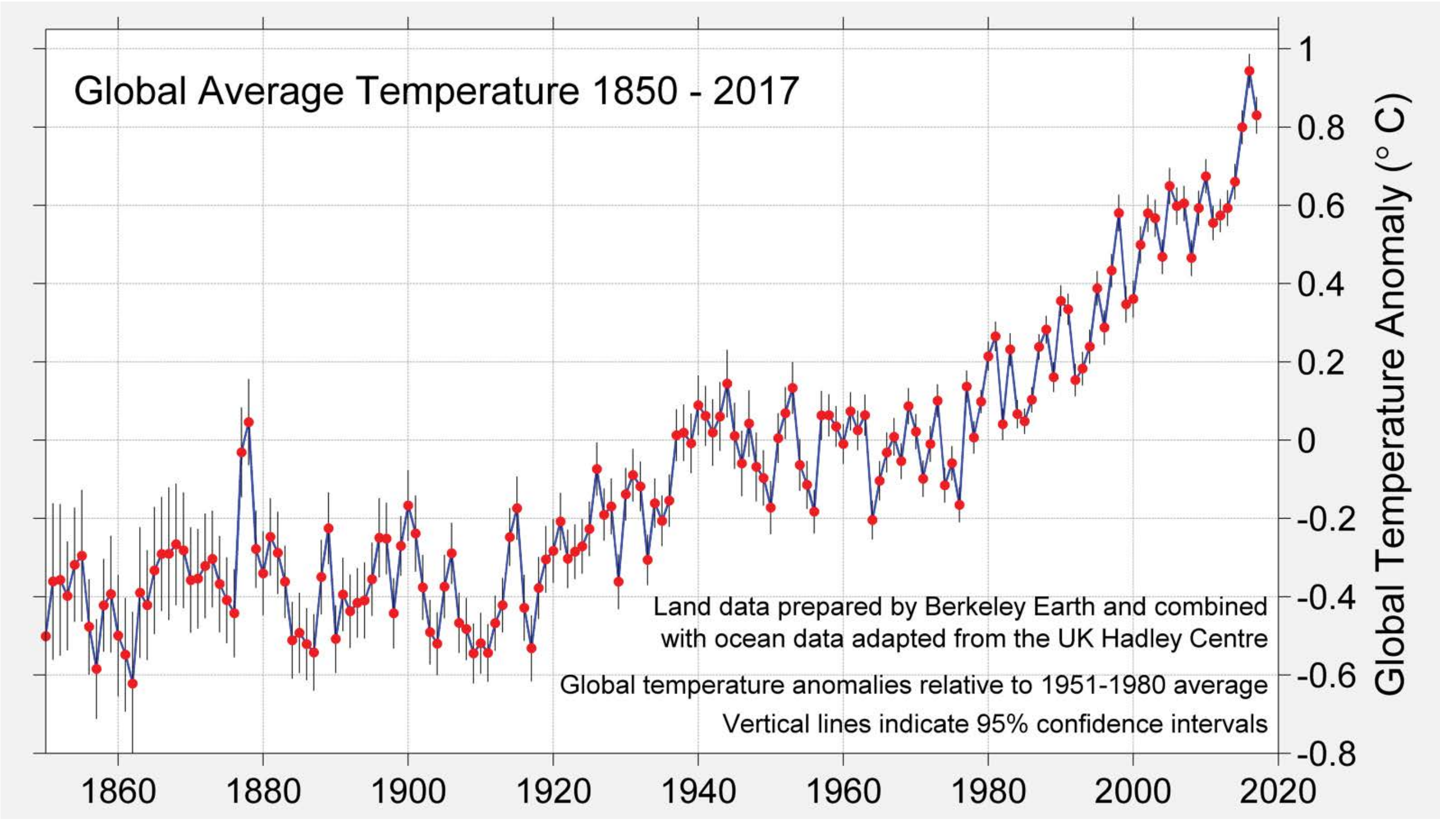
Context for this Challenge



Reducing the Rate and Magnitude of Climate Change

- Sharp reduction in GHG emissions by mid-century needed to avoid worst impacts
- Limiting warming to 1.5 C requires:
  - Dramatic reductions in CO_2
  - Active removal of CO_2
  - Powering transportation, buildings, and industry with electricity generated with low-carbon emissions.

Advances Needed to Curb Climate Change

- Use energy more efficiently
- Switch to low-carbon energy sources
  - Advances to make renewables more cost effective
  - Advanced nuclear to improve safety and performance
- Climate intervention strategies
  - Capture carbon

Adapting to Climate Change

- Infrastructure is optimized for 20th century climate
- Sea level could rise as much as 1.2 feet more by 2050
- Extreme weather—heavier rain in some regions, more droughts in other regions
- Impacts to water management, ecosystems, biodiversity, agriculture, infrastructure, and human health.

Adapting to Climate Change

- Develop strategies and technologies to:
  - Strengthen disaster resilience
  - Increase resilience of critical infrastructure.
  - Adapt to coastal flooding
  - Mitigate and respond to health threats
- Assess adaptation options in terms of potential impacts, benefits, costs, and future risks

GRAND CHALLENGE 3:

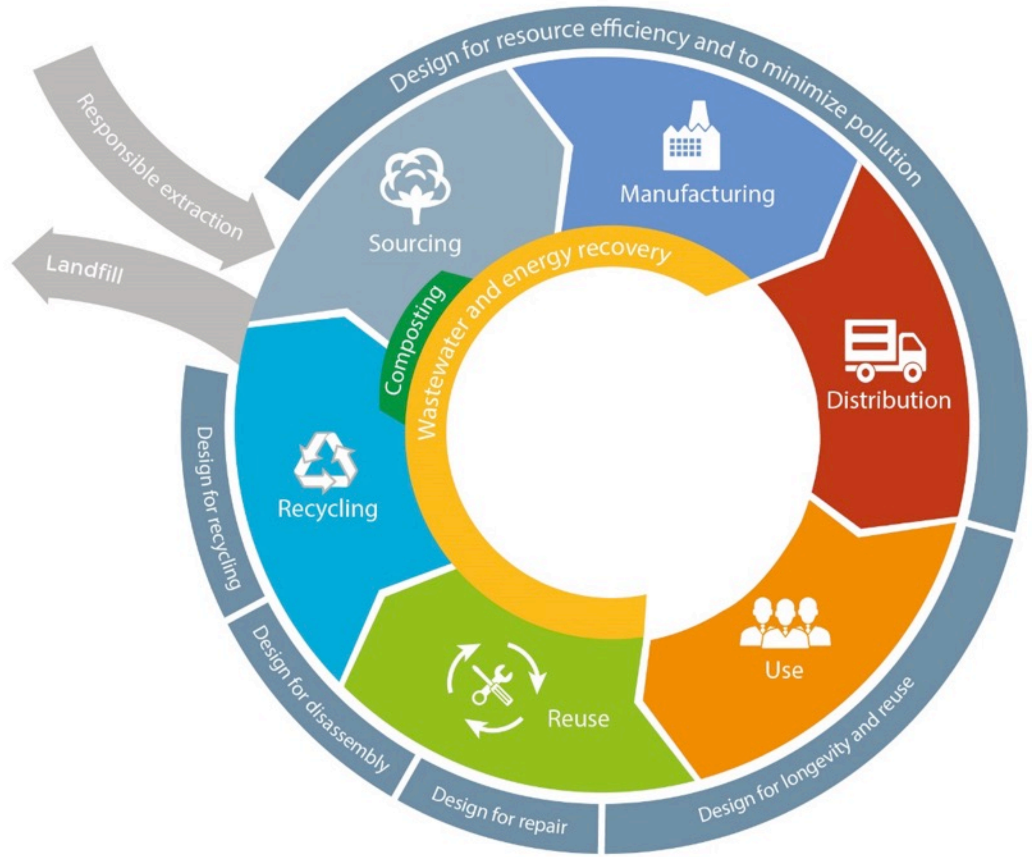
Design a Future Without Pollution or Waste

Context for this Challenge

- Industrial revolution linear model: take-make-waste
  - 94% of materials extracted from the Earth end up as waste versus 6% that end up in a product
- Diseases driven by pollution accounted for 1 in every 6 deaths
- Legacy pollution challenges
  - Persistent, bioaccumulating, toxic

Design to Reduce or Eliminate Pollution and Waste

- Develop a circular economy that eliminates pollution and waste, using:
  - Life-cycle and systems thinking
  - Green chemistry and engineering
- Anticipate consequences
- Avoid unintended consequences



Eliminating the Concept of Waste

- Waste is a human construct
- Designing products, processes and systems that put unutilized materials and energy to valuable use
- Opportunities to recover valuable resources from:
  - Municipal waste / Wastewater
  - Agricultural waste
  - Carbon capture
- Advances needed to:
  - Identify resources in waste streams
  - Assess costs, market, and impacts
  - Design processes to enhance waste recovery

GRAND CHALLENGE 4:

Create Efficient, Healthy, Resilient Cities

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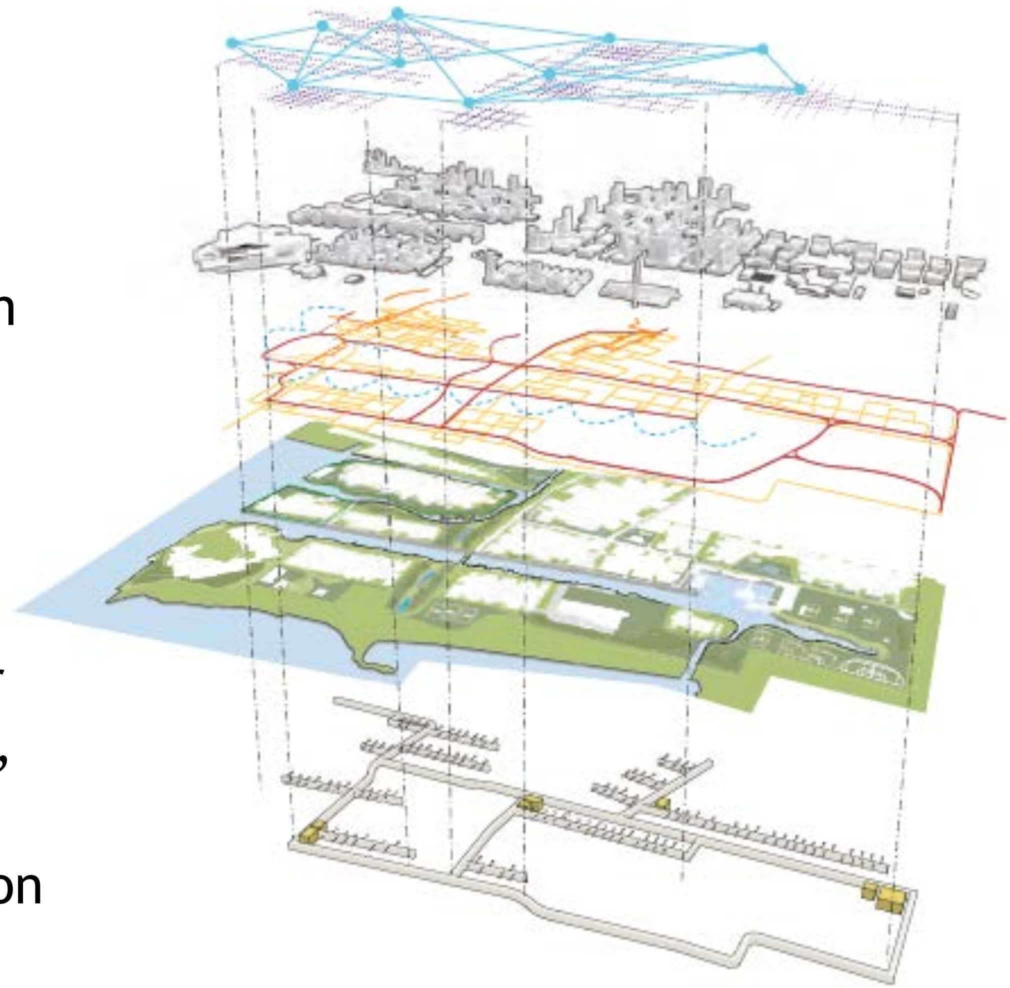
Context for this Challenge

- The future is urban; cities will have 2 billion more people by 2050.
- Number of megacities (>10 million) will go from 31 to 41
- Aging urban infrastructure presents opportunities to;
  - Improve quality of life
  - Address other challenges, such as climate change adaptation, pollution, water supply, waste

Creating Efficient Cities

- Re-envision urban architecture
  - Transform existing infrastructure, urban form
  - Create alternatives for energy and water efficiency, other benefits
- Advance smart cities
  - Embed sensors to monitor traffic, water, energy use, use of trash bins, etc.
  - Use data to inform decision making



Creating Healthy Cities

- Design equitable access to recreation, green space
- Improve indoor and outdoor air quality
- Reduce water pollution
- Prevent, detect, and mitigate the spread of infectious disease
- Ensure reliable provision of clean water and manage waste

Creating Resilient Cities

- Assess vulnerabilities (sea level rise, heat island effects)
- Develop systems that have multiple benefits (flood control/parks)
- Build resilient infrastructure

GRAND CHALLENGE 5:

Foster Informed Decisions and Actions

Context for this Challenge

- Solutions to the grand challenges require widespread adoption.
- Action will only come about if
  - Society is well informed about how the environment affects human well-being
  - Experts and stakeholders act in partnership to identify problems/solutions

Linking Environmental-Societal Impacts

- Identify and quantify the full consequences of actions
  - How do changes in policy and technology shape behavior and affect the environment?
  - How does environmental change affect human prosperity?
  - How to measure these effects?
- Develop and use decision support tools

Engaging with Stakeholders

- Understand community context for challenges and solutions
  - Understand broader economic, social, institutional factors
  - Create open dialogue
- Increase diversity in the engineering community

Informing Policy Solutions

Strategies include:

- Providing information
  - Educate the public
- Changing the decision context (e.g., opt in or opt out)
- Creating incentives
- Setting rules and regulations

THE ULTIMATE CHALLENGE FOR ENVIRONMENTAL ENGINEERING:

Preparing The Field to Address A New Future

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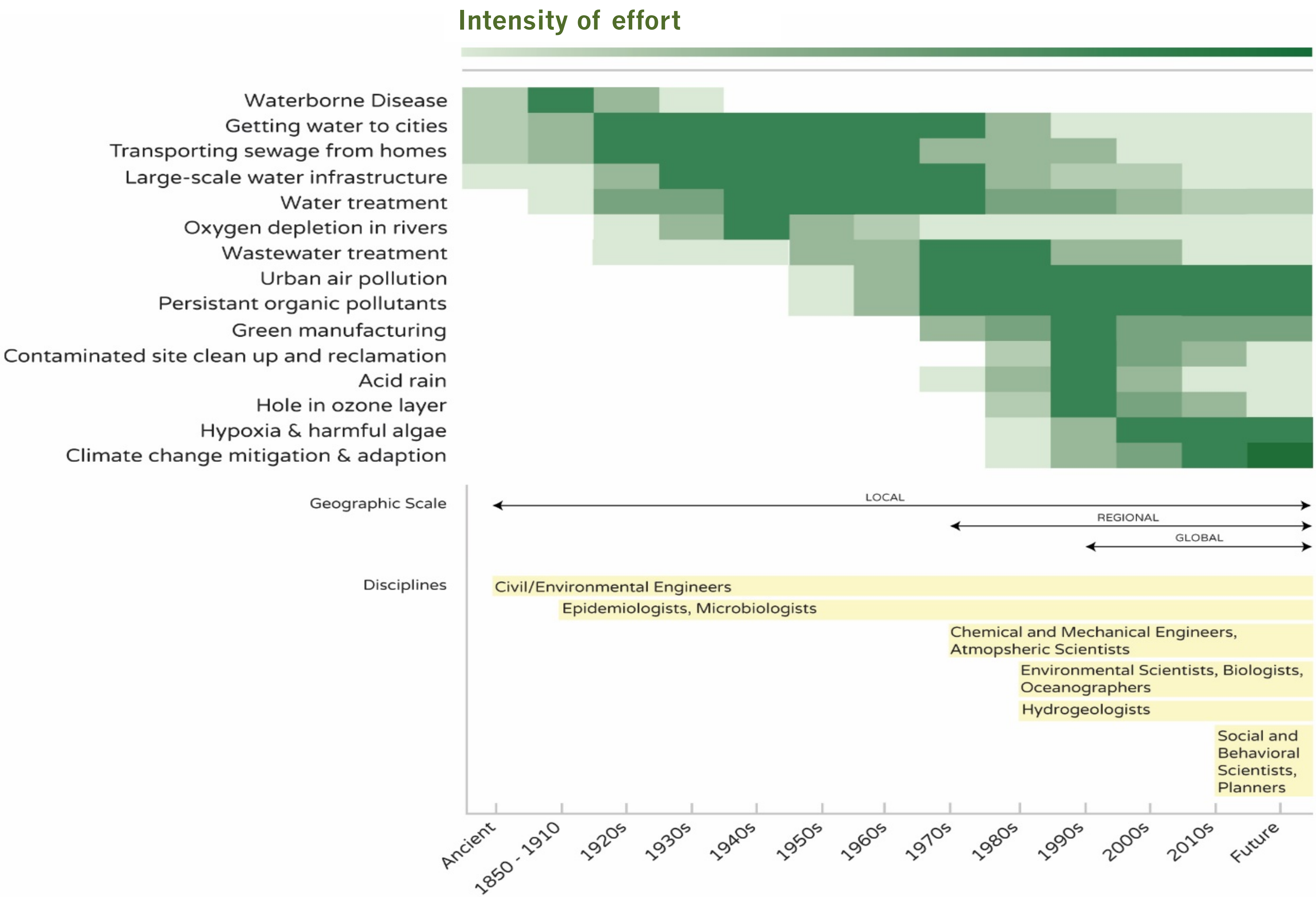
Challenges Broader in Scope and Scale



Evolving Practice

- Cultivate a more diverse workforce, from K-12 through graduate training.
- Enhance stakeholder engagement
- Use tools to help stakeholders understand the consequences of decision alternatives

Evolving Education

- Enhance curriculum
  - Build emphasis on complex systems and social science
  - Keep pace with global challenges
- Build essential skills among graduates
  - Collaboration
  - Critical thinking
  - Real-world problem solving
  - Effective communication

Possible Strategies for Improving Education

- Increase reliance on graduate training to allow more breadth in undergraduate training
- Create practice and service-based models
- Grand Challenges Scholars Program

Evolving Research

- Universities should promote and reward interdisciplinary work
  - Enhance interdisciplinary mentoring
- Research and funding institutions should facilitate effective collaboration
  - Early career awards on interdisciplinary themes
  - Expand interdisciplinary research support
  - Develop Engineering Research Centers around grand challenges

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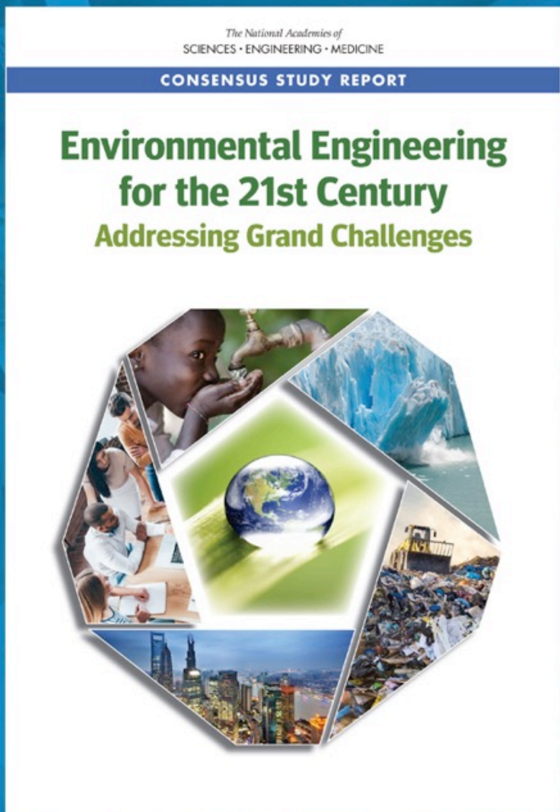

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Download the report at: https://www.nap.edu/catalog/25121

Questions? EEchallenges@nas.edu