Environmental Engineering for the 21st Century: Addressing Grand Challenges
Environmental Engineering’s Legacy

- Successes and ongoing work in:
  - Wastewater and sanitation
  - Air pollution controls
  - Industrial pollution controls
  - Cleanup of contaminants

- 20\textsuperscript{th} century work was regulation-driven

- 21\textsuperscript{st} century pressures will be challenge-driven
Motivation: 21st Century Pressures
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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
Presentation Structure

• GC 1: Kimberly Jones, Howard University
• GC 2: Robert Perciasepe, Center for Climate and Energy Solutions
• GC 3: Julie Zimmerman, Yale University
• GC 4: Dan Greenbaum, Health Effects Institute
• GC 5: Stephen Polasky, University of Minnesota
• Ultimate Challenge: Domenico Grasso, University of Michigan, Dearborn
GRAND CHALLENGE 1:

Sustainably Supply Food, Water, and Energy

Kimberly Jones
Howard University
Committee member
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

Robert Perciasepe
Center for Climate and Energy Solutions
Committee Member
Context for this Challenge

Global Average Temperature 1850 - 2017

Land data prepared by Berkeley Earth and combined with ocean data adapted from the UK Hadley Centre

Global temperature anomalies relative to 1951-1980 average

Vertical lines indicate 95% confidence intervals
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 CO₂
  – Active removal of CO₂
  – 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 20\textsuperscript{th} 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

Julie Zimmerman
Yale University
Committee member
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

Dan Greenbaum
Health Effects Institute Committee member
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

Stephen Polasky
University of Minnesota
Committee member
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

Domenico Grasso
University of Michigan, Dearborn
Committee chair
Challenges Broader in Scope and Scale

Intensity of effort

- Waterborne Disease
- Getting water to cities
- Transporting sewage from homes
- Large-scale water infrastructure
- Water treatment
- Oxygen depletion in rivers
- Wastewater treatment
- Urban air pollution
- Persistent organic pollutants
- Green manufacturing
- Contaminated site clean up and reclamation
- Acid rain
- Hole in ozone layer
- Hypoxia & harmful algae
- Climate change mitigation & adaptation

Geographic Scale

Disciplines

Civil/Environmental Engineers
- Epidemiologists, Microbiologists

Chemical and Mechanical Engineers,
Atmospheric Scientists
- Environmental Scientists, Biologists,
Oceanographers
- Hydrogeologists
- Social and Behavioral Scientists, Planners

Ancient
1850 - 1910
1920s
1930s
1940s
1950s
1960s
1970s
1980s
1990s
2000s
2010s
Future
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
Environmental Engineering for the 21st Century
Addressing Grand Challenges

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

Questions? EEchallenges@nas.edu