Environmental Problems of the 21st Century: The Engineer as Villain and Hero

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Major Environmental Issues

- **Air Pollution**
  - $SO_2$, $NO_x$, PM, etc
  - Air toxics
  - Acid deposition
- **Ozone Depletion**
- **Global Warming**
- **Water Pollution**
  - Drinking water
  - Surface waters
  - Groundwater
- **Solid Wastes**
- **Hazardous Wastes**
- **Radioactive Wastes**
- **Depletion of Natural Resources**
- **Land Use Impacts**
  - Loss of habitat
- **Ecological Impacts**
  - Biodiversity
  - Marine life
A Pop Quiz
Engineers as Villains

Question:

Which of the following environmental problems is a direct result of engineering design?
(a) Industrial air pollution
(b) Automobile waste disposal
(c) Toxic metal water pollution
(d) Radioactive wastes
(e) Urban smog
(f) Global warming
Pop Quiz

(g) All of the above
(h) None of the above
Answer:

(g) All of the above
Are engineers really the bad guys responsible for all these problems?
Sources of Environmental Impacts and Solutions

- Human population and economic activity
- Resource consumption, land use, and emissions (from industry, transportation, buildings, etc.)
- Technology development
- Pollutant transport and transformation in air, water, and soils
- Physical, chemical, and biological changes in the environment
- Valuation of environmental changes (impacts, costs, risks, and damages)
- Economics, culture, values, etc.
- Political process
- Public policy measures (laws, regulations, and standards)
Human population and economic activity

Resource consumption, land use, and emissions (from industry, transportation, buildings, etc.)

Pollutant transport and transformation in air, water, and soils

Physical, chemical, and biological changes in the environment

Valuation of environmental changes (impacts, costs, risks, and damages)

Economics, culture, values, etc.

Technology development

Public policy measures (laws, regulations, and standards)

Political process

Mapping of environmental topics into undergraduate disciplines
Number of Federal U.S. Environmental Laws, 1870-1990

Source: EPRI
Engineers as Heroes

Question:

Which of the following engineers is working to solve environmental problems?
Who is the environmental hero?

Professor A? Professor B? Professor C? Professor D?

(e) All of the above? (f) None of the above?
Answer:

(d) All of the above
INTRODUCTION TO
engineering &
the environment

EDWARD S. RUBIN
with CLIFF J. DAVIDSON
Sources of Environmental Impact that Engineers Can Influence

- *Design* of technology
- *Deployment* of technology
- *Operation/Use* of technology

leading to . . .

- Land use impacts
- Discharges to the environment (gases, liquids, solids)
  - Routine
  - Accidental
  - Direct
  - Indirect
How to Become a Hero

• Apply Principles of:
  – Green Design
  – Pollution Prevention
  – Industrial Ecology
  – Sustainable Development
Reducing Environmental Impacts

- Produce desired goods and services in ways that:
  - Use less material
  - Produce less waste
  - Use less energy

- Use alternative materials, technologies and energy sources that offer environmental benefits
A Life Cycle Framework for Environmental Assessments

Materials Extraction

Materials Processing

Manufacturing

Operation

Waste Management

Recycle

Remanufacture

Reuse
21st Century Challenges

- **Air Pollution**
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  - Loss of habitat
- **Ecological Impacts**
  - Biodiversity
  - Marine life
Growth in Atmospheric Greenhouse Gas Concentrations

- **Carbon dioxide**
  - Concentration (ppmv) range from 260 to 360, increasing over time.
  - Year range from 1750 to 2000.

- **Methane**
  - Concentration (ppbv) range from 600 to 1,800, increasing over time.
  - Year range from 1750 to 2000.

- **Nitrous oxide**
  - Concentration (ppbv) range from 280 to 310, increasing over time.
  - Year range from 1750 to 2000.

- **CFC-11**
  - Concentration (ppbv) range from 0.1 to 0.3, increasing over time.
  - Year range from 1750 to 2000.
Predicted Temperature Changes for a Doubling of Atmospheric CO\textsubscript{2} Concentration

Temperature Increase (\textdegree C)
Framework Convention on Climate Change (1992)

..... achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.
CO$_2$ From Energy Use is the Dominant Greenhouse Gas

- Nitrous Oxide: 5%
- Methane: 9%
- Other CO$_2$: 2%
- HFC/PFC/SF$_6$: 2%

CO$_2$ from Energy: 82%

Emissions weighted by 100-yr Global Warming Potential
U.S. Energy Consumption by Fuel Type

- **Fossil Fuels**: 85%
  - Gas: 24%
  - Coal: 22%
  - Oil: 38%
- Nuclear: 8%
- 4% Hydro
- 0.6% Solar, Wind, Geo
- 3% Biomass
Sources of U.S. CO$_2$ Emissions

- **Transport**: 32%
- **Industry**: 33%
- **Commercial**: 15%
- **Residential**: 20%
- **Electricity**: 36%
- **Other**: 32%

- **Coal**: 36%
- **Oil**: 42%
- **Natural Gas**: 22%
Controlling CO$_2$ Emissions Growth

\[
\frac{\text{CO}_2 \text{ emissions}}{\text{per year}} = \left( \frac{\text{Population}}{\text{per year}} \right) \times \left( \frac{\text{GDP}}{\text{per capita}} \right) \times \left( \frac{\text{Energy use}}{\text{per GDP}} \right) \times \left( \frac{\text{CO}_2 \text{ emissions}}{\text{per unit energy}} \right)
\]

(12.46)

What role can engineers play?
CO₂ Mitigation Options

- Improved Energy Efficiency
  - Demand Side
  - Supply Side

- Decarbonization
  - Lower-C Fuels
  - Nuclear
  - Renewables
    - Solar, Wind, Geothermal

- Sequestration
  - Indirect (biological)
  - Direct (capture)
CO₂ Mitigation Options

Improved Energy Efficiency
  - Demand Side
  - Supply Side

Decarbonization
  - Lower-C Fuels
  - Nuclear
  - Renewables (Solar, Wind, Geothermal)

Sequestration
  - Indirect (biological)
  - Direct (capture)
A Success Story

Appliance Efficiency Standards

much more can be done
Information Technology is the Fastest-Growing Use of Electricity
Energy Sources for U.S. Electricity

• Fossil Fuels
  ▪ Coal 52%
  ▪ Natural Gas 14%
  ▪ Petroleum 3%

• Nuclear
  ▪ Uranium 20%

• Renewables
  ▪ Hydro 8%
  ▪ Other 3%
The Biggest Challenge

Improved Automotive Fuel Economy
CO₂ Mitigation Options

- Improved Energy Efficiency
  - Demand Side
  - Supply Side

- Decarbonization
  - Lower-C Fuels
  - Nuclear
  - Renewables (Solar, Wind, Geothermal)

- Sequestration
  - Indirect (biological)
  - Direct (capture)
The Biggest Challenge

Alternative Fuels for Transportation
U.S. Electricity Generation by Fuel
(DOE/EIA Reference Case)
A Modern U.S. Wind Farm
A Building-Integrated Photovoltaic System
Cost Trends for Renewable Energy Technologies

- **Photovoltaics** (learning rate ~ 20%)
  - 1982
  - USA
  - 1983
  - Japan
- **Windmills (USA)** (learning rate ~ 20%)
  - 1981
  - 1982
  - 1992
- **Gas turbines (USA)** (learning rate ~ 20%, ~10%)
  - 1963
  - 1980

Source: IIASA
CO₂ Mitigation Options

- Improved Energy Efficiency
  - Demand Side
  - Supply Side

- Decarbonization
  - Lower-C Fuels
  - Nuclear
  - Renewables Solar, Wind, Geothermal

- Sequestration
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Why the Interest in Carbon Capture and Sequestration (CCS)

*CCS technology may be a way to:*

- Have your cake and eat it: use fossil fuels without CO$_2$ emissions
- Minimize the overall cost of reducing greenhouse gas emissions
- Provide a bridge to a more sustainable energy future
Schematic of CO₂ Capture and Storage System

1. **Coal or Natural Gas**
   - Energy Conversion Process
   - Useful Products (Electricity, Fuels, Chemicals, Hydrogen)

2. **Air or Oxygen**
   - CO₂ Capture

3. **CO₂ Transport**

4. **CO₂ Storage (Sequestration)**
CO₂ Capture at a Coal-Fired Power Plant
(Shady Point, Oklahoma)

Source: ABB Lummus
Coal Gasification Combined Cycle Plant
CO$_2$ Sequestration Options

- **Geologic Sequestration**
  - Deep saline reservoirs
  - Depleted oil and gas wells
  - Unmineable coal seams

- **Ocean Sequestration**
Geologic Sequestration of CO$_2$
(Sleipner Gasfield, North Sea, Norway)
Geologic Sequestration with Enhanced Oil Recovery (EOR)
Cost of Alternative Options

- Wind, Biomass
- Coal and Gas Plants with CO₂ Capture
- Nuclear, Hydro
- Natural Gas Combined Cycle
- Coal Plants (combustion, gasification)
- IGCC
- PC
Use of Carbon Capture Technologies in Climate Change Mitigation

- **Demand Reduction**
- **Fuel Switching** (mainly shifts away from coal)
- **Scrubbing and Removal** - Synthetic fuels production
- **Scrubbing and Removal** - Power sector (natural gas)
- **Scrubbing and Removal** - Power sector (coal)
Final Exam
(take home)
For Faculty

- Identify ways to incorporate environmental considerations into your courses
- Challenge your students to propose ways of reducing environmental impacts without sacrificing other key needs (functionality, reliability, etc.)
For Students

• Think about how your research and courses could have environmental consequences

• Challenge your professors to discuss and propose ways of reducing environmental impacts without sacrificing other key needs (functionality, reliability, etc.)
Who will be the new environmental hero?
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<td>Ellen J. Bass</td>
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<td>Donald E. Brown</td>
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<td>Professor and Chair</td>
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<td>Stephanie Guerlain</td>
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<td>Barry Horowitz</td>
<td>Thomas E. Hutchinson</td>
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<td>Garrick E. Louis</td>
<td>Christina M. Mastrangelo</td>
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<tr>
<td>William T. Scherer</td>
<td>K Preston White Jr</td>
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<td>Associate Professor</td>
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All of the above
None of the above
Answer:

*All of the above!*