CM4310 Chemical Process
Safety/Environment

Introduction to Green Engineering

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Course web site:
http://www.chem.mtu.edu/~drshonna/teaching/index.html

Presentation Outline

• An Introduction to Green Engineering for Chemical Processes

• Organizational Structure of the Green Engineering Portion of the Course
What is Green Engineering?

Design, commercialization and use of processes and products that are feasible and economical while minimizing:

Risk to human health and the environment

Generation of pollution at the source

Examples of Green Engineering

- Chemical reactions using environmentally-benign solvents
- Improved catalysts
  - that increase selectivity and reduce wastes
  - that improve product quality and reduce environmental impacts
  - that process wastes into valuable products
- Separations using supercritical CO$_2$ rather than R-Cl solvents
- Separative reactors that boost yield and selectivity
- Fuel cells in transportation and electricity generation
- CO$_2$ sequestration
- New designs that integrate mass and energy more efficiently
- Process modifications that reduce emissions
- Environmentally-conscious design methods and software tools.
Motivation for Green Engineering for Chemical Engineering

- Stringent environmental regulations and escalating costs of pollution control.
- Source reduction, eco-efficient production, pollution prevention are solutions.
- Little understanding of environmental issues and risks posed by chemical production.
- No systematic design tools for factoring the environment into design of processes and products.
- Accreditation - ABET / AIChE criteria
- Professional codes of management practice - ACC

Growth of Environmental Laws; USA

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Source Reduction and Pollution Prevention

Pollution Prevention Act, 1990

<table>
<thead>
<tr>
<th>Higher priority</th>
<th>Source Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-Process Recycle</td>
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<tr>
<td></td>
<td>On-Site Recycle</td>
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<tr>
<td></td>
<td>Off-Site Recycle</td>
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<tr>
<td></td>
<td>Waste Treatment</td>
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<tr>
<td></td>
<td>Secure Disposal</td>
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</tbody>
</table>

| Lower priority | Direct Release |

Higher priority

Lower priority
Motivation for a Green Engineering Textbook for Chemical Engineering

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Environmental Issues and Risk

<table>
<thead>
<tr>
<th>Environmental Issues</th>
<th>Risk Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming</td>
<td>Exposure Assessments</td>
</tr>
<tr>
<td>Ozone Depletion in Stratosphere</td>
<td>Hazard Assessment</td>
</tr>
<tr>
<td>Acidification</td>
<td>Toxicity</td>
</tr>
<tr>
<td>Smog Formation</td>
<td>Environmental Fate</td>
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<tr>
<td>Ecology Concepts</td>
<td>Persistence</td>
</tr>
<tr>
<td>Energy Consumption</td>
<td>Dose</td>
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<td>Water Quality</td>
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<tr>
<td>Life-Cycle Concepts</td>
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<tr>
<td>Product Stewardship</td>
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</table>

What is the contribution from the chemical industry?
Motivation for Green Engineering for Chemical Engineering

- No systematic design tools for including the environment into design of processes and products. → hierarchy of environmental assessments methods
- Accreditation - ABET / AIChE criteria
  → societal/global issues, ethical issues, analysis tools
  → environmental aspects of chemical engineering practice
- Professional codes of management practice - ACC
  → pollution prevention, product stewardship

Organizational Structure of the GE Textbook: A Hierarchy of Design Activity

<table>
<thead>
<tr>
<th>Design Stage</th>
<th>P2 Tools</th>
<th>Environmental Evaluation</th>
<th>Book Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reaction pathways, conversions, and yields, raw materials, solvents</td>
<td>• Green Chemistry • atom efficiency</td>
<td>Tier 1 (simplified)</td>
<td>7, 8</td>
</tr>
<tr>
<td>2. Flowsheet synthesis, specific process units defined</td>
<td>Release estimation, optimum choice of • mass separating agents • process units • processing conditions</td>
<td>Tier 2 (intermediate)</td>
<td>8, 9</td>
</tr>
<tr>
<td>3. Detailed design</td>
<td>• Process integration methods • multimedia environmental fate modeling • environmental impact assessment</td>
<td>Tier 3 (more rigorous)</td>
<td>10, 11</td>
</tr>
</tbody>
</table>
Organizational Structure of the GE Textbook: 

Major Book Sections

Part I. A CHEMICAL ENGINEER’S GUIDE TO ENVIRONMENTAL ISSUES AND REGULATIONS

PART II. EVALUATING AND IMPROVING ENVIRONMENTAL PERFORMANCE OF CHEMICAL PROCESSES

PART III. MOVING BEYOND THE PLANT BOUNDARY

Green Engineering Outline and Textbook Chapters

Chapter 1

Chapter 5

Chapter 11

Chapter 13

Sustainable Development for the Chemical Industry
Course Objectives: Green Engineering

Chapter 1: Introduction to Environmental Issues for the Chemical Industry

Chapter 5: Estimating Environmental Properties of Chemicals from Chemical Structure → Environmental Fate

Chapter 11: Environmental Impacts of Chemical Processes

Chapter 13: Life Cycle Assessment: Environmental Considerations Beyond the Plant Boundary

Sustainable Development: 8 Grand Challenges for the Chemical Industry

Chapter 1: What are the most important environmental issues for you?
Chapter 11: Environmental Impacts of Process Flowsheets

Process Simulator Output or Conceptual Design

List of Chemicals, Equipment specifications, Utility consumption, Annual throughput

Chemicals, Equipment specifications, annual throughput

Chemicals, $K_W$, $K_{OW}$

Air Emission Calculator

Chemical Partition Calculator

Relative Risk Index Calculator

Chemicals, e.g. LC50, HV, MIR...

Multi-Criteria Decision Analysis

Report

MS Excel®
Chapter 13: Life Cycle Assessment Example
Hydrogen production.

Centralized Hydrogen Production from Biomass Gasification

www.hydrogen.energy.gov/docs/cs_central_biomass_gasification.doc

Sustainable Development for the Chemical Industry
from the National Academy of Sciences, 2005

Figure E-1: The Grand Challenges (ovals) for Sustainability (large arrows) that address the transition from current thinking to the ideal vision for the chemical industry over the next 100 years. See text for a more detailed description of future and the Grand Challenges.