Green Chemistry and Engineering

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Adapted from presentations by E. Beckman (U. Pitt) and J. Brennecke (U. Notre Dame)
12 Principles of Green Engineering

1. Inherent rather than circumstantial
2. Prevention rather than treatment
3. Design for separation
4. Maximize mass, energy, space, and time efficiency
5. Output-pulled versus input-pushed
6. Conserve complexity
7. Durability rather than immortality
8. Meet need, minimize excess
9. Minimize material diversity
10. Integrate local material and energy flows
11. Design for commercial afterlife
12. Renewable rather than depleting

From Paul Anastas
Inherent Rather than Circumstantial / Prevent Rather than Treat

A Case Study:
Polyacrylamide vs. Poly (N-vinyl) Formamide

Used in papermaking, oil recovery, personal care products, water treatment
Inherent Rather than Circumstantial / Prevent Rather than Treat

A Case Study: Polyacrylamide vs. Poly (N-vinyl) Formamide

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Monomers:

Acrylamide

Highly toxic, causes CNS paralysis

(N-vinyl) formamide

Low toxicity, not a neurotoxin
A Case Study:
Polyacrylamide vs. Poly (N-vinyl) Formamide

Used in papermaking, oil recovery, personal care products, water treatment

Monomers:
- Acrylamide
  - Highly toxic, causes CNS paralysis
  - Green enzymatic synthesis
  - ~ $1/kg
- (N-vinyl) formamide
  - Low toxicity, not a neurotoxin
  - Synthesis uses hydrogen cyanide
  - ~ $4.50/kg
Conserve Complexity / Minimize Excess

- IBM PC’s used to be made with 15 different types of screws (unnecessary complexity)
- Replaced with 1 type of screw
- Easier to disassemble & recycle

Diana Bendz, IBM
Presentation at ND, 2000
Conserve Complexity / Minimize Excess

• IBM PC’s used to be made with 15 different types of screws (unnecessary complexity)
• Replaced with 1 type of screw
• Easier to disassemble & recycle
• Why not reuse computers?
  – Make modular to replace processors, memory

Diana Bendz, IBM
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- Replaced with 1 type of screw
- Easier to disassemble & recycle
- Why not reuse computers?
  - Make modular to replace processors, memory
  - Economic…

Diana Bendz, IBM
Presentation at ND, 2000
Durability Rather Than Immortality

Example: CFC’s

- $C_xH_yF_zCl_q$
- Non-flammable
- Non-toxic
- Inexpensive
- Effective
- Stable
Durability Rather Than Immortality

Example: CFC’s

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- Long-lived, migrate to upper atmosphere
- UV-induced fragmentation in upper atmosphere leads to ozone depletion
Durability Rather Than Immortality / Design For Commercial Afterlife

Example: Packing materials

Polyethylene, packaging Vs. Photodegradable analog

Biodegradable analog

Differences in cost, density, and energy intensity
Design for Separation, the Serendipitous Result.....

Polypropylene Cap (sometimes present…)
Aluminum Ring

Polyethylene Terephthalate Bottle

Paper/adhesive Label

Polyethylene Base Cup
Recycling of PET bottles

- Color sort using spectroscopy; green dye chemically incorporated into PET
- Shred bottles, wash to remove labels
- Separation of PET and HDPE by density using water
- HDPE
- PET for re-use
- Removal of aluminum ring by electrostatic technique
Integrate Material and Energy Flows / Maximize Efficiency

Kalundborg Industrial Park

sulfuric acid plant

refinery

waste treatment

Lake fish farm

fjord greenhouses

power plant

Plaster board plant

sulfur
district heating

gypsum

fly ash
Kalundborg Industrial Symbiosis - 1995

Drawn by D. B. Holmes based on information from various sources, including L.K. Evans, N. Gertler, and Y. Christensen.
My Research Interests

• Ionic liquids
  – Non-volatile alternative solvents
    “Prevent rather than treat”

• Nanoporous materials
  – Selective separations
    • Water purification
    • Heavy metal capture
  – Targeted sensing materials

• “Greenness Factor” – assessment tools
References


• Segars et al., *ES&T*, 2003, 37, 5269.