ICE 10.490
Designing for the Environment

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MIT Energy Initiative

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Topics Outline

- **Environmental Consciousness**
- **Regulatory Issues**
- **Impact of Regulations on Industries**
- **Impact on Engineering**
- **Future Outlook - Problems and Opportunities**

Environmental Consciousness

- **Historic: Environment as Convenient Waste Sink**
- **Industrial Zoning**
- **Environmental Disasters**
  - **DDT - Carson's "Silent Spring"**
  - **Love Canal**
  - **Times Beach, smog, acid rain, etc., etc.**
- **Environmental Protection: air, water, land**
- **Environmental Stewardship: conserve, reuse, recycle**
- **Environmental Sustainability: legacy for future**

Environmental Risk Perspectives

- **Paracelsus (1493-1541): "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy."**

  "Risk" = Likelihood (frequency) x Consequence

  Consequences: Release of contaminant, financial liability, ….
  Exposure pathways (air, water, food, consumer products, etc.)
  Dose to receptor (how much *in toto*)
  Response (how receptor responds to dose)
  Effects (Health? Liability? etc.)

  Engineered response for mitigation

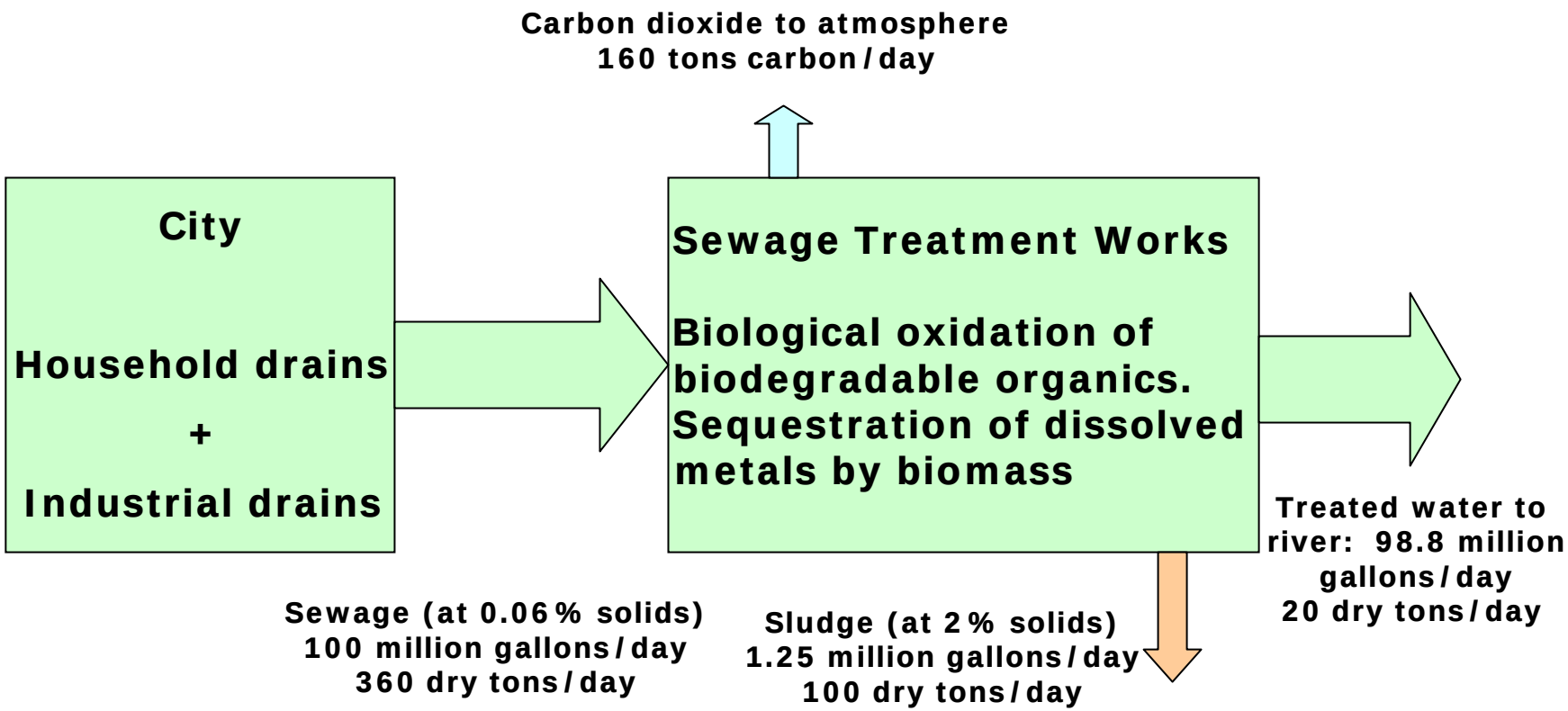
Is This Chemical Safe? (What is it??)

- **Used as industrial solvent and coolant**
- **Causes about 5000 individual deaths per year**
- **Has caused several thousand fatalities at a time in rare catastrophic accidents**
- **Can cause serious burns in the vapor phase**
- **Can cause death through ingestion into the lungs**
- **Is measured in high concentrations in the human body**
- **Remains on produce even after washing**
- **Often is a carrier of toxic materials**

Issues: Public safety? Worker safety? Environmental safety?

The Fate of Contaminants in Sewage Treatment

(Quantities from a population of 1 million)



Regulatory Issues

- **USA: 1940 - 1990 [see http:/www.epa.gov/]**
  - **Clean Water Acts: 1948, 1965, 1970, 1972, 1977, 1987, 2002**
  - **Clean Air Acts: 1955, 1963, 1967, 1970,1977, 1990, 2003? (pending!)**
  - **TSCA (Toxic Substances Control Acts):1972, 1976**
  - **Safe Drinking Water Act: 1974, 1986, 2002**
  - **RCRA (Resource Conservation and Recovery Acts): 1976, 1984**
  - **Superfund Acts (CERCLA): 1980, (SARA) 1986**
- **USA: Health and Worker Safety - OSHA [http://www.osha.gov/comp-links.html]**

Regulatory Issues: Global Examples

- **Germany, The Netherlands: 1985 - present**
  - **Land-filling Ban - Thermal treatment of organic wastes**
  - **Waste from Products: Manufacturer's responsibility**
- **European Union: Harmonization of member laws**
- **United Nations Environmental Programme (1972): International environmental oversight, monitoring, aid, resolution of trans-boundary issues**
- **Law of the Sea: bans ocean dumping**
- **Kyoto Protocol: Reduction in Greenhouse Gas emissions**

Clean Water Acts

(USEPA: 1948, 1965, 1970, 1972, 1977, 1987, 2002)

- **Reduction of emissions to Rivers, Lakes, and Oceans**
  - **Municipal and industrial sewage collection and treatment**
  - **Permits for discharge of water to receiving bodies**
  - **Limit standards for contaminants in aqueous discharges**
  - **Ban on ocean dumping of sludges and garbage**
  - **Great Lakes legacy protection**

Clean Air Acts

(USEPA: 1955, 1963, 1967, , 1970, 1977, 1990, 2003)

- **Smog Reduction**
  - **Prohibition of open burning**
  - **Emissions requirements for hydrocarbons, particulates, CO (auto exhaust and stacks)**
- **Acid Rain Reduction**
  - **Limits on sulfur emissions from power plants**
- **Ozone Layer Protection**
  - **Elimination of CFCs as refrigerants**
- **“Clear skies” (pending)**
  - **relaxes rules for older “grand-fathered” plants making efficiency improvements**

Toxic Substances Control Acts
(USEPA: 1972, 1976)

- **Definition of Highly Toxic Substances**
  - **Pesticides, metals, organic chlorides**
- **Ban on Manufacturing - DDT, PCBs**
- **Standards for Disposal and Treatment**
  - **Criteria for construction of hazardous waste landfills**
  - **Criteria for incineration of hazardous wastes**

Safe Drinking Water Acts
(USEPA: 1974, 1986, 2002)

- **Monitoring and Standards for Contaminants**
  - **Bacteria, Metals, Radon**
- **Treatment Criteria for Contaminant Removal**

Resource Conservation and Recovery Acts (RCRA)

(USEPA: 1976, 1984)

- **Hazardous Waste Definitions - toxic, flammable, corrosive**
- **Permitting and Reporting - waste generation, storage, treatment**
- **Public Participation - hearings as part of the permitting process**
- **National Census - Identification of sources and quantification of wastes**

Superfund Acts - CERCLA

Comprehensive Envir. Response, Compensation, and Liability Acts (USEPA: 1980, SARA - 1986)

- **Identification of Dangerous Buried Waste Sites**
  - **National priority list of 2000+ landfill sites**
  - **Minimization of contamination to underground aquifers**
- **Identification of and Penalties for Probable Responsible Parties (PRPs)**
- **Joint and Several Responsibility**
- **Oversight of Cleanup Activities**

Continual Improvement?

- **Present US policies have rolled back some of the earlier more stringent legislation**
- **Government agencies are not pursuing enforcement as actively as in the past – Superfund not renewed**
- **Legal actions have diminished and revenues from various fines and fees have substantially decreased (Criminal referrals for toxic substance violations down 80%; exemptions for Superfund polluters)**

Climate Change Initiatives

- **Framework Convention on Climate Change (ratified) commits to principle of *"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."***
- **US is choosing a voluntary reduction program rather than committing to limits of the Kyoto Protocol**

Impact of Regulations on Industries

- **Enforces minimum standards of compliance that are consistent (hopefully) across the industry – thus reducing any penalties on relative cost competitiveness**
- **Creates problems for large companies whose operations extend across regions with non-uniform regulations**
- **Inefficient when regulations are deficient and require subsequent change (e.g., MTBE, CFCs)**

Comparison of Contaminant Limits for Land Application of Sludges

Concentrations in ppm, dry basis

Element	USA	Germany	The Netherlands	
	1992	1992	1993	1995
Arsenic	41			25
Lead	300	900	500	225
Cadmium	39	10	10	1.25
Chromium	1,200	900	500	75
Copper	1,500	800	60	75
Nickel	420	200	100	38
Mercury	17	8	10	0.75
Zinc	2,800	2,500	2,000	300

Alternative Waste Practices in the Pharmaceutical Industry

Waste Types	Weight fraction	Conservative approach		Moderate approach		Least costly approach	
		Disposal method	$/ton ~1995	Disposal method	$/ton ~1995	Disposal method	$/ton ~1995
Waste-water sludge	0.30	Off-site hazardous incineration	2500	Hazardous landfill	1000	Sanitary landfill	145
Chlorin-ated still bottoms	0.06	Off-site hazardous incineration	1200	Off-site hazardous incineration	1200	Off-site hazardous incineration	1200
Non- Chl. still bottoms	0.36	Off-site hazardous incineration	1200	Off-site hazardous incineration	1200	On-site incineration	80
Pharma. waste streams	0.30	Off-site hazardous incineration	1200	Hazardous landfill	200	Special landfill	135
Total costs ($/ton)			1600		840		162

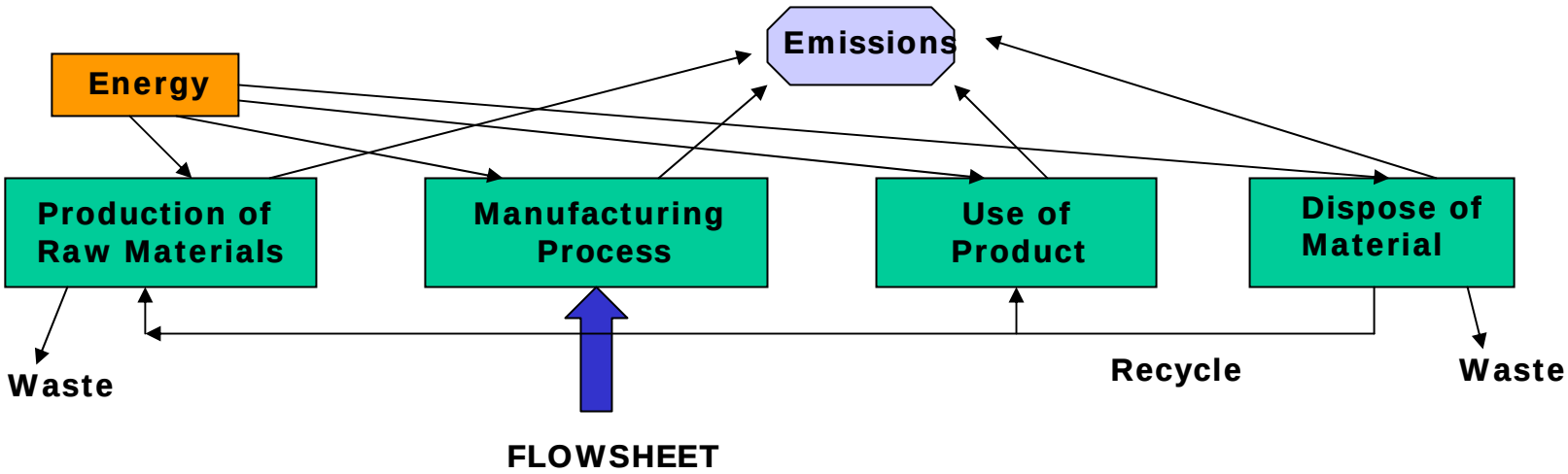
Impact of Regulations on Industries

- **Migration of Dirty Manufacturing to Developing Nations**
  - **Smelting - SO_2 generation**
  - **Vinyl chloride - VOCl vapor emissions**
- **Few new grass root plants in US**
  - **Refineries, Chemicals, Petrochems, Pulp & Paper**
- **Criteria for Manufacturing Plant Expansion?**
  - **Zero Sum Impact on Environment? Or Max $$?**

Impact of Regulations on Engineering

- **Increasing Cost of Meeting Environmental Regulations**
- **Requirements for Formal Environmental Impact Assessment**
- **Incentive to Integrate Environmental Goals into Design**
  - **HazOp Analysis including environmental impacts**
  - **Waste minimization goals**
  - **Life cycle design (anticipating future changes)**

Life Cycle Analysis



Attributes: Costs, Resource use, Emissions, Wastes, Costs, Performance, etc.

Sum cumulative attributes over total life cycle of product to compare net impacts

MacDonald's Styrofoam or paper?

Trees (natural)

↓

Paper (good ?)

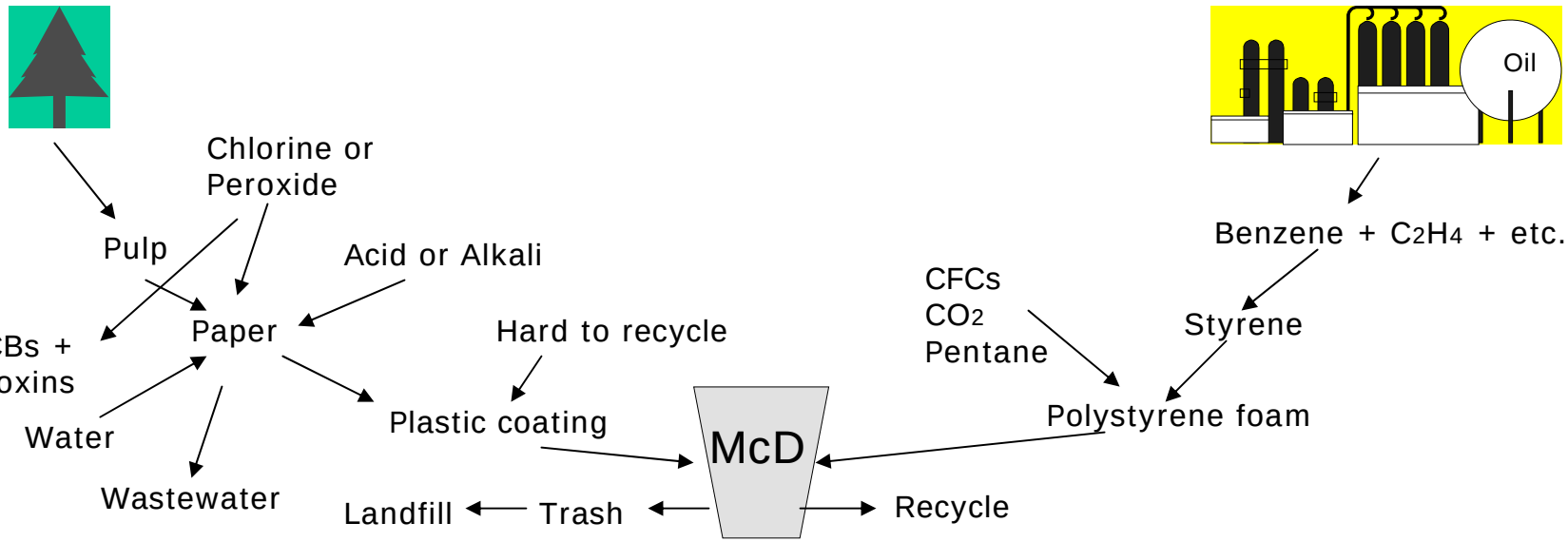
Oil (bad)

↓

Chemicals (worse)

↓

Styrofoam (??)



Is Regulation the Only Approach?

- **Command and Control Regulations address individual impacts one medium and one chemical at a time**
- **Might be better to abate problems on a total risk-based assessment**
- **BUT, health and environmental risk impacts are often very uncertain and vary with specific circumstances….**

Risk-based Environmental Stewardship

- **EPA Risk Management Program (under CAA) - 1996**
  - **covers about 64,000 facilities**
    - **tracks hazardous chemical inventories**
    - **used for database (15 year archive), prevention planning, enforcement, emergency response planning**
  - **5 year plans were due June 1999**
    - **5 year accident history**
    - **hazmat inventories now and projected for 5 years**
    - **“worst case hazard scenario analysis**
    - **risk-based, life cycle prevention programs**
    - **emergency response plans**

Risk-based Environmental Stewardship

- **International Organization for Standardization - ISO 14,000 series (Environmental Management Systems)**
  - **Developed by committees of experts and published in 1996 (Geneva, Switzerland)**
  - **Voluntary adoption by industrial organizations who can then be "ISO 14,000 certified"**
    - **Top management makes formal commitment**
    - **Internally-performed environmental risk audit**
    - **Development of environmental management plan based on ranked risks to health and the environment**
    - **Third party certification (EMAS - Eco Mgmt. & Audit Scheme)**
    - **Implementation**
    - **Commitment to continuous improvement**
    - **Periodic review**

How to reduce the risk?

- **Where specific waste problems are identified:**
  - **Eliminate the source of the problem (substitution, redesign, etc.)**
  - **Reduce the generation rate and/or inventories**
  - **Recycle the materials (solvents, catalysts, etc.)**
  - **Treatment of waste stream (immobilization, neutralization, separations, etc.**
  - **Improved disposal technology**
- **Do these provide risk reduction?**
  - **Separations may contaminate another waste stream**
  - **Dilution may not be the answer**
  - **Ultimate fate? Biodegradable, cumulative?**

Future Outlook: Problems and Opportunities

- **Remediation of contaminated disposal sites**
  - **New technologies for cleaning soils and leachates**
- **Limited disposal or land-filling -**
  - **reuse organics wherever possible**
  - **destroy organic and biological residuals**
  - **recover and recycle all metals and other materials**
- **Cleaner chemistries**
  - **lower/adjust reaction temperatures to minimize by-product formation**
  - **more use of catalysis to increase selectivities and yields**

Future Outlook: Problems and Opportunities

- **Reduction in water usage**
  - **New washing methodologies for clothes and dishes**
  - **Multiple, hierarchical uses of water before disposal**
- **Better separations technologies**
  - **Improvements in contaminant removal from water**
  - **Innovative technologies and processes to improve efficiency and reduce energy consumption**
- **Co-location of synergistic processes**
  - **Co-generation**
  - **Heat and work integration**
  - **Integration of wastes and feedstocks**

Future Outlook: Globalization – Good or Bad?

- **Multinational corporations locate production facilities where resources and labor costs (and environmental compliance costs) are cheapest**
- **Poorer countries welcome income and jobs provided by such activities and rapidly learn to build their own capabilities – as their wealth increases, they then start to address any serious environmental problems**
- **Cheap fossil fuel makes global transportation affordable – this might change in the future**
- **Heavy chemical industry disappearing from US**

Future Outlook: Long Term Challenges

- **Future Uncertainties (Limits to Growth?)**
  - **Availability and costs of critical resources (energy, water, land, minerals, etc.)**
  - **Transition from the present business paradigm that is based on largely unfettered growth in global population and development (and probably undervalued resources) to a more sustainable society with smaller gaps between the richest and poorest and a preservation of resources for future generations – implying some difficult societal changes and different "sustainable" economic rules!**

Some Reading

- **Douglas, J.M., "Conceptual Design of Chemical Processes," p 417-421, McGraw-Hill, New York, 1988.**

- **Masters, Gilbert, "*Introduction to Environmental Engineering and Science*," 2nd Edition, Prentice-Hall, 1997.**

- **Meadows, D., D. Meadows, and J. Randers, 1992. *Beyond the Limits.* Chelsea Green Publ. Co., Post Mills, VT.**

- **Web sites:**
  - **www.epa.gov - www.worldbank.org**
  - **www.unep.org - www.ncseonline.org**
  - **www.iso14000.com - www.osha.gov**