“Green Chemistry”

Significance

- In 1970's , it was recognized that we need to prevent harm to the environment caused by industrial activities
  - Control ⇔ Laws
  - Contaminants are typically produced during various industrial processes and THEN treated before releasing them to the environment
  - Excellent idea if there is good control and handling of environmental laws
    - It is continuous, slow and expensive

What is Green Chemistry?

… or sustainable/environmentally benign chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances

www.epa.gov/greenchemistry

What is Green Chemistry?

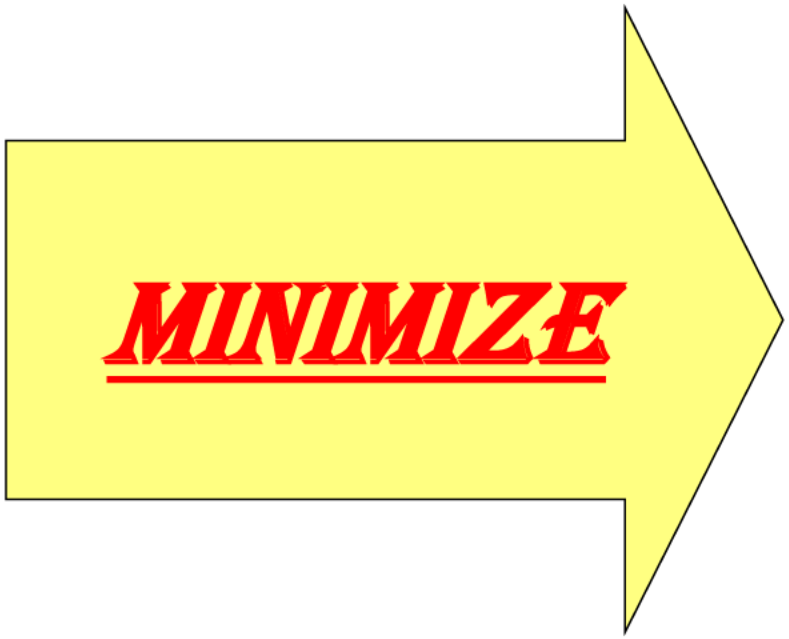
… principles to reduce or eliminate use or production of dangerous chemicals in the design, manufacture and application of chemical products.

Green Chemistry Theory & Practice, P T Anastas & J C Warner, Oxford University Press 1998

Green Chemistry Goals

- Reduction or elimination of
  - Waste
  - Toxic chemicals or processes
  - Energy use

Green chemistry is looking to:

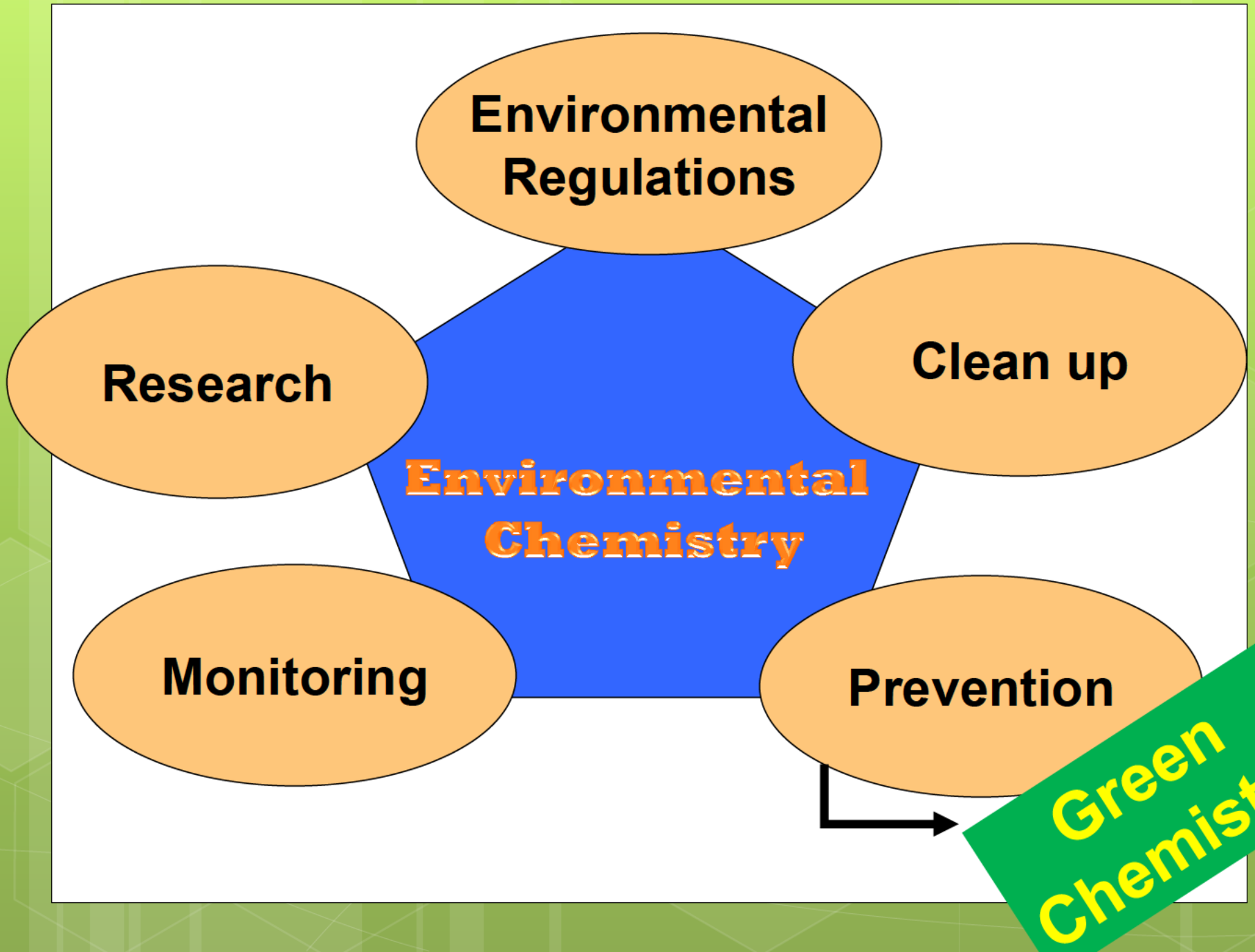


- Waste
- Materials
- Danger
- Risk
- Energy
- Adverse Environmental Impact
- COST!

Green Chemistry vs. Environmental Chemistry

- Environmental Chemistry:
  - *Study of sources, reactions, transport, effects and destruction of chemical compounds in the ground, water and air.*

Stanley Manahan, Env. Chemistry, 6th Ed. *CRC Press. 2005*


Environmental Regulations
Research
Clean up
Environmental Chemistry
Monitoring
Prevention
Green Chemistry

Benefits of Green Chemistry:

- Reduced waste, eliminating costly end-of-the-pipe treatments
- Safer products
- Reduced use of energy and resources
- Improved competitiveness of chemical manufacturers and their customers

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Impact of Awareness and New Practices

- 1.2 billion pounds of chemicals and solvents saved per year
  - Enough to fill 5000 train tanks or a 62 miles long train
- 57 million pounds of CO_2 has been reduced
  - equivalent to take out circulation 37000 cars.
- 16 billion gallons of water per year have been saved

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Twelve Principles of Green Chemistry

- Paul Anastas and John Warner in **Green Chemistry: Theory and Practice** (Oxford University Press: New York, 1998).

Twelve Principles of Green Chemistry:

1. Prevent waste

- Design chemical syntheses to prevent waste, leaving no waste to treat or clean up.
- Easier than clean up, transport or store them
- Transforming chemical reactions that incorporate the largest amount of the starting materials = Less waste!

Impact of different industries

Industry	Products (tons)	Kg byproducts/ Kg products
Petroleum Refinery	$10^6 – 10^8$	<0.1
Chemical Production	$10^4 – 10^6$	1-5
Specialized Chemical Compounds	10^2 - 10^4	5 – 50
Pharmaceutical	10 - 10^3	25 – 100+

- New Industries:
  - Large gain margins
  - More complex chemistry
  - More waste production

R A Sheldon J Chem Tech Biotechnol 1997 68 381

Possible sources of waste reduction:

Inputs

"eco-friendly" solvents, high purity reagents, solvent recycling.

Production

Optimization of reaction time, temperature and pressure. New synthesis pathways.

Discharges

Reduce water usage, improve filtering procedures and reuse waste products.

Chemical waste impacts environment adversely: Some Examples

- The Arctic city of Norilsk is now the world's largest heavy metals smelting complex
- Copper, nickel, lead and other heavy metals taint the soil and water supply while sulfur dioxide emissions contribute to chronic diseases of the lungs, respiratory tracts, and digestive systems, and can result in lung cancer.

Chemical waste impacts environment adversely: Some Examples

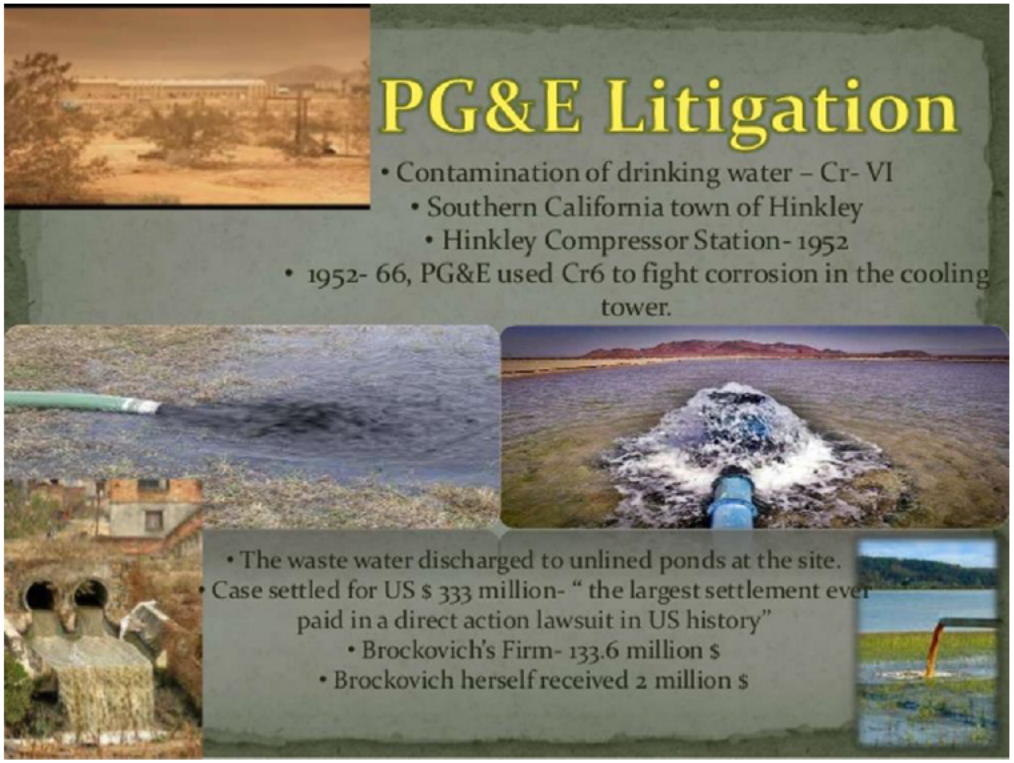
- The Sukinda Valley in Orissa state, India contains 97% of India's chromite ore deposits—used mainly to make chrome plating and stainless steel. Mining processes leave toxic chromium(VI) in surface and drinking water, the soil, and the air, and can cause gastrointestinal bleeding, tuberculosis, and asthma, infertility and birth defects.

Chemical waste impacts environment adversely: Some Examples

- Cr(VI) pollution is an issue in Kanpur due to the leather industries.
- The leather industry in Kanpur, which includes tanneries and product makers, is estimated to be worth Rs 12,000 crore. It provides direct and indirect employment to a million people in Kanpur and Unnao districts, but is a major source of pollution.

Chemical waste impacts environment adversely: Some Examples

- Cr(VI) pollution was widely publicized courtesy of a Hollywood movie based on the work of Erin Brockovich who discovered Cr(VI) pollution in a town called Hinckley by the company PG&E.



Erin Brockovich

Movie Poster

Twelve Principles of Green Chemistry:

2. Design safer chemicals and products:

- Design chemical products to be fully effective, yet have little or no toxicity.
- …chemicals that are less hazardous to human health and the environment are:
  - Less toxic to organisms and ecosystems
  - Not persistent or bioaccumulative in organisms or the environment
  - Inherently safer with respect to handling and use

Twelve Principles of Green Chemistry:

3. Design less hazardous chemical syntheses:

- Use and generate substances with little or no toxicity to humans and the environment.
- Avoid reactions that give dangerous by-products

Twelve Principles of Green Chemistry:

4. Use renewable feedstocks:

- Use raw materials and feedstocks that are renewable rather than depleting
  - Agricultural products
  - Wastes of other processes
- Reduce dependency from fossil fuels (petroleum, natural gas, or coal) or are mined

Twelve Principles of Green Chemistry:

5. Use catalysts, not stoichiometric reagents:

- They are selective
- Catalysts are used in small amounts
- Can carry out a single reaction many times.
- Improve production and energy consumption
- They are preferable to stoichiometric reagents, which are used in excess and work only once.

Twelve Principles of Green Chemistry:

6. Avoid chemical derivatives:

- Avoid:
  - blocking or protecting groups or any temporary modifications if possible.
  - Derivatives use additional reagents and generate waste.

Twelve Principles of Green Chemistry:

7. Maximize atom economy:

- Final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
- Relation between atoms in the products and atoms in the reagents
  - Addition – good atom efficiency
  - Elimination – not so good…