The Principles of Green Chemistry

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GREEN CHEMISTRY

DEFINITION

Green Chemistry is the utilisation of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products *.

GREEN CHEMISTRY IS ABOUT

- Waste Minimisation at Source
- Use of Catalysts in place of Reagents
- Using Non-Toxic Reagents
- Use of Renewable Resources
- Improved Atom Efficiency
- Use of Solvent Free or Recyclable Environmentally Benign Solvent systems

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

The 12 Principles of Green Chemistry (1-6)

1. **Prevention**
   It is better to prevent waste than to treat or clean up waste after it has been created.

2. **Atom Economy**
   Synthetic methods should be designed to maximise the incorporation of all materials used in the process into the final product.

3. **Less Hazardous Chemical Synthesis**
   Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to people or the environment.

4. **Designing Safer Chemicals**
   Chemical products should be designed to effect their desired function while minimising their toxicity.

5. **Safer Solvents and Auxiliaries**
   The use of auxiliary substances (e.g., solvents or separation agents) should be made unnecessary whenever possible and innocuous when used.

6. **Design for Energy Efficiency**
   Energy requirements of chemical processes should be recognised for their environmental and economic impacts and should be minimised. If possible, synthetic methods should be conducted at ambient temperature and pressure.

Source: Green Chemistry Theory and Practice, Anastas & Warner, OUP, 2000

The 12 Principles of Green Chemistry (7-12)

7 **Use of Renewable Feedstocks**
A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

8 **Reduce Derivatives**
Unnecessary derivatization (use of blocking groups, protection/de-protection, and temporary modification of physical/chemical processes) should be minimised or avoided if possible, because such steps require additional reagents and can generate waste.

9 **Catalysis**
Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10 **Design for Degradation**
Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

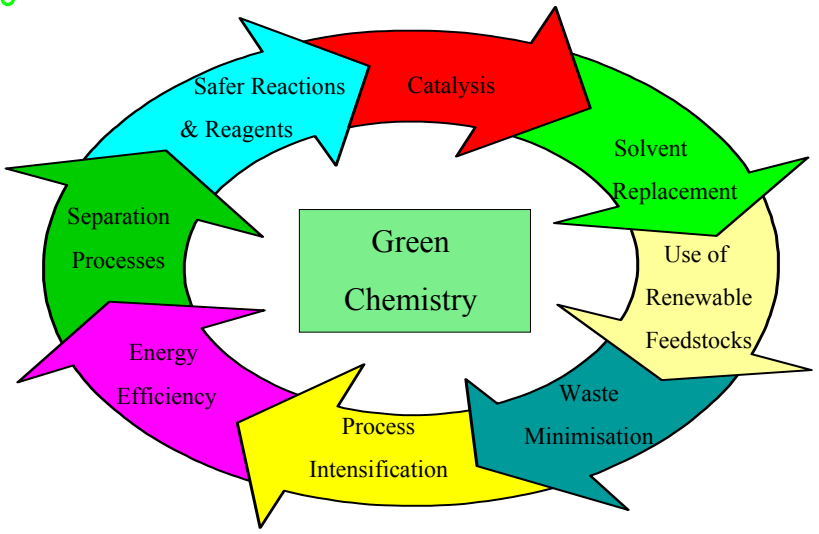
11 **Real-time Analysis for Pollution Prevention**
Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12 **Inherently Safer Chemistry for Accident Prevention**
Substances and the form of a substance used in a chemical process should be chosen to minimise the potential for chemical accidents, including releases, explosions, and fires.

Green Chemistry Is About...

- Waste
- Materials
- Hazard
- Risk
- Energy
- Environmental Impact
- COST

Some Aspects of Green Chemistry



WASTE AND THE CHEMICAL INDUSTRY

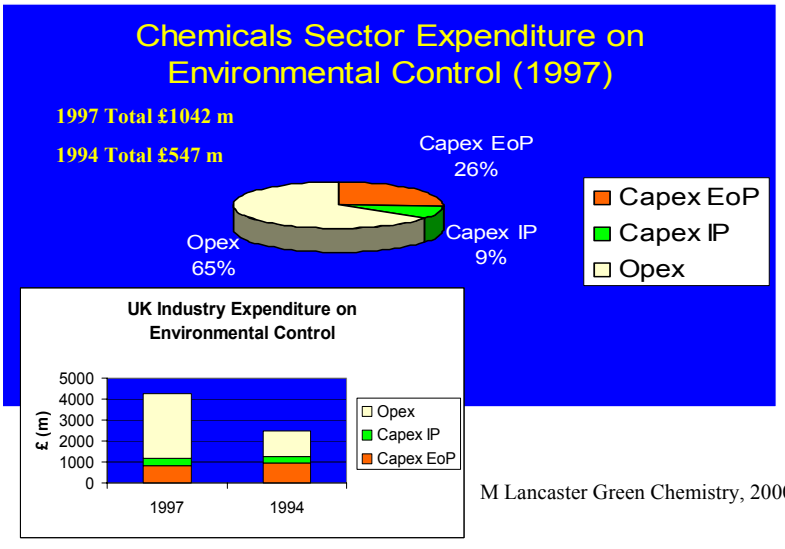
Where does the waste come from?

Industry Segment	TONNAGE	RATIO Kg Byproducts / Kg Product
Oil Refining	10^6 - 10^8	<0.1
Bulk Chemicals	10^4 - 10^6	1 - 5
Fine Chemicals	10^2 - 10^4	5 - 50
Pharmaceuticals	10 - 10^3	25 - 100+

- Areas traditionally thought of as being dirty (oil refining & bulk chemical production) are relatively clean - they need to be since margins per Kg are low.
- Newer industries with higher profit margins and employing more complex chemistry produce much more waste relatively.

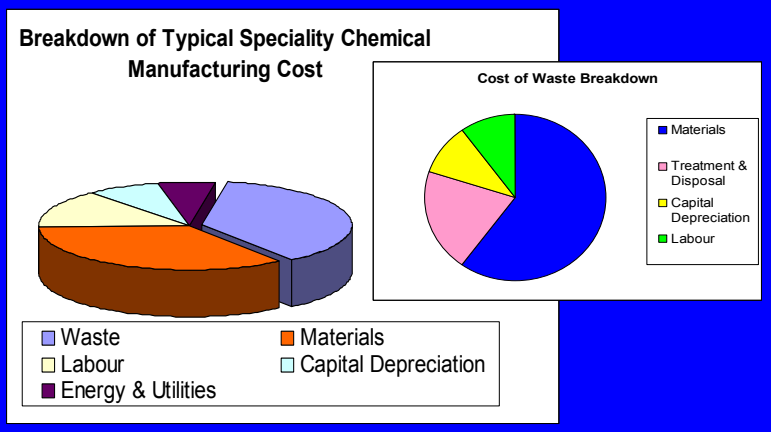
R A Sheldon J Chem Tech Biotechnol 1997 68 381

Expenditure on Environmental Control



M Lancaster Green Chemistry, 2000, 2, G65

Waste in the Speciality Chemicals Industry



Pollution Prevention Hierarchy