What is Green Chemistry?

Concepts & Ideas

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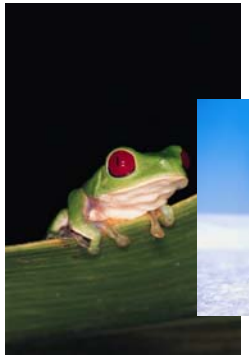
What does a chemist do?

- Chemists make things such as:
  - Medicines
  - Materials: plastics, metals
  - Coatings: paint, lacquers
  - Electronics: cell phones and computers

- Chemists investigate!
  - To understand things in the world around them
    - Global problems: The ozone layer in the atmosphere
    - Natural processes: What is in a flower that makes it's petals a particular color

Scientists' Roles in Environmental Problems



Biologists

Chemists

Environmental Scientists

Engineers

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Questions to Post to Your Students

- What does a chemist do?
- What are some chemical products?
- What do you think about when you hear the words “green chemistry”?
- What is environmental science?
- Do you think our world has environmental problems? What problems?
- How do you think we will go about solving those problems?

12 Principles of Green Chemistry

1. Pollution Prevention
2. Atom Economy
3. Less Hazardous Chemical Synthesis
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

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1. Pollution Prevention

It is better to prevent waste than to treat or clean up waste after it is formed.

1. Pollution Prevention

What do we do to prevent pollution?

- Drive smaller, more efficient cars
- Take the commuter train
- Riding a bike
- Fix a leaky faucet
- Recycle paper or compost leaves

An ounce of prevention is worth a pound of cure.

A chemist in a green chemistry lab is performing pollution prevention on a molecular level!

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2. Atom Economy

Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product

2. Atom Economy

Waste not, want not!

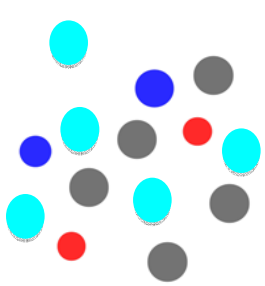
A chemical reaction:

A + B → **Product** + C + D

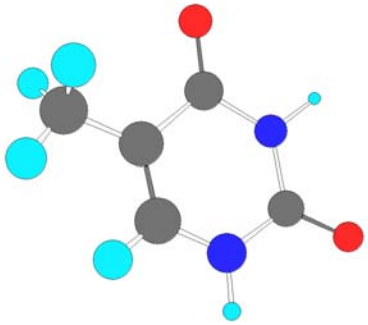
Cooking analogy:
Ingredients in → product out (any by-products??)

Atom Economy = (FW of Product ÷ FW of Reactants) x 100%

Where do products come from?



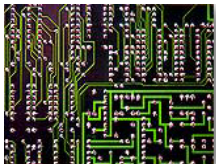
Atoms



Molecules

Materials

Products



Atom Economy Focuses on:
Atoms → Molecules

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3. Less Hazardous Chemical Synthesis

Whenever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

3. Less Hazardous Chemical Synthesis

Function is related to hazard.
We do risky things all the time…

When chemists “do chemistry,” they have a choice in how they do it. Choosing the safer method in Chemistry is like using a screwdriver instead of a knife to tighten a screw. The knife might be able to tighten the screw, but it’s dangerous!

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4. Designing Safer Chemicals

Chemical products should be designed to preserve efficacy of the function while reducing toxicity.

4. Designing Safer Chemicals

Chemists are molecular designers; they design new molecules and new materials. Green Chemists make sure that the things that we make not only do what they're supposed to do, but they do it safely. This means that it's not only important *how* chemists make something, it's also important that *what* they make isn't harmful.

In Chemistry: Function is NOT related to hazard.

Making safe, non-toxic products is the goal!

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5. Safer Solvents and Auxiliaries

The use of auxiliary substances (solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.

5. Safer Solvents and Auxiliaries

We use solvents for all kinds of things:

- Cooking
- Nail polish (lots of fumes!)
- Paints
- Cleaning products
- Decaffeinated coffee
- Chemical reactions

Many solvents are hazardous and toxic. There are safer alternatives!

What is a solvent?

A **solvent** is a substance (usually a liquid) that dissolves something else.

A **solute** is the substance that is dissolved in the solvent.

Example: If you dissolve sugar in water – which substance is the solvent and which is the solute?

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6. Design for Energy Efficiency

Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

6. Design for Energy Efficiency

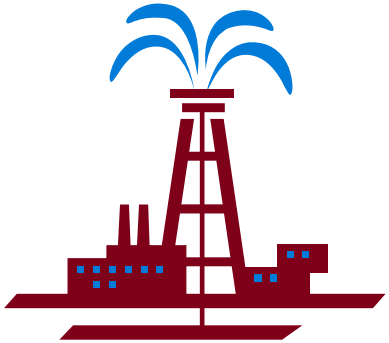
We use lots of energy:
- Driving our cars
- Heating and cooling our houses
- Cooking food
- Drying our hair

Chemists also use lots of energy:
- Heating
- Drying
- Cooling

Energy is not only expensive – most of the time the power plant that creates the energy contributes to pollution.

7. Use of Renewable Feedstocks

A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.



7. Use of Renewable Feedstocks

Why are gas prices so high?
One reason is that oil is not a renewable resource.
90-95% of the products we use (plastic bottles, pharmaceuticals, paint, non-stick coatings, fabrics, etc.) come from oil?

What will happen when we run out of oil and petroleum?

Green chemists look for alternative sources for making materials. Renewable feedstocks (corn, potatoes, biomass) can be used to make many products: fuels (ethanol and bio-diesel), plastics and more.

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8. Reduce Derivatives

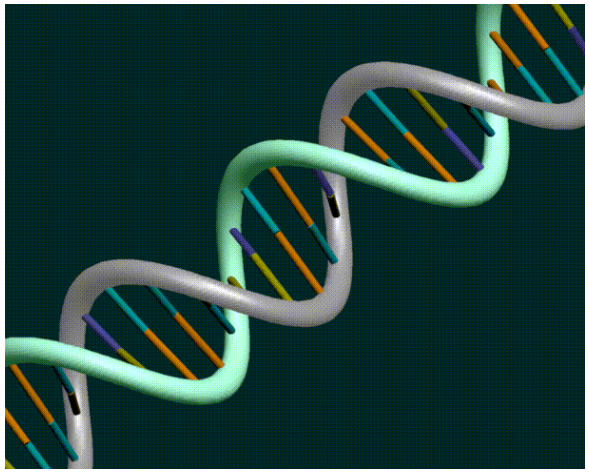
Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

8. Reduce Derivatives

Natural systems – Low energy, self-assembly

Chemistry – Traditionally high energy, high toxicity

Covalent versus non-covalent bonds



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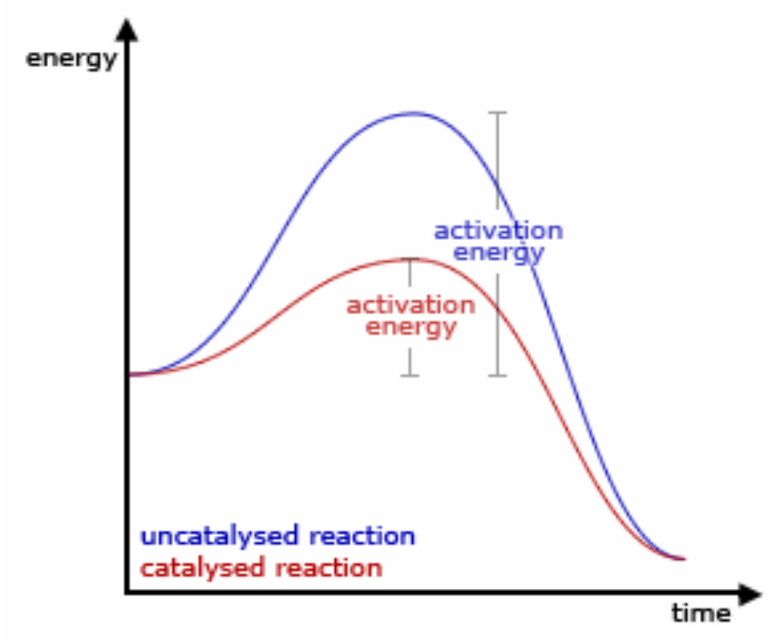
9. Catalysis

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

9. Catalysis



In chemistry and biology, **catalysis** is the acceleration (increase in rate) of a chemical reaction by means of a substance, called a **catalyst**, which is itself not consumed by the overall reaction.

- Reduces energy
- Increases efficiency
- Reduces by-product formation

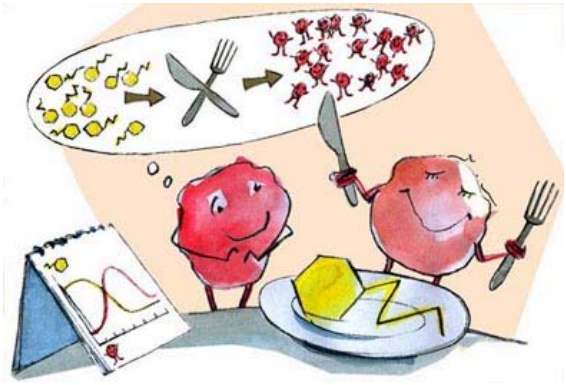
10. Design for Degradation

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

10. Design for Degradation

Recycling is one way of reducing waste… but, can we recycle everything?

What happens when we throw things away?



Design for degradation means that when green chemists design a new chemical (i.e., a pharmaceutical drug or medicine) or material (i.e., a new plastic) – they design it so that it breaks down at the end of its useful lifetime.

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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.

11. Real-time analysis for Pollution Prevention

Real time analysis for a chemist is the process of “checking the progress of chemical reactions as it happens.”

Knowing when your product is “done” can save a lot of waste, time and energy!

12. Inherently Safer Chemistry for Accident Prevention

Substance and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

12. Inherently Safer Chemistry for Accident Prevention

Tragedy in Bhopal, India - 1984

In arguably the worst industrial accident in history, 40 tons of methyl isocyanate (MIC) were accidentally released when a holding tank overheated at a Union Carbide pesticide plant, located in the heart of the city of Bhopal. 15,000 people died and hundreds of thousands more were injured.

Chemists try to avoid things that explode, light on fire, are air-sensitive, etc.

In the “real world” when these things happen, lives are lost.

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