GREEN CHEMISTRY

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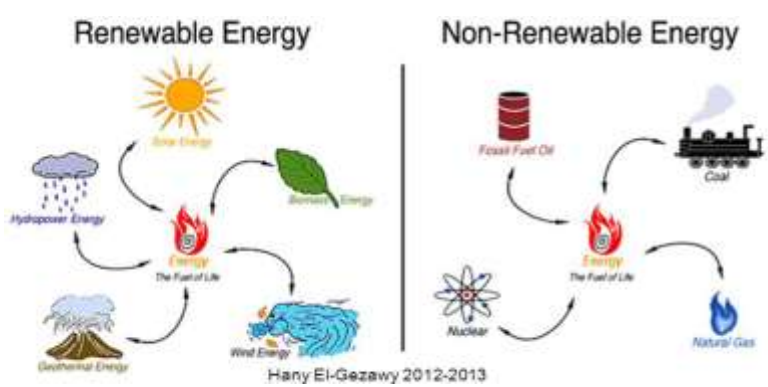
- **(i) Green chemistry** (sustainable chemistry), is an area of chemistry and chemical engineering focused on the designing of products and processes that are safe and minimize the use and generation of hazardous substances.

- **(ii) Green chemistry** focuses on the environmental impact of chemistry, including reducing consumption of nonrenewable resources.



- The **overarching goals of green chemistry**—namely, more resource-efficient and inherently safer design of molecules, materials, products, and processes—can be pursued in a wide range of contexts.

Syllabus

- **Sep. 03 and Sep. 10:** What is green chemistry, and the basic building blocks of green chemistry
- **Sep.17 and Sep. 24** Green reagents and compounds: safer materials without damaging the environment
- **Oct. 01 and Oct. 08:** Green Solvents: Water, the ultimate green solvent: its uses and environmental chemistry
- **Oct. 15 and Oct. 22:** Green Catalyst + student presentation
- **Oct. 29 and Nov.05:** Green Technologies + student presentation
- **Nov. 12 and Nov. 19:** Designing Greener Processes + student presentation
- **Nov. 26 and Dec. 03 :** Renewable Resources and green products (I)
- \+ student presentation
- **Dec. 10 and Dec. 17:** Renewable Resources and green products (II) + student
- presentation
- **Dec. 24:** **Final exam**

Student presentation

(I) Starting from Oct. 15

(II) in 9 groups, and each group has 3 students.

(III) Each student has 10-15 min for presentation， 2 min for question and answer.

Each student can choose your own topic that is related with green chemistry, or you can use the topics I told in class to do further extension with more details.

The weighting used for the final course grade

Grading:

Attendance: 10%

Home work: 10%

Presentation: 40%

Final Exam: 40%

Texts:

1. Stanley E. Manahan. 2006. *Green Chemistry and the Ten Commandments of Sustainability*. ChemChar Research, Inc Publishers, Columbia, Missouri U.S.A.

2. Mike Lancaster.2002. *Green Chemistry: **An** Introductory Text*. Green Chemistry Network, University of York.

What is green chemistry?

1.1 What is green chemistry and its objectives

Green chemistry can be summarized to six simple words.

1.2 Green chemistry metrics and its basic principles

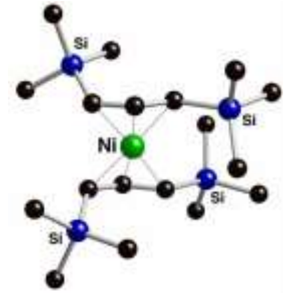
- **Inorganic chemistry:** dealing with the synthesis and behavior of inorganic and organometallic compounds.

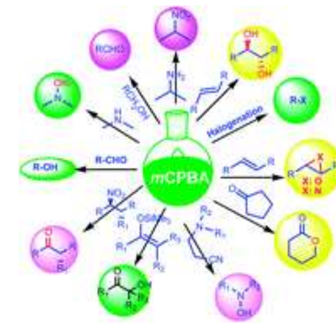
- **Organic chemistry:** involving the scientific study of the structure, properties, and reactions of organic compounds and organic materials made from carbon.

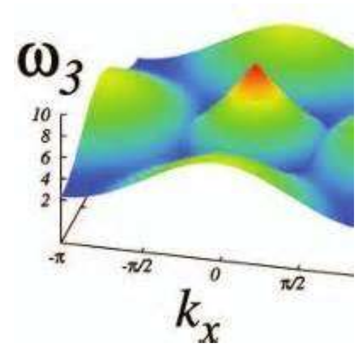
- **Physical chemistry:** using underlying theory (kinetics, thermodynamics, quantum chemistry, statistical mechanics, and chemical equilibrium) to explain different physical phenomena and chemical processes.

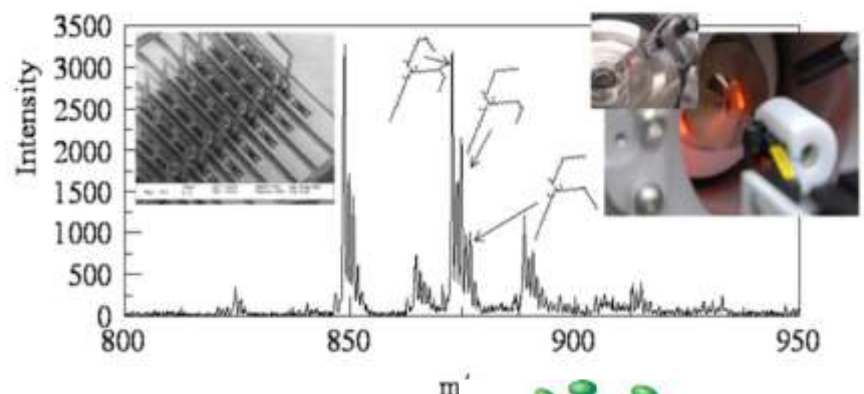
- **Analytical chemistry**: The branch of chemistry dealing with the determination of kinds and quantities of chemical species.

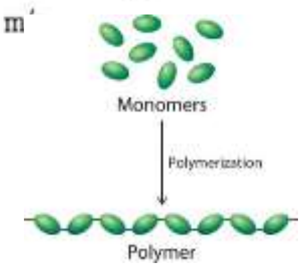
- **Biochemistry or poymer chemistry:** The chemistry that living organisms perform or related with synthetic polymers.











1.1 Chemistry is good

- Pharmaceuticals-have improved health and extended life, such as artificial joints, ‘blood bags’, anaesthetics, disinfectants, anti-cancer drugs, vaccines, dental fillings, contact lenses
- Fertilizers and pesticides-have greatly increased food productivity
- Semiconductors-have made possible computers, cell phones other electronic devices.
- Transportation - production of gasoline and diesel from petroleum, fuel additives for greater efficiency and reduced emissions.
- Clothing - man-made fibres such as rayon and nylon, dyes, waterproofing and other surface finishing chemicals.

Sport - advanced composite materials for tennis and squash rackets, all-weather surfaces.

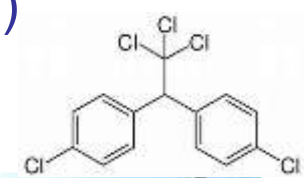
- Home - material and dyes for carpets, plastics for TVs and mobile phones, CDs, video and audio tapes, paints, detergents.

Without the persistent efforts of chemists and the enormous productivity of the chemical industry, we can not enjoy the high standard of living, and modern industrialized societies would be impossible.

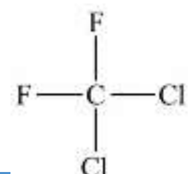
Adverse impacts caused by chemistry

- Release of pollutants and toxic substances to air and water (Nitrous Oxide, CO_2,NaOH, sulfonic acid, organic solvents)
- Production of nonbiodegradable materials and chemicals (e.g. synthetic polymers,DDT(Dichlorodiphenyltrichloroethane, 双对氯苯基三氯乙烷), and other pesticides)
- Chlorofluorocarbon (CFCs), and plastics)
- Exploitation of limited earth resources (woods, coal mines, petroleum, and rare metals)

DDT



CFC

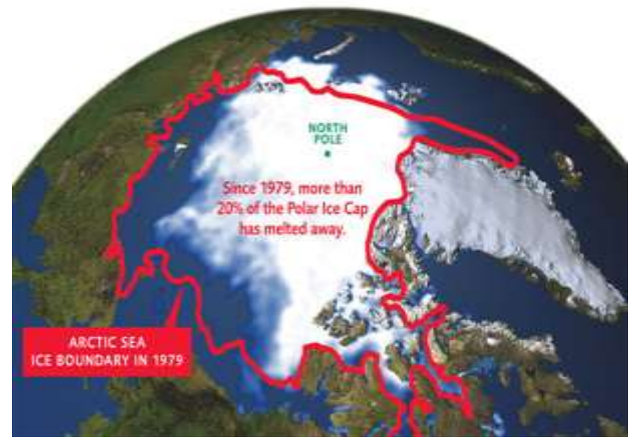


2. What is green chemistry and its objectives

- Green chemistry present a body of chemical knowledge from the most fundamental level within a framework of the relationship of chemical science to human beings, their surroundings, and their environment, such as the practice of chemical science and manufacturing in a manner that is sustainable, safe, and non-polluting and consuming minimum amounts of materials and energy while producing little or no waste material.

extreme weather events Hurricane katrina

global warming



increasing pollution emissions

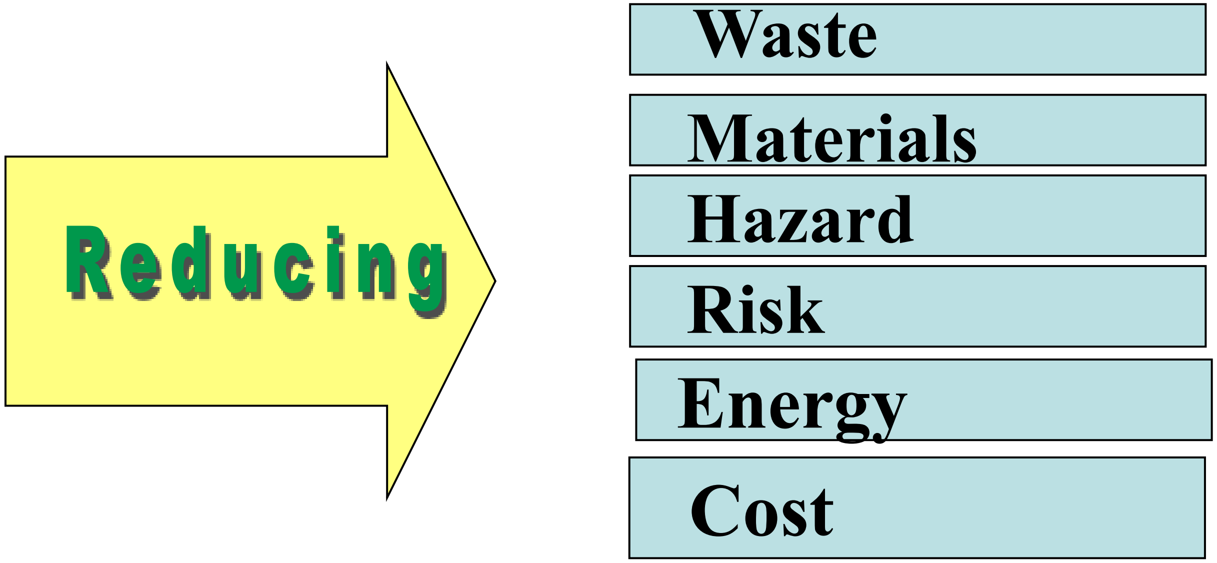
shortage of fossil fuel resources

Green chemistry is sustainable chemistry. There are several important aspects that green chemistry cares about:

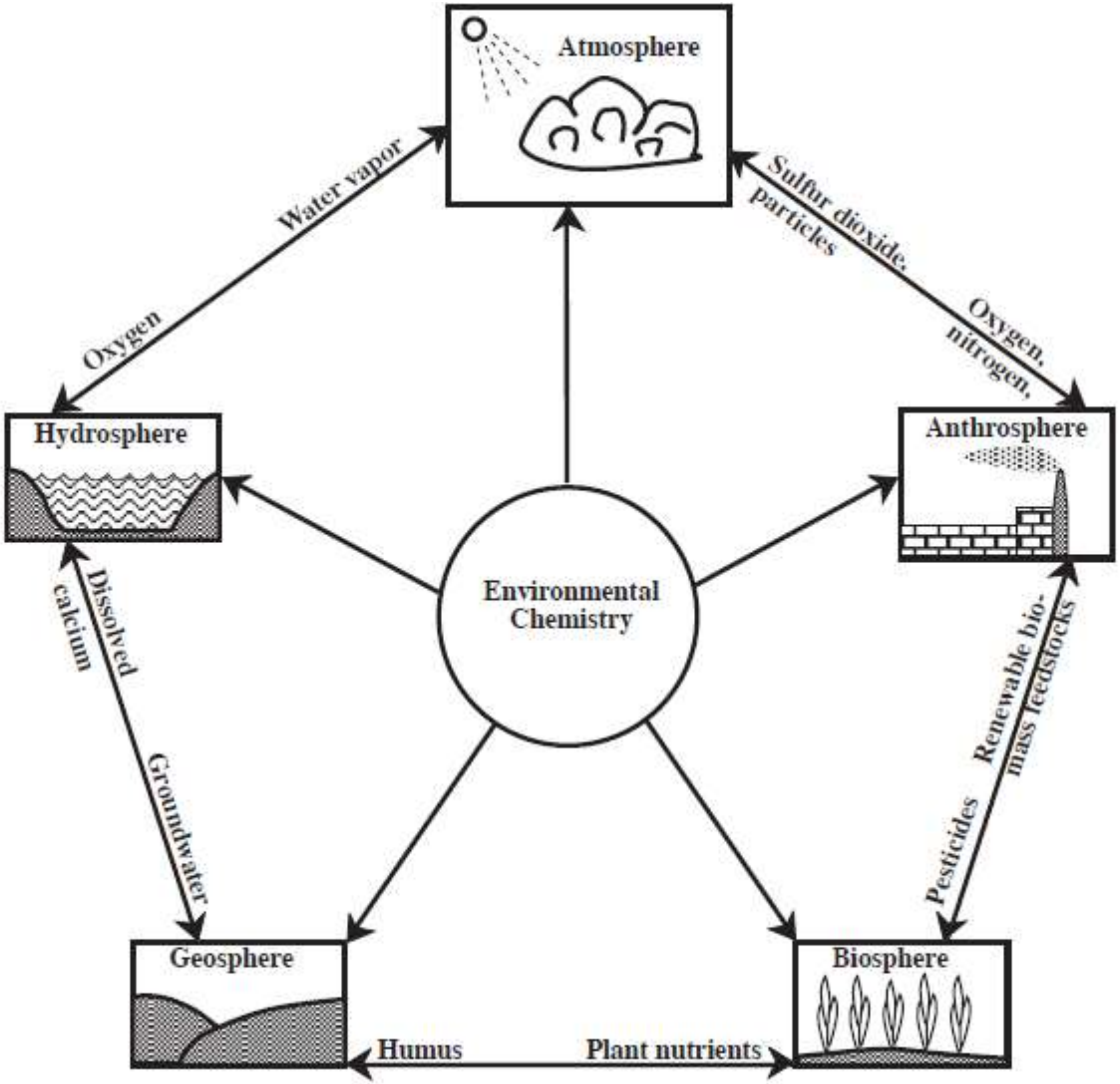
- Economic: costs less in strictly economic terms than chemistry as it is normally practiced.

- Materials: By efficiently using materials, maximum recycling, and minimum use of virgin raw materials.

- Waste: By reducing insofar as possible, or even totally eliminating their production.



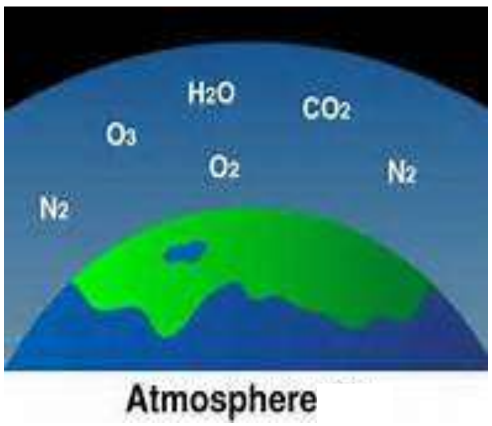
Green chemistry contributes to environmental sustainability



- Atmosphere
- Hydrosphere
- Geosphere
- Biosphere
- Anthrosphere

Illustration of the five major spheres of the environment. These spheres are closely tied together, interact with each other, and exchange materials and energy.

Atmosphere and atmosphere chemistry



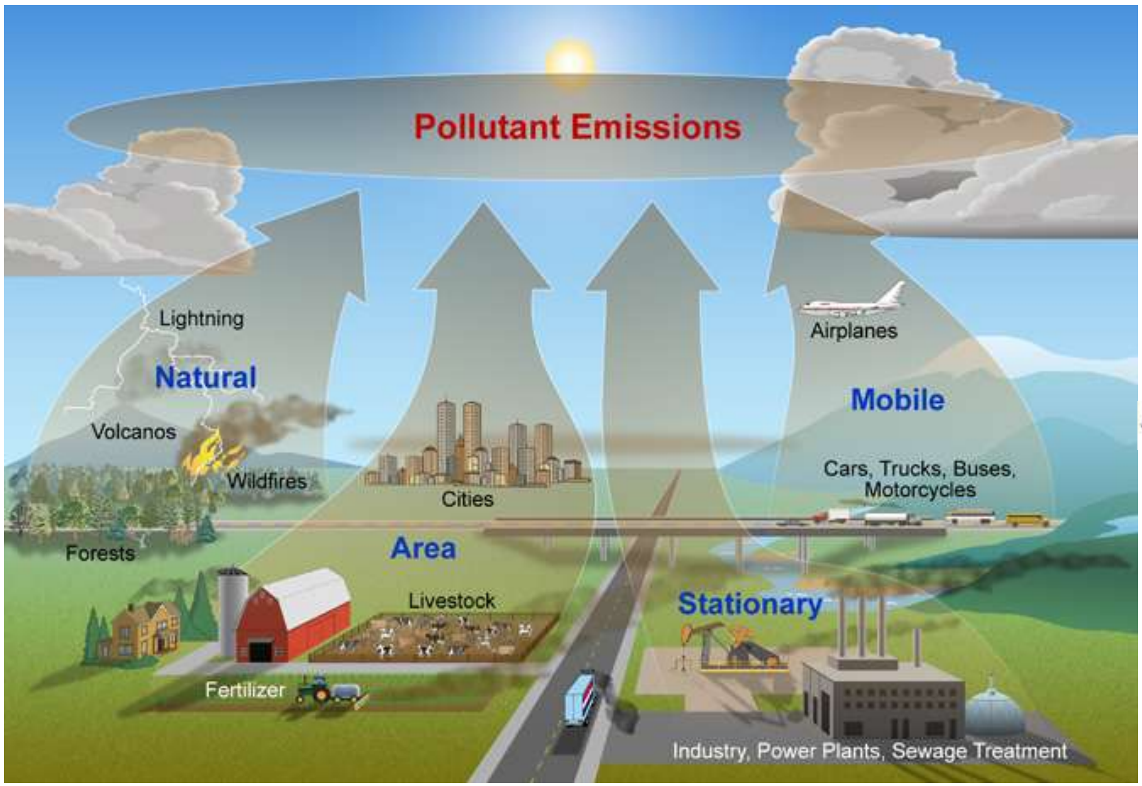
- The atmosphere provides oxygen for living organisms, carbon dioxide required for plant photosynthesis, nitrogen that organisms use to make proteins, allowing for liquid water to exist on the Earth's surface.

- The ozone layer serves a vital protective function in that it absorbs highly energetic ultraviolet radiation from the sun that would kill living organisms exposed to it.

- The atmosphere stabilizes Earth’s surface temperature by absorbing infrared radiation from earth.

- The atmosphere also serves as the medium by which the solar energy that falls with greatest intensity in equatorial regions is redistributed away from the Equator through water vapor circulation.

Air pollution



Carbon Dioxide CO_2:
greenhouse effect

Nitrous Oxide Nox: acid rain

$$N_2\,(g) + O_2\,(g) \xrightarrow{1483K} 2NO(g)$$

$$2NO\,(g) + O_2\,(g) \rightarrow 2NO_2\,(g)$$

$$4NO_2\,(g) + O_2\,(g) + 2H_2O\,(l) \rightarrow 4HNO_3\,(aq)$$

sulfur dioxide Sox: acid rain

$$2SO_2\,(g) + O_2\,(g) \rightarrow 2SO_3(g)$$

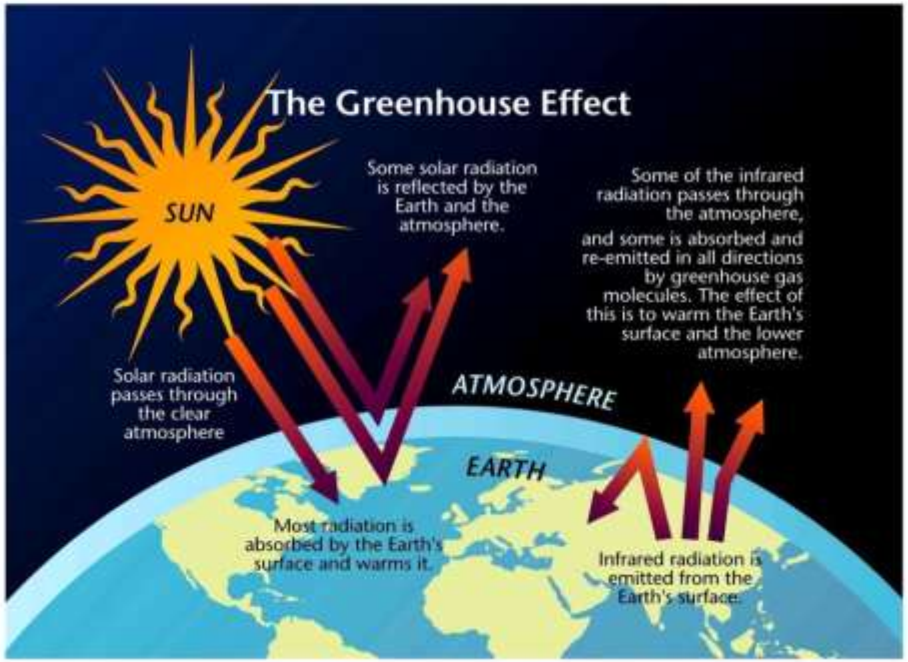
$$SO_2\,(g) + O_3\,(g) \rightarrow SO_3(g) + O_2\,(g)$$

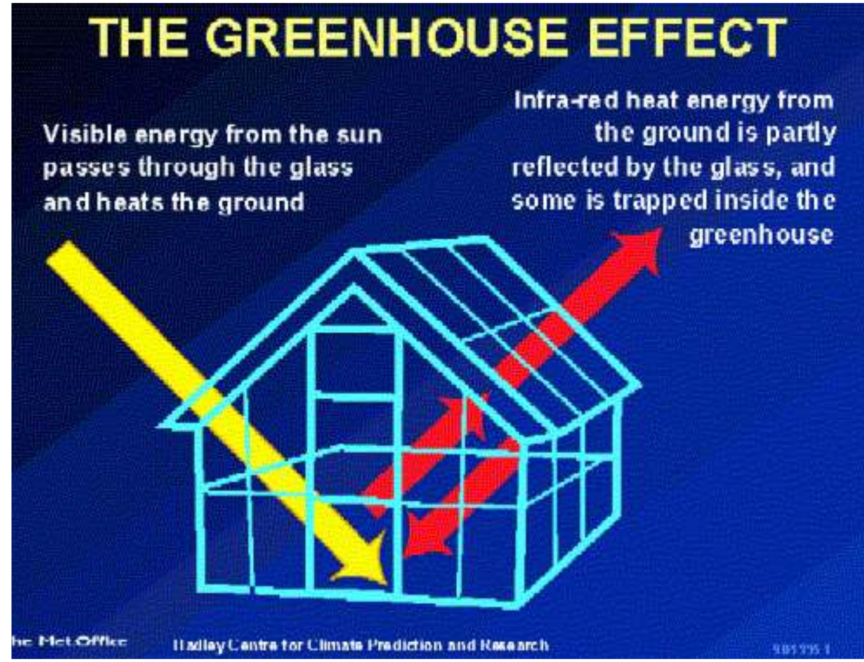
$$SO_2(g) + H_2O_2(l) \rightarrow H_2SO_4(aq)$$

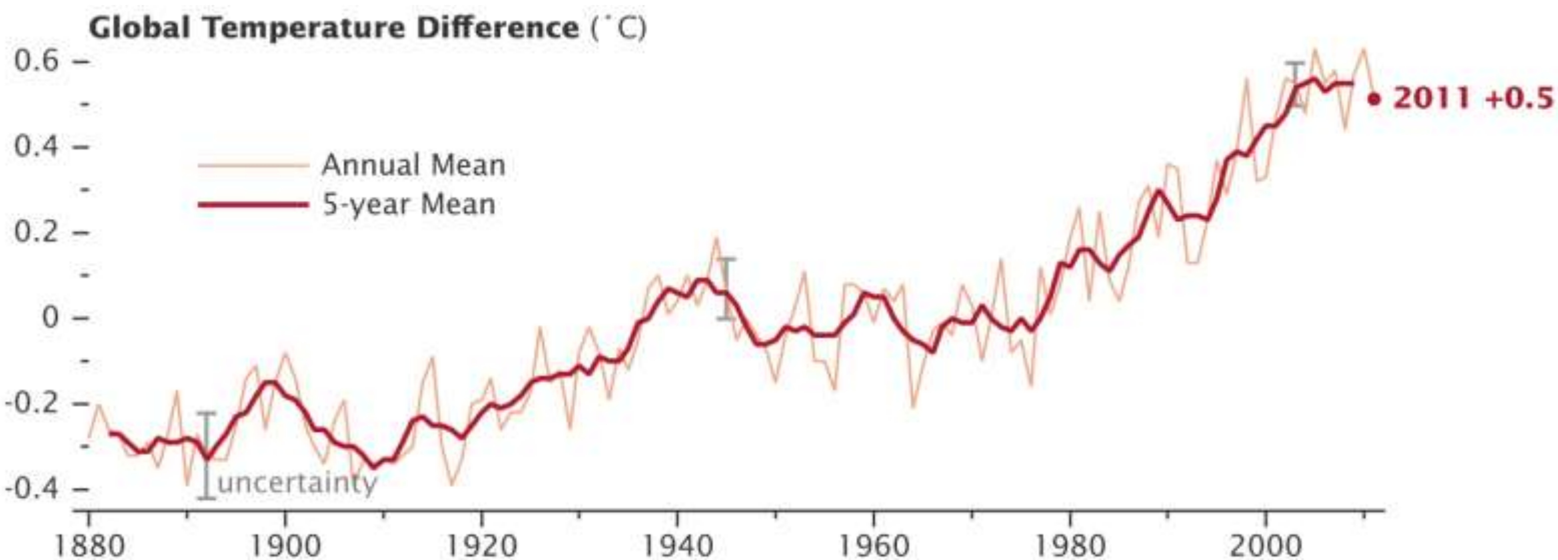
Methane CH_4:green house effect

Fluorocarbons CFC's:
Ozone damage

The Greenhouse effect

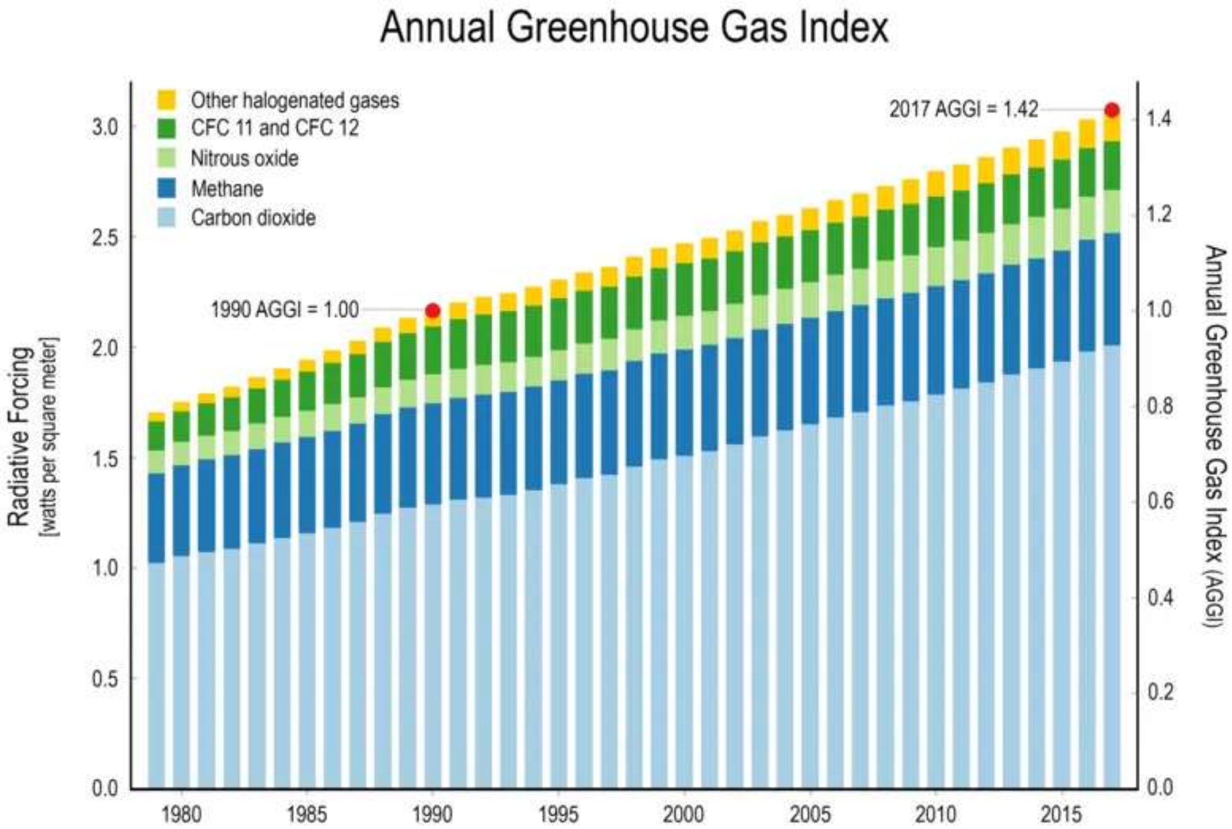






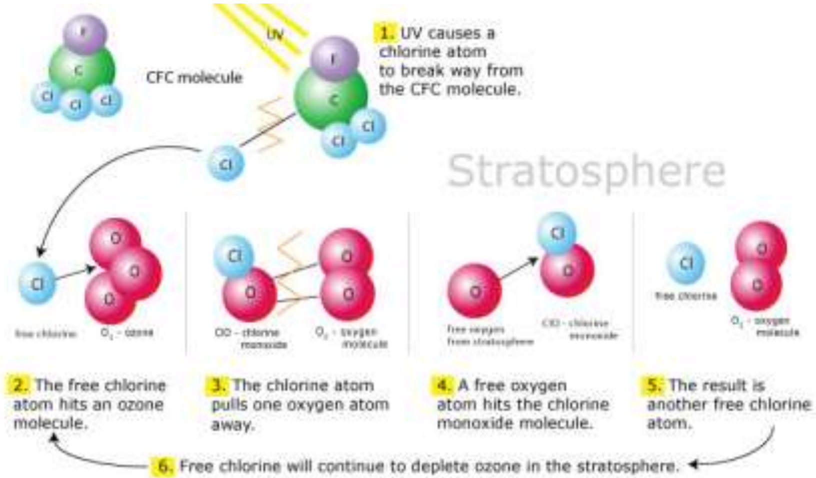
Greenhouse gases

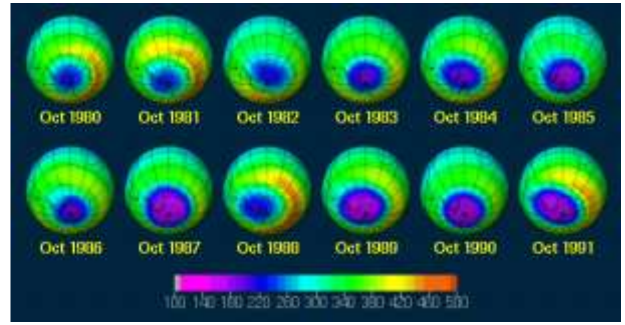
- Water Vapor H_2O
- Carbon Dioxide CO_2
- Methane CH_4
- Nitrous Oxide NO_x
- Fluorocarbons CFC’s (part of Haloalkanes)
- Ozone O_3

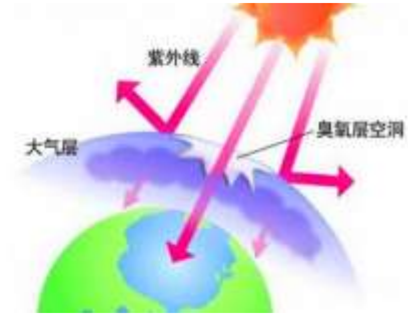


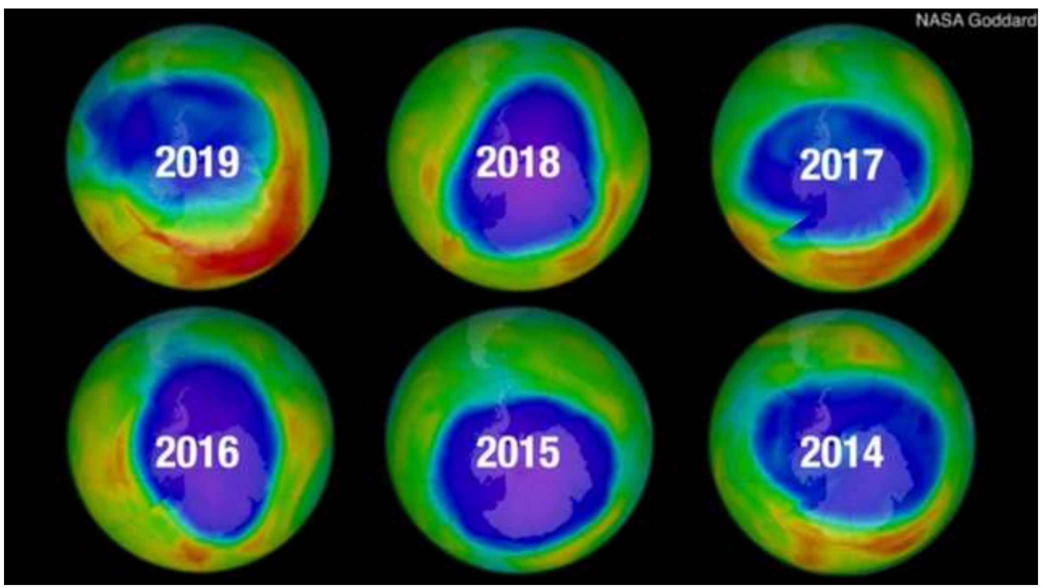
- Water Vapor H_2O **same levels**
- Carbon Dioxide CO_2 **increased**
- Methane CH_4 **doubled since 1800**
- Nitrous Oxide NOx **increased**
- Fluorocarbons CFC's **now banned**
- **Ozone (STRATOSPHERIC) DROPPED**

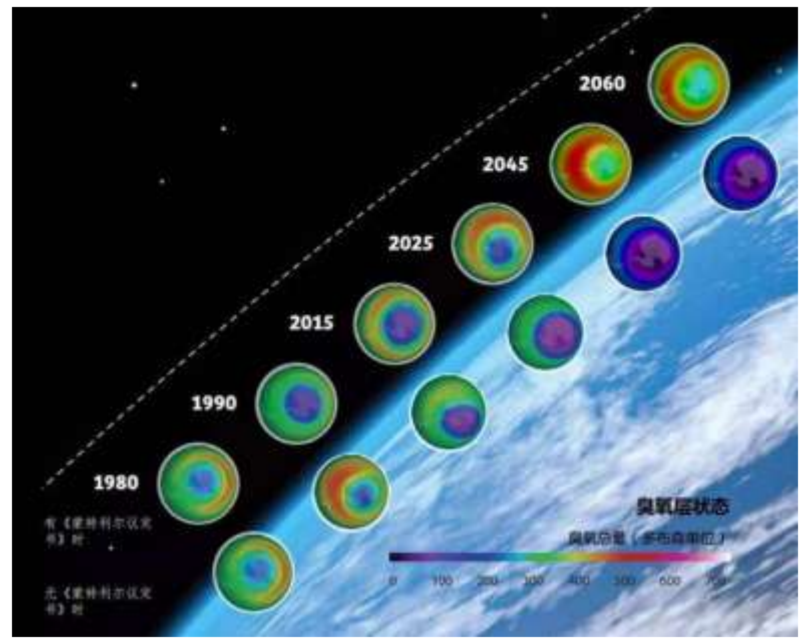
Evidence of stratospheric Ozone Depletion





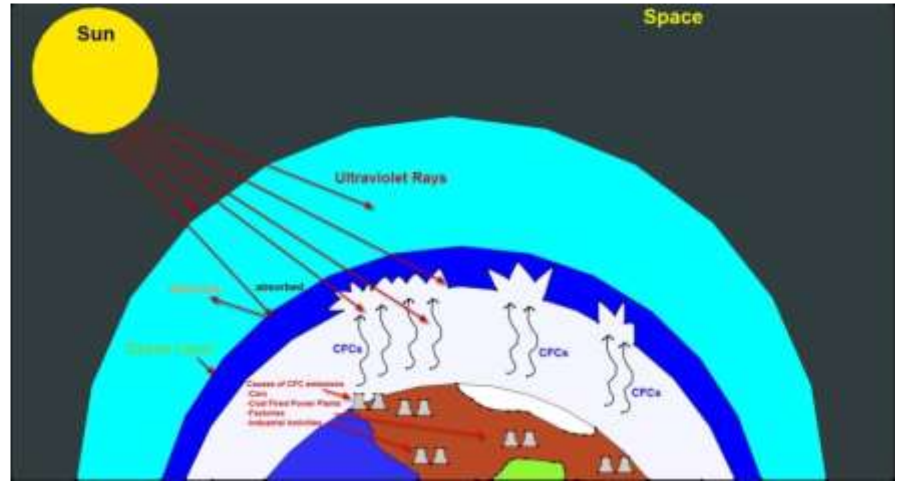






Depletion of Ozone Layer

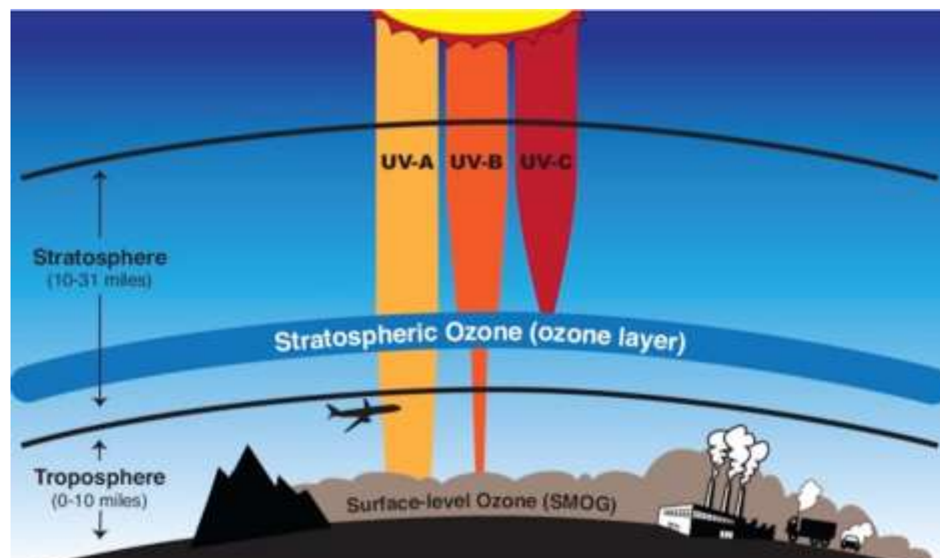
- O_3 is naturally occurring in Stratosphere
- Protects us from UV-B radiation
- Often called “good” ozone



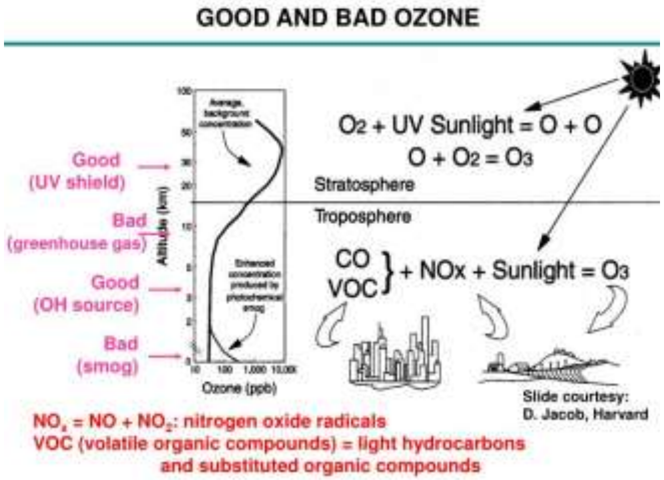
UV-A: 320～420nm, accounting for up to 95 percent of the UV radiation reaching the Earth's surface. UVA penetrates the skin more deeply than UVB, and has long been known to play a major part in skin aging and wrinkling
.

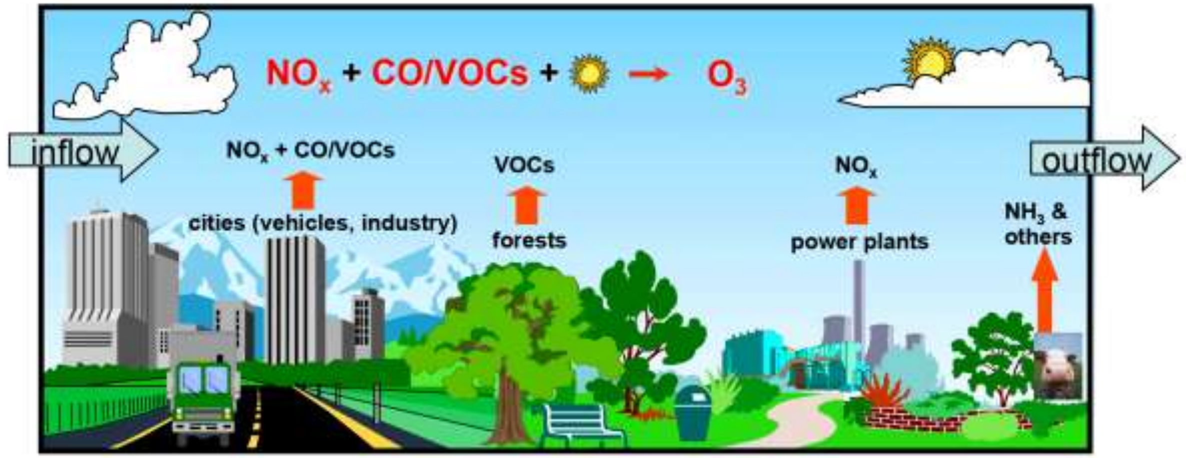
UV-B: 275～320nm，only 2% of UV-B can reach the Earth’s surface. The chief cause of skin reddening and sunburn, tends to damage the skin's more superficial epidermal layers. It plays a key role in the development of skin cancer and a contributory role in tanning and photoaging.

UV-C: 200～275nm, the most damaging type of UV radiation. However, it is completely filtered by the atmosphere and does not reach the earth's surface.



Tropospheric Ozone

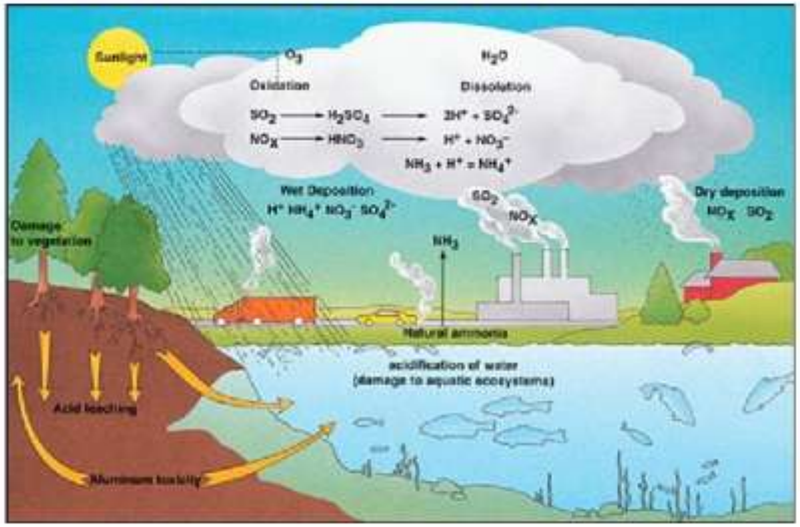




- Tropospheric ozone is known as bad ozone . This gas is found in the troposphere. It does not exist naturally. It is formed from Nitrous oxide (found in automobile exhaust) and VOC's under sunlight irradiation.
- Bad ozone is the main component of smog.
- Repeated exposure may permanently damage their lungs or suffer from respiratory infections.
- Tropospheric ozone is also harmful to plants and animals, damaging ecosystems and leading to reduced crop and forest yields.

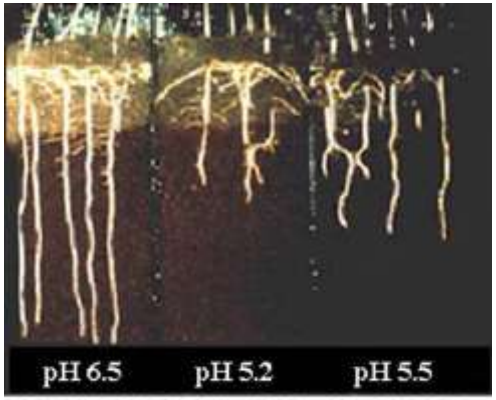
Acid Rain

The Formation of Acid Rain



Acid rain is a rain or any other form of precipitation that is unusually acidic, caused by emissions of sulfur dioxide and nitrogen oxide, which react with the water molecules in the atmosphere to produce acids.

aquatic bodies



COTTON ROOT GROWTH RESTRICTION DUE TO ACID SUB-SOIL AND ALUMINUM TOXICITY

(i) Acidification of water: damage to aquatic cosystems by lowering the pH

(ii) Acidification of soil: acid leaching , aluminum toxicity and disruption of soil nutrients.

Acid rain can also have harmful effects on forests, plants, infrastructure, architectures, killing insect and aquatic life-forms, causing paint to peel, corrosion of steel structures such as bridges, and weathering of stone buildings and statues as well as having impacts on human health.

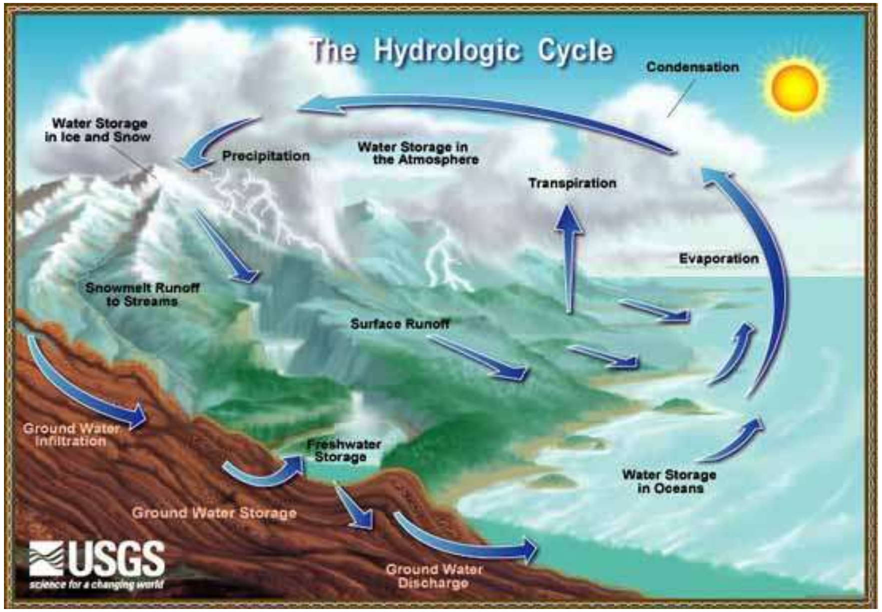
forests

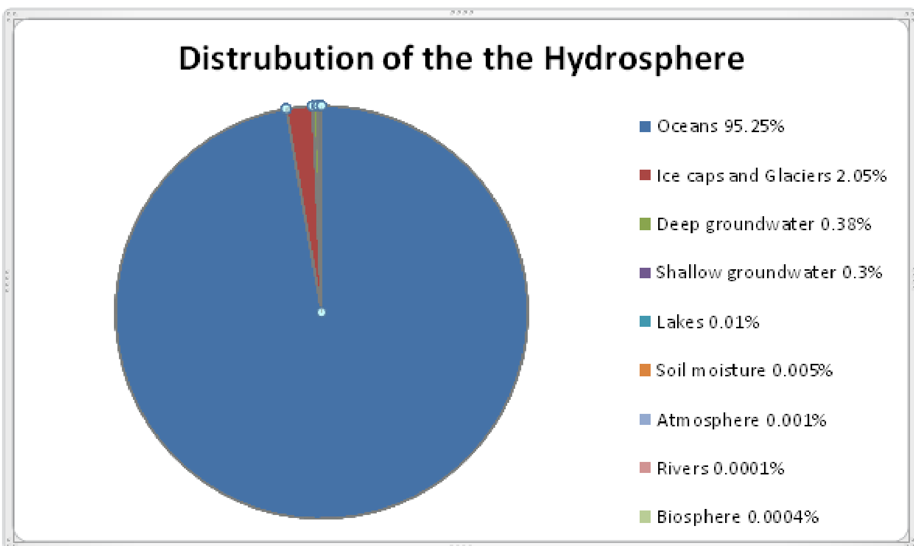
infrastructure

architectures

statue

Hydrosphere and aquatic chemistry





- More than 95% of Earth water is seawater in the oceans, containing two many salts and minerals.
- 2% of Earth water is present as ice in polar ice caps and glaciers.
- A small fraction of the total water is present as vapor in the atmosphere.
- Only 1% of fresh water is that available for growing plants and other organisms and for industrial uses.
- This water may be present on the surface as lakes, reservoirs, and streams, or it may be underground as groundwater.

Sources of pollution of hydrosphere

Water pollution is the contamination of water bodies(e.g. lakes, rivers, oceans, aquifers and groundwater)

- Industrial and communal waste products are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds.

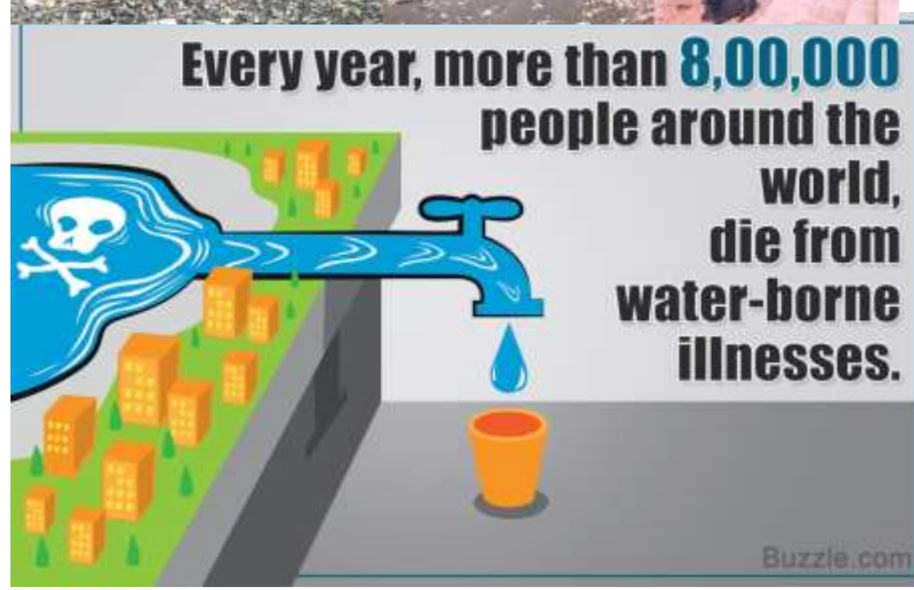
- Petroleum and mineral oil spill from wrecked or damaged supertankers, or discharges and tanker operations.

- Waste products of agriculture accumulated and discharged into waters, increase the growth of algae, which causes the depletion of oxygen.

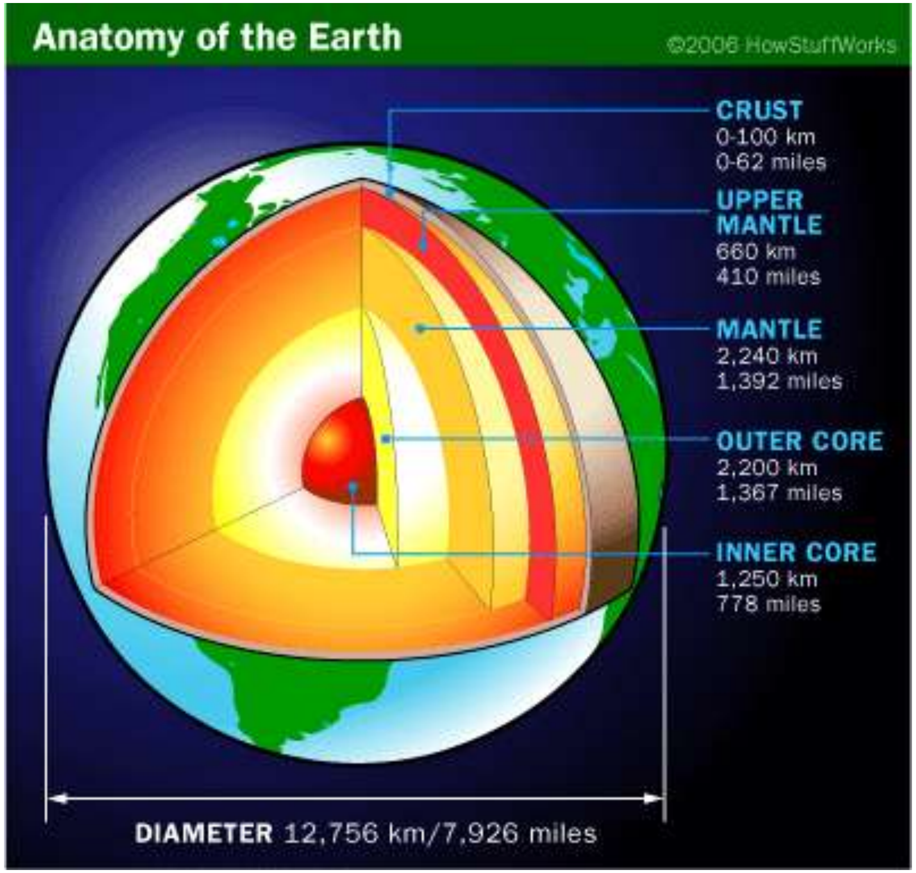
- Pesticides and mineral fertilizers, radioactive substances end up in aquatic environments can accumulate in fish that are later eaten by humans.

Consequences of pollution of hydrosphere

- Water contamination from pollution causes serious damage within wildlife in ecosystems.
- Swimming in and drinking contaminated water causes skin rashes (皮疹) and health problems like cancer, reproductive problems, typhoid fever (伤寒热) and stomach sickness in humans.
- Pollution reduces growth and fertility of aquatic organisms and leads to death of other creatures.



Geosphere and geochemistry



- The geosphere is a relatively thin solid layer extending from Earth's surface to depths of 50–100 km, which contains soil, rocks and minerals to support plant growth, the basis of food for all living organisms.
- It is the part of the geosphere that is available to interact with the other environmental spheres and that is accessible to humans.

Causes Of soil pollution

•Leakages from sanitary sewage.
•Acid rains, when fumes released from industries get mixed with rains.
•Fuel leakages from automobiles, that get washed away due to rain and
• Seep into the nearby soil.
•Unhealthy waste management techniques, which are characterized by release of sewage into the large dumping grounds and nearby **streams or rivers.**




Effects of soil pollution

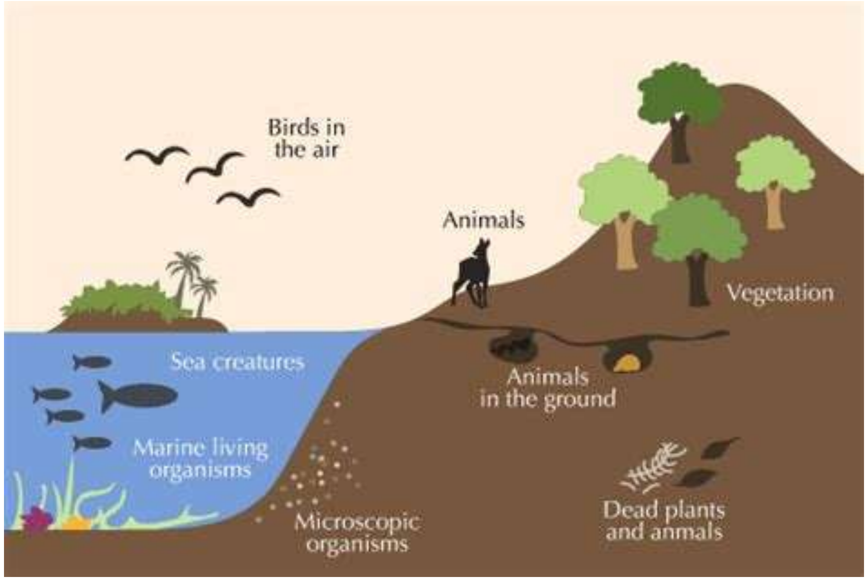
Disturbance in the balance of flora and fauna residing in the soil.

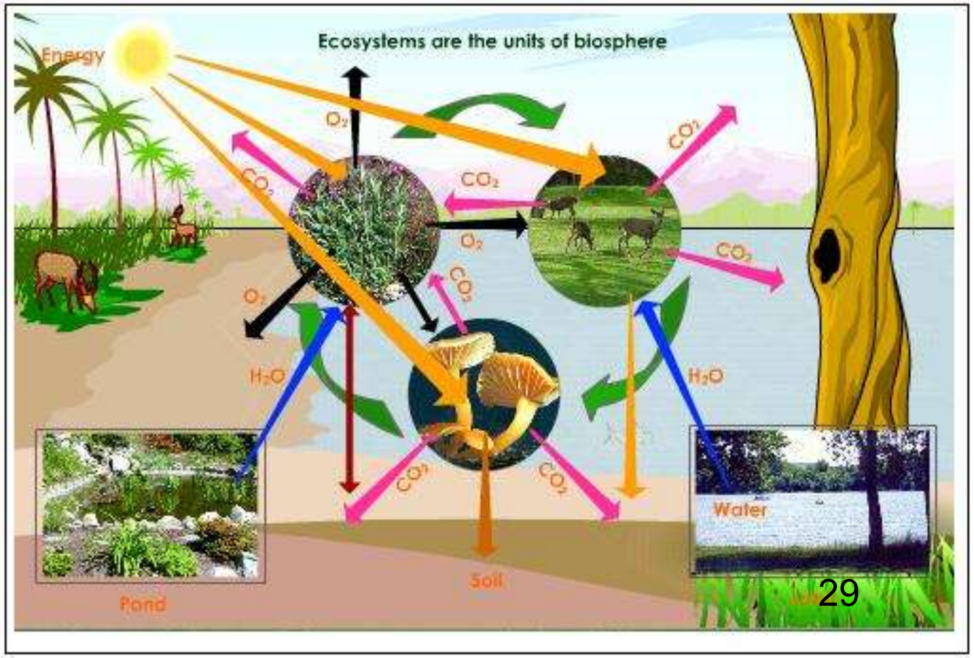
Increase in salinity of the soil, which therefore makes it unfit for vegetation, thus making it useless and barren.

Generally crops cannot grow and flourish in a polluted soil. Yet if some crops manage to grow, then those would be poisonous enough to cause serious health problems in people consuming them.

Biosphere

- The biosphere is composed of all living organisms living on the surface of the geosphere on soil, below the soil surface, or the oceans and other bodies of water.
- The biosphere is a very thin layer at the interface of the geosphere and the atmosphere.
- The biosphere is involved with the geosphere, hydrosphere, and atmosphere in biogeochemical cycles through which materials such as nitrogen and carbon are circulated.





Anthrosphere

The anthrosphere (technosphere) is that part of the environment that is made or modified by humans for use in human activities and human habitats.

The anthrosphere has developed strong interactions with the other environmental spheres through human activities.

- By cultivating large areas of soil for domestic crops, humans modify the geosphere and influence the kinds of organisms in the biosphere.
- Humans divert water from its natural flow, use it, sometimes contaminate it, then return it to the hydrosphere.
- Emissions of particles to the atmosphere by human activities affect visibility and other characteristics of the atmosphere.
- The emission of large quantities of carbon dioxide to the atmosphere by combustion of fossil fuels may be modifying the heat-absorbing characteristics of the atmosphere to the extent that global warming is almost certainly taking place.

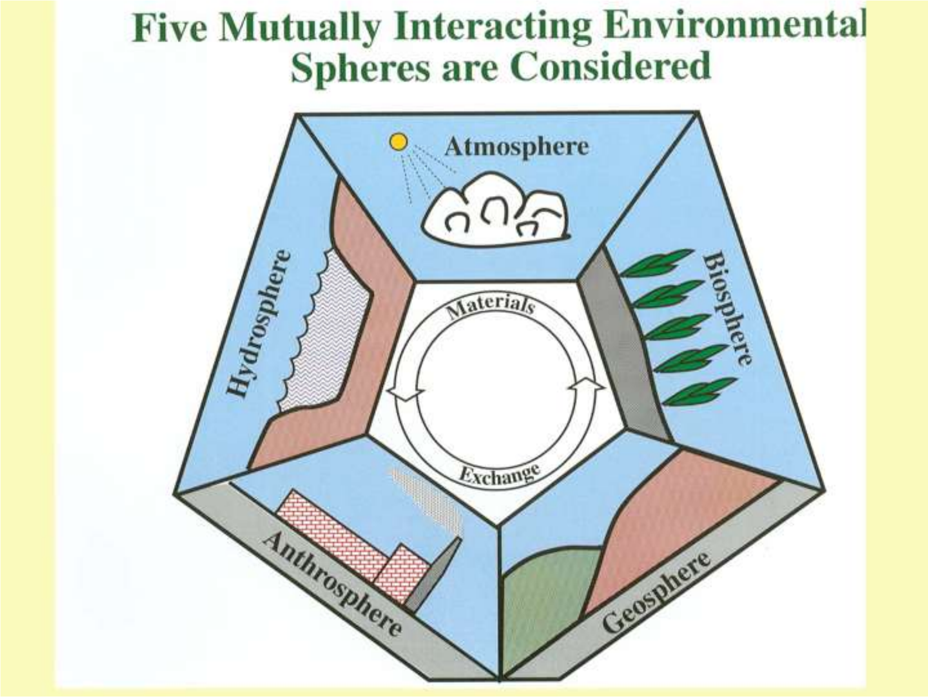
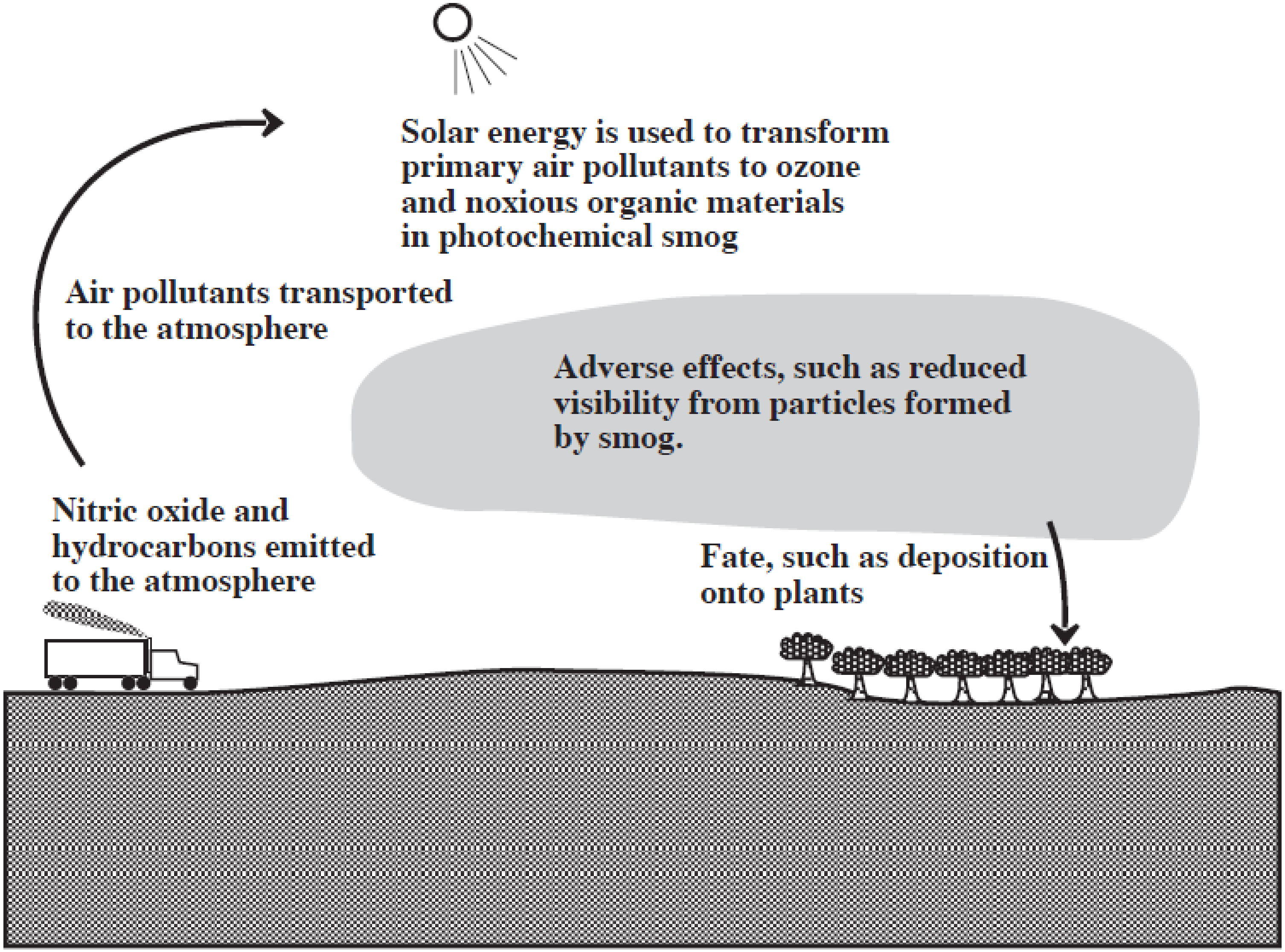


Illustration of the definition of environmental chemistry with a common environmental contaminant.



The 12 Principles of Green Chemistry (1-6)

1. **Prevention**
   It is better to prevent waste generation 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 starting 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 preserve their desired function while minimising their toxicity (DTT and CFC).

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 minimised from the considerations of both environmental and economic impacts. If possible, synthetic methods should be conducted at ambient temperature and pressure.

The 12 Principles of Green Chemistry (7-12)

7 Use of Renewable Feedstocks
A raw material or feedstock should be renewable rather than depleting one 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.

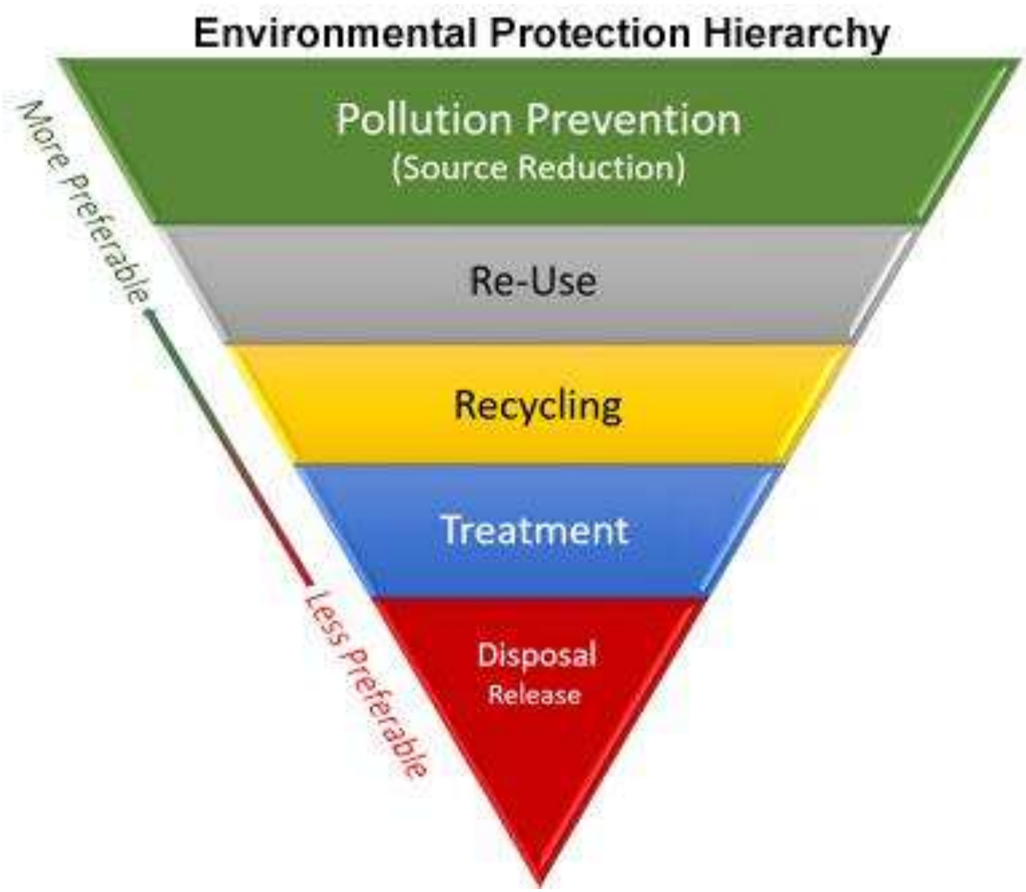
11 Real-time Analysis for Pollution Prevention
Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

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.

1. Pollution Prevention

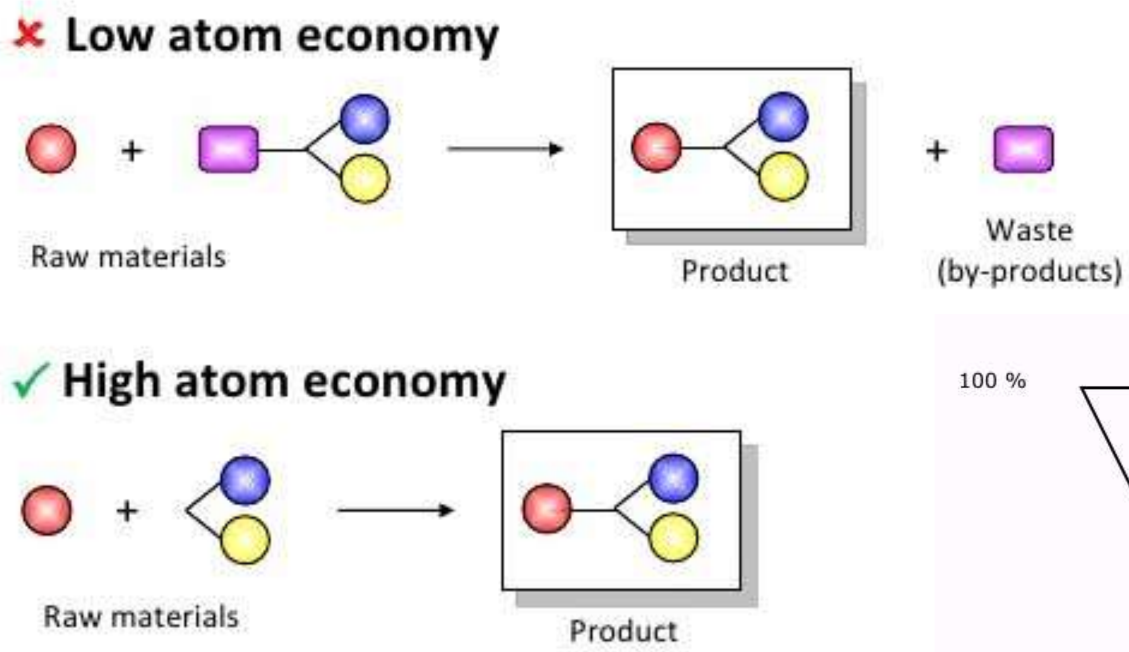
- Pollution prevention: Source reduction and other practices that reduce or eliminate the creation of pollutants through the increased efficiency in the use of raw materials, energy, water or other resources, or the protection of natural resources by conservation.

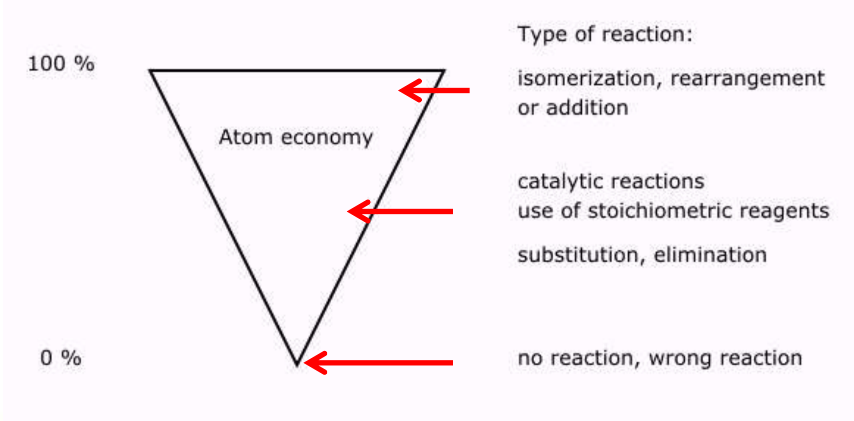
It is better to prevent waste than to treat or clean up waste after it is formed.



How could we do to prevent pollution?
• Waste was separated and collected properly
• Recycling usage of paper, metals and other non-renewable resources
• Take the commuter train
• Riding a bike
• Fix a leaky faucet
•Drive smaller, more efficient cars

2. Atom Economy





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

"Waste not, we don't want it!"

2. Atom Economy

A chemical reaction:

$$\mathbf{A} + \mathbf{B} \longrightarrow \mathbf{C} + \mathbf{D}$$

Measures of Reaction Efficiency

$$\%\ \text{yield} = 100 \times \frac{\text{actual quantity of products achieved}}{\text{theoretical quantity of products achievable}}$$

$$\%\ \text{selectivity} = 100 \times \frac{\text{yield of desired product}}{\text{amount of substrate converted}}$$

Cooking analogy: Ingredients in with product out, without the generation of any by-products??

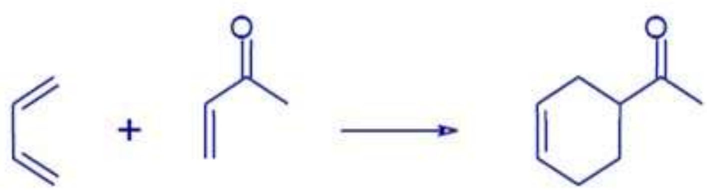
Atom Economy = (molecular mass of Product ÷ molecular mass of Reactants) x 100%

Atom Economy: The fraction of reactant material that actually ends up in final product

Atom Economy

$$\text{Atom economy} = \frac{\text{MW of desired product}}{\Sigma\ \text{MWs of all substances produced}}$$

•Diels-Alder Reaction



100% Atom economy

buta-1,3-diene Methyl vinyl ketone 3-cyclohexenyl methyl ketone

•Wittig Reaction

cyclohexanone methylenecyclohexane triphenylphosphine oxide

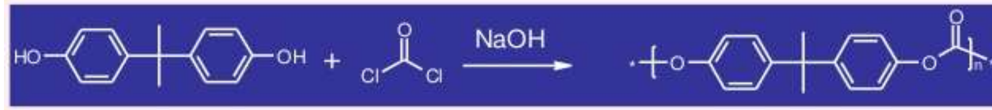
25.67% Atom economy

98.15 276.32 96.17

3. Less Hazardous Chemical Synthesis

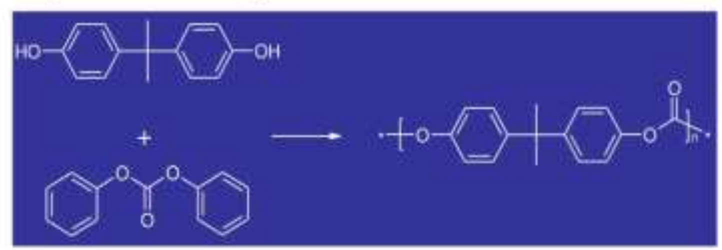
Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to people or the environment.

Polycarbonate Synthesis: Phosgene Process



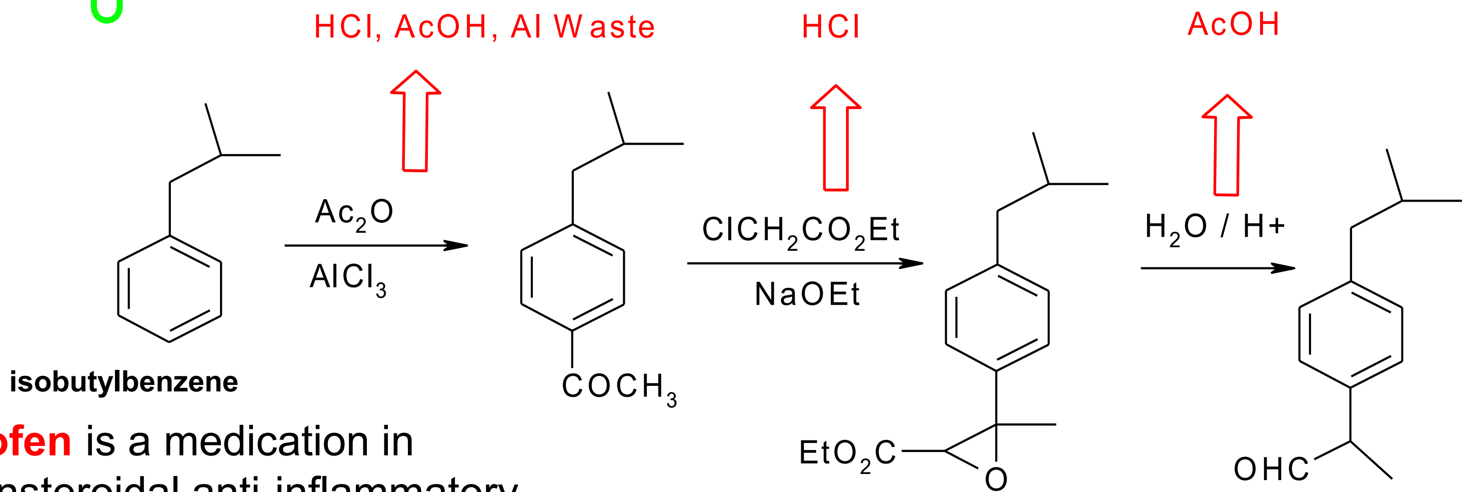
- Disadvantages
  - phosgene is highly toxic, corrosive
  - requires large amount of CH_2Cl_2
  - polycarbonate contaminated with Cl impurities

Polycarbonate Synthesis: Solid-State Process

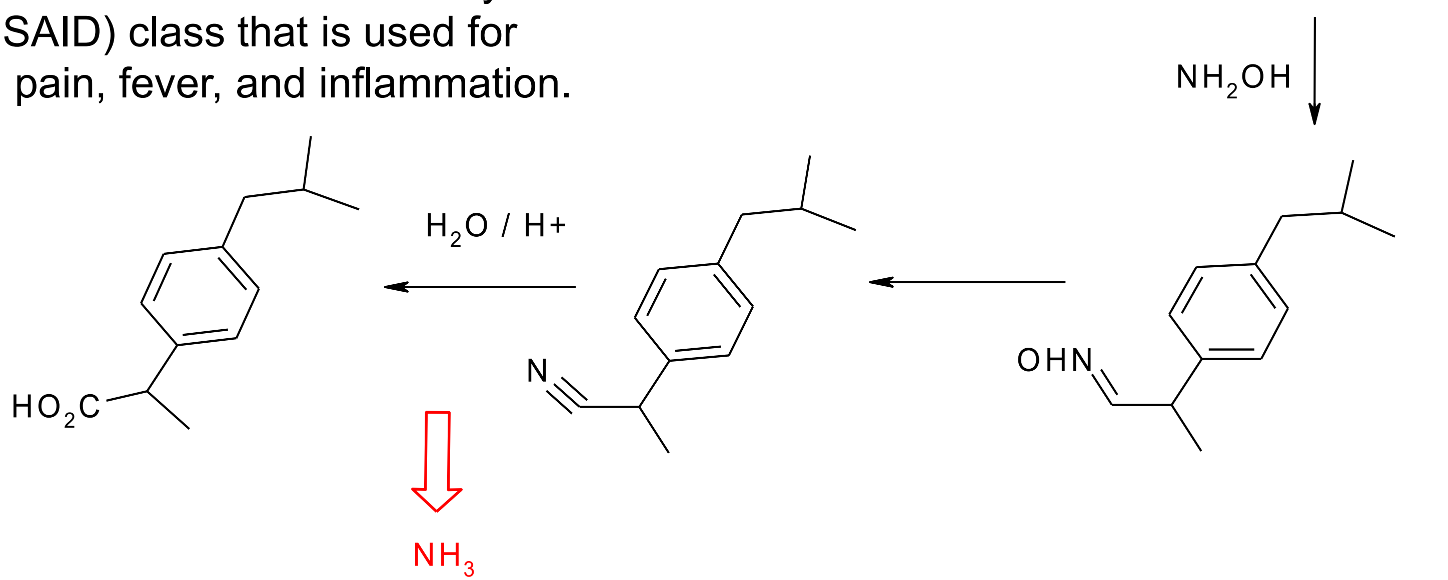


- Advantages
  - diphenylcarbonate synthesized without phosgene
  - eliminates use of CH_2Cl_2
  - higher-quality polycarbonates

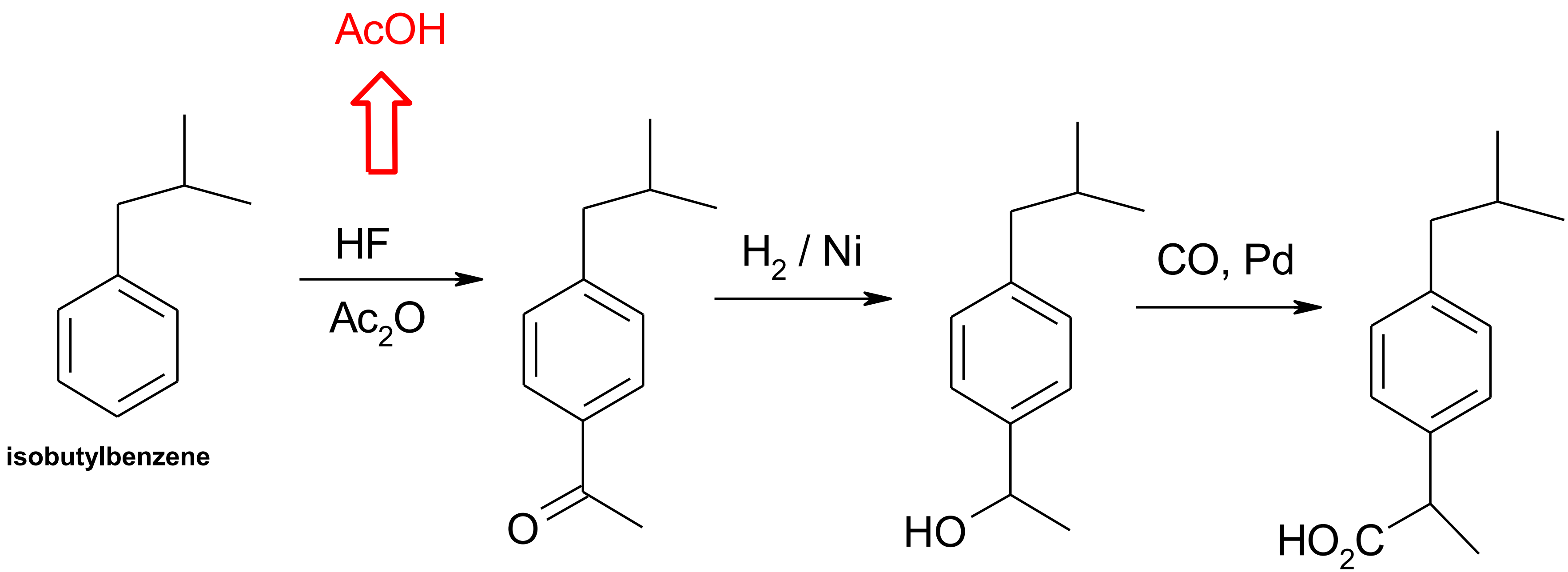
Classic Route to Ibuprofen



Ibuprofen is a medication in the nonsteroidal anti-inflammatory drug (NSAID) class that is used for treating pain, fever, and inflammation.



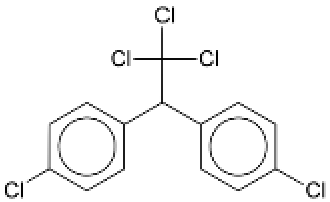
Hoechst Route To Ibuprofen



4. Designing Safer Chemicals

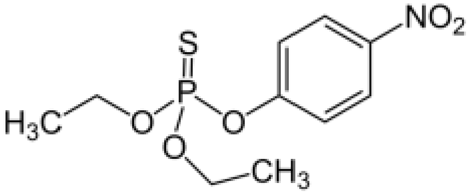
- Chemical products should be designed to preserve efficacy of the function while reducing toxicity

- 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.



Dichlordiphenyl trichlorethan

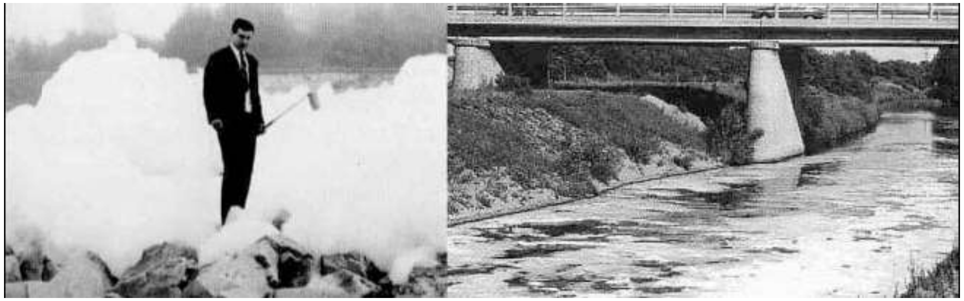
Non-degradable



Parathion

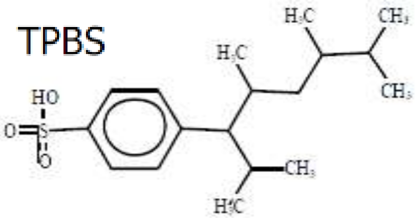
biodegradable

Benzenesulfonate Anionics



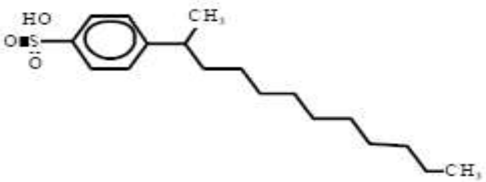
Tetrapropylene alkylbenzene sulfate

TPBS



- ►Yields clean laundry
- ►In extreme cases, POTW staff asphyxiated (i.e., KILLED) after slipping from walkways and falling into foaming tanks
- ►Reduced efficiency of treatment plants
- ►Increased dispersal of pathogenic bacteria
- ►Water foamed at the tap

Linear alkylbenzene sufonate



LAS

- ►Yields clean laundry
- ►Very biodegradable—none of the problems shown at left

Green Chemistry, 2007, 9:899-907

5. Safer Solvents and Auxiliaries

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

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

We use solvents for all kinds of things:
- Cooking
- Nail polish (lots of fumes!)
- Paints
- Cleaning products
- Decaffeinated coffee
- Chemical reactions

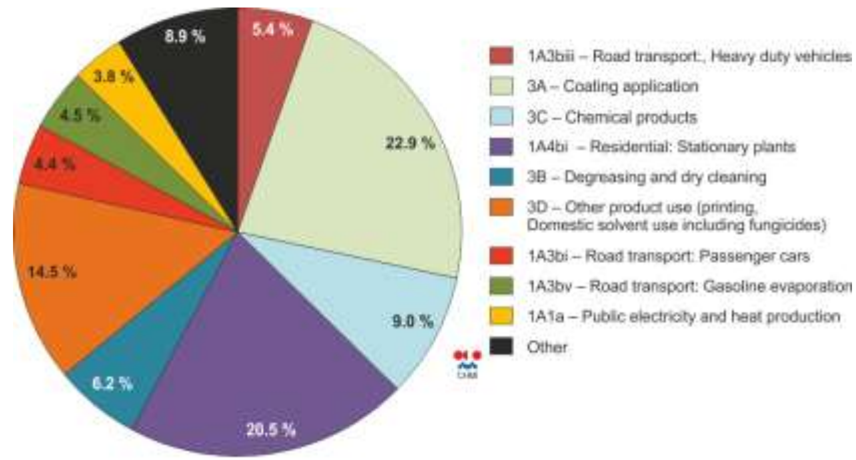
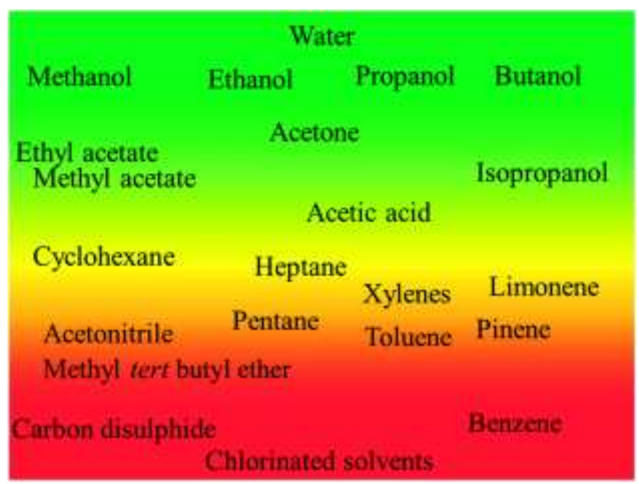
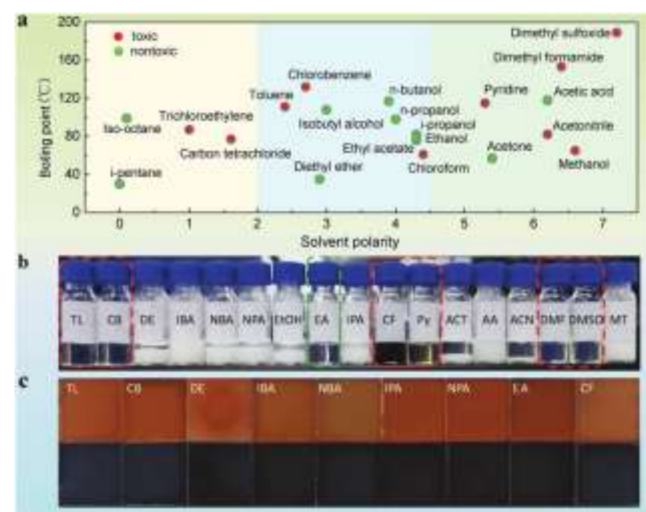


Fig. IV.9.1.2 Emissions of VOC sorted out by NFR sectors, 2012

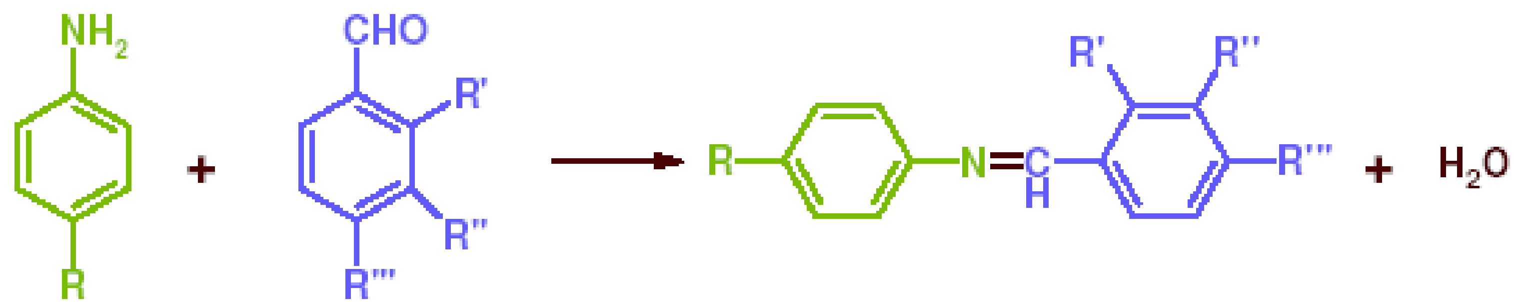




5. Safer Solvents and Auxiliaries

A solventless reaction:

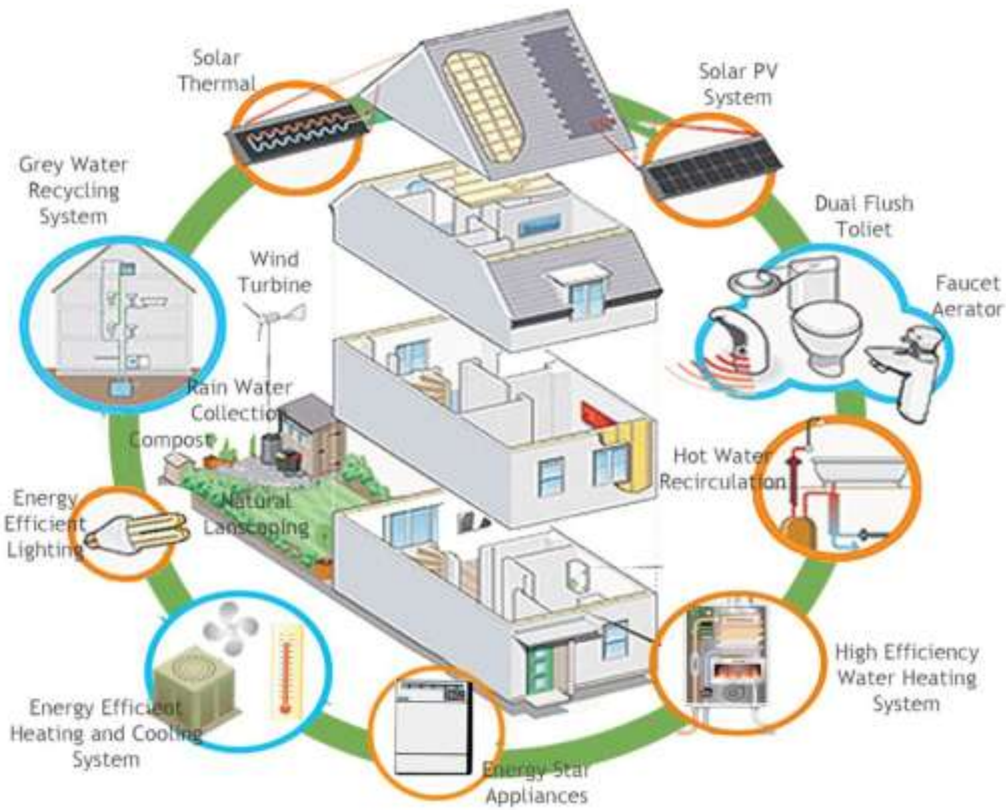
Solid A + Solid B $\xrightarrow{\text{Grind}}$ Solid C (quantitative yield)



aniline benzaldehyde imine

6 Design for Energy Efficiency

- Energy requirements of chemical processes should be minimised from the considerations of both environmental and economic impacts. If possible, synthetic methods should be conducted at ambient temperature and pressure.



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

Chemists also use lots of energy:
- Heating and high pressure
- Drying
- Cooling

Heating
Cooling
Stirring
Distillation
Compression
Pumping
Separation

GLOBAL WARMING

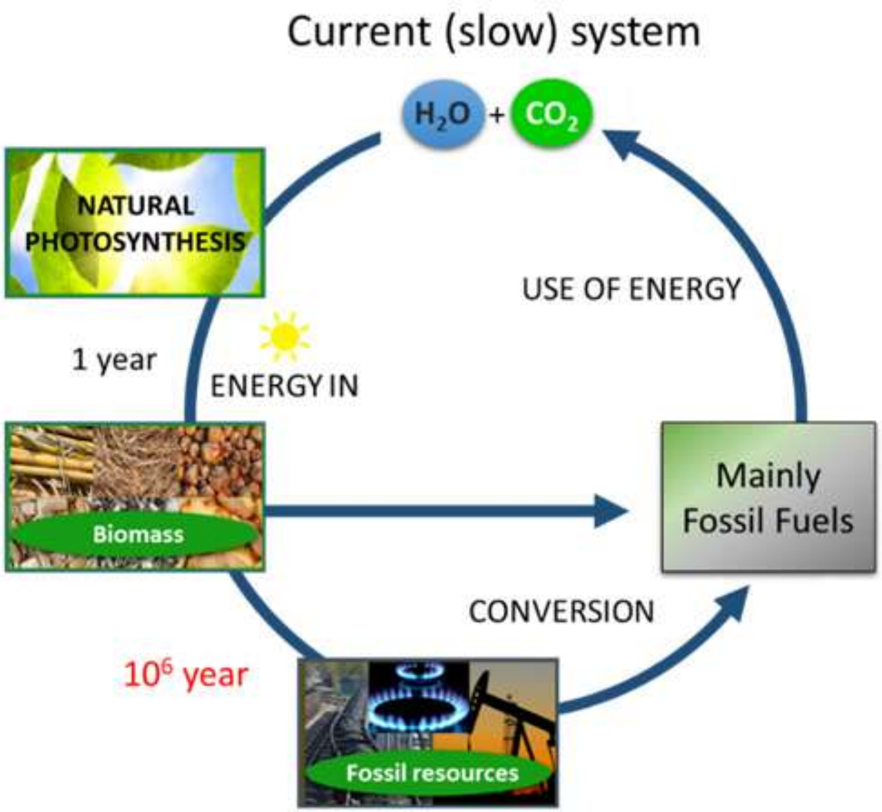
Energy Requirement (electricity) → Burn fossil fuel → CO_2 to atmosphere

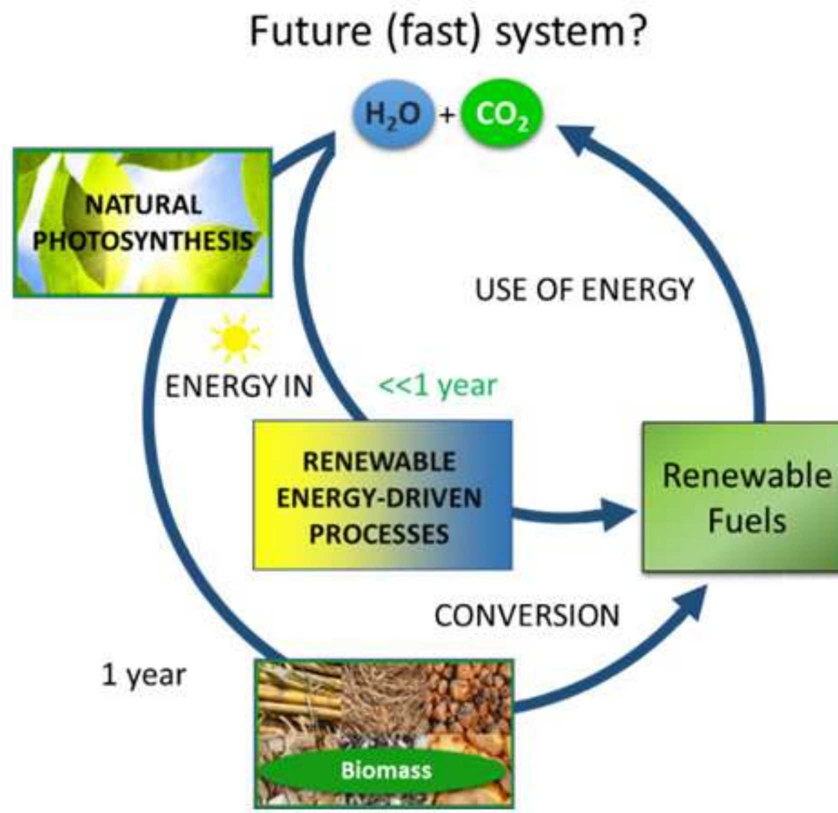
7 Use of Renewable Feedstock

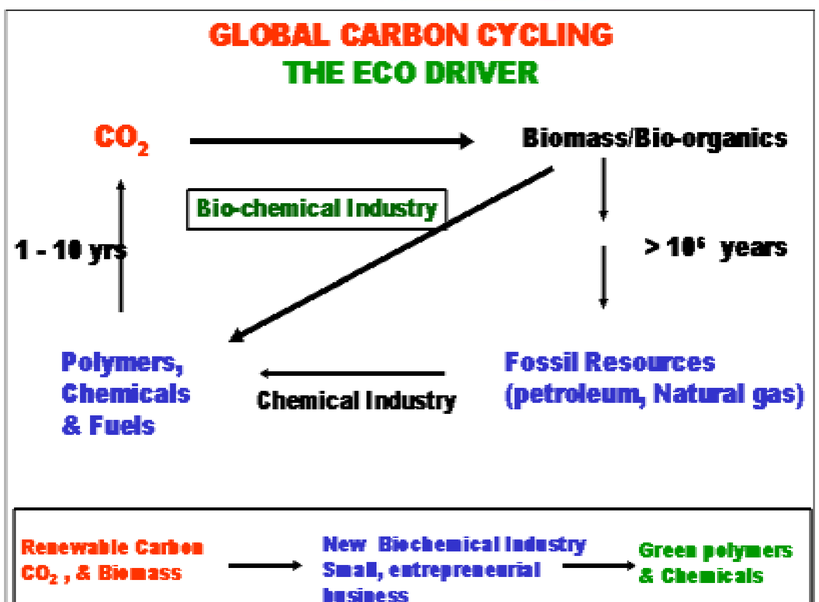
- A raw material or feedstock should be renewable rather than depleting whenever technically and economically practical.

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 feedstock (corn, potatoes, biomass) can be used to make many products: fuels (ethanol and bio-diesel), plastics and more.


Current (slow) system
H_2O + CO_2
NATURAL PHOTOSYNTHESIS
USE OF ENERGY
1 year
ENERGY IN
Biomass
Mainly Fossil Fuels
CONVERSION
10^6 year
Fossil resources

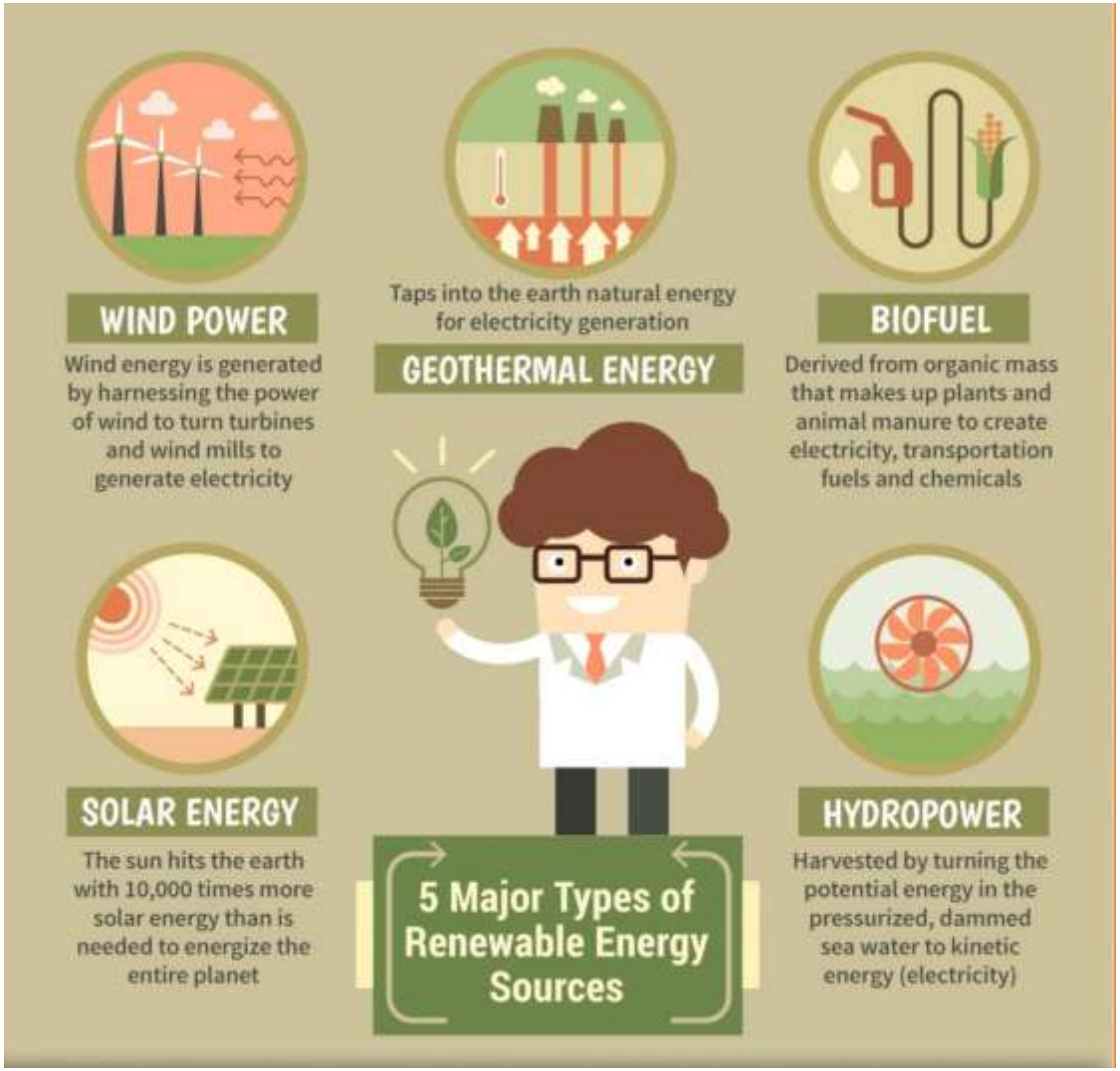

Future (fast) system?
H_2O + CO_2
NATURAL PHOTOSYNTHESIS
USE OF ENERGY
ENERGY IN
<<1 year
RENEWABLE ENERGY-DRIVEN PROCESSES
Renewable Fuels
CONVERSION
1 year
Biomass


GLOBAL CARBON CYCLING
THE ECO DRIVER
CO_2
Biomass/Bio-organics
Bio-chemical Industry
1 - 10 yrs
> 10^6 years
Polymers, Chemicals & Fuels
Chemical Industry
Fossil Resources (petroleum, Natural gas)
Renewable Carbon CO_2, & Biomass
New Biochemical Industry Small, entrepreneurial business
Green polymers & Chemicals


Bio-based plastics are made from a wide range of renewable BIO-BASED feedstocks.
Agro-based feedstocks – plants that are rich in carbohydrate, such as corn or sugar cane.
Ligno-cellulosic feedstocks – plants that are not eligible for food or feed production.
Organic waste feedstocks
Biorefinery
© European Bioplastics

Resource Depletion

- Renewable resources can be made increasingly viable technologically and economically through green chemistry.



Biomass

Carbon dioxide

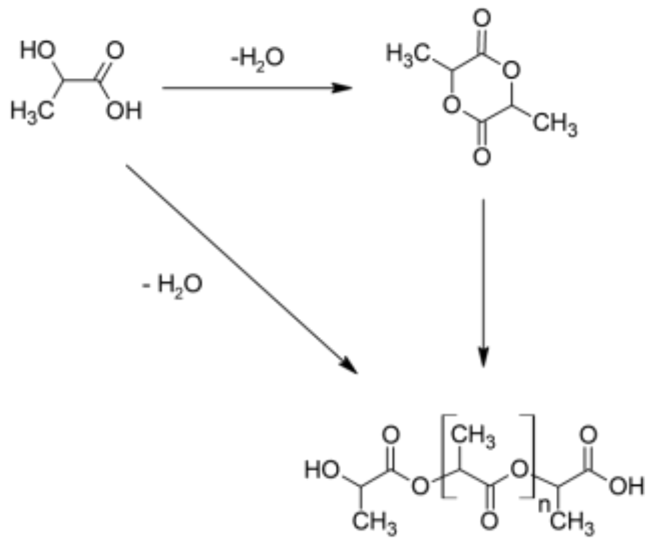
Solar

Nanoscience

Waste recycle and utilization

Polylactic acid (PLA) for plastics production

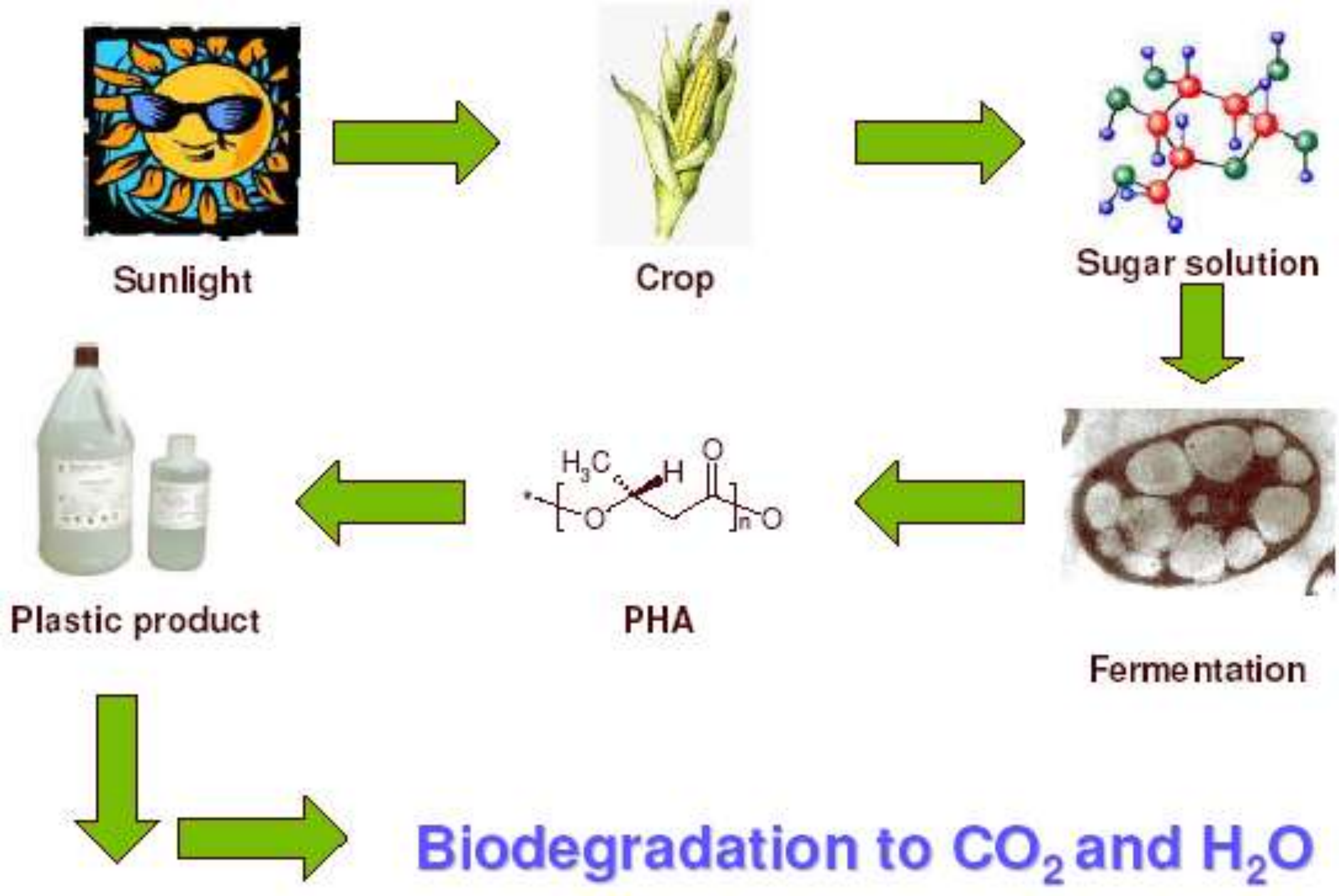
Corn → *Starch* → *Unrefined Dextrose* → ***Fermentation*** → *Lactic Acid* → ***Monomer Production*** → *Lactide* → ***Polymer Production*** → *PLA* → ***Polymer Modification***



Polymer Grades

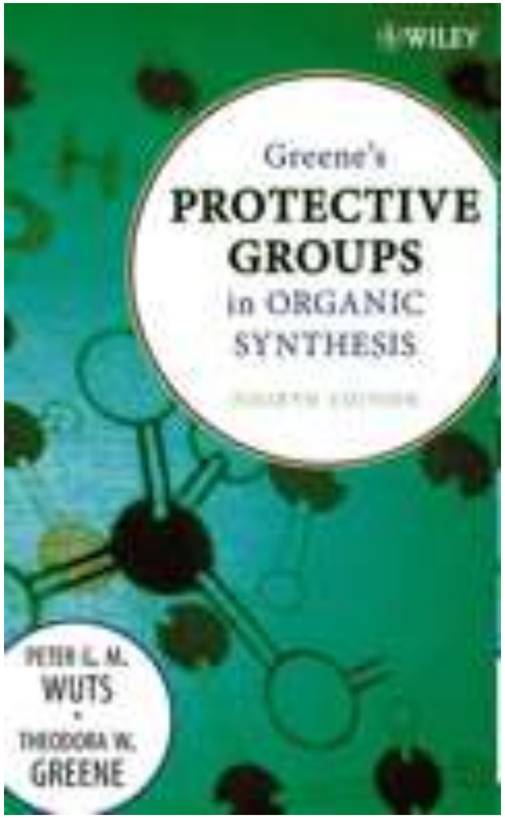
- Fiber
- Film
- Thermoforming
- Bottle
- Woven
- Non-woven
- Etc.

Polyhydroxyalkanoates (PHA’s) 聚羟基脂肪酸酯



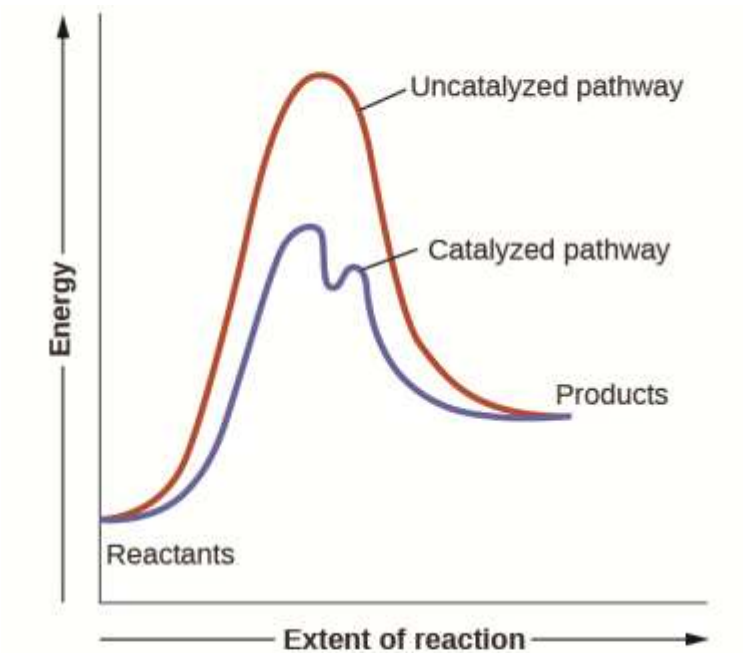
8 Reduce Derivatives

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



9 Catalysis

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



In chemistry and biology, **catalysis** is the substance which can accelerate the rate of a chemical reaction by lowering activation energy, and itself is not consumed during the overall reaction.

• Catalysts allow the development of new reactions which require fewer starting materials and produce fewer waste products.
• They can be recovered and reused time and time again.
• They allow reactions to run at lower temperatures, cutting the amount of activation energy required.

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.

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.

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.

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

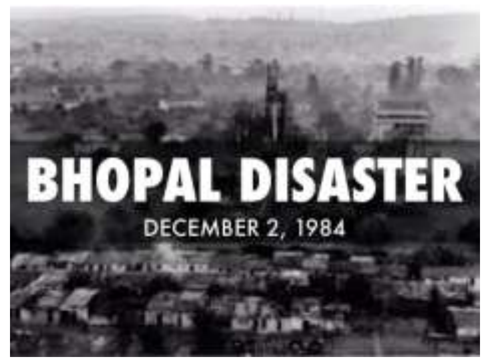
Knowing when your product is "done" can save a lot of waste, time and energy!

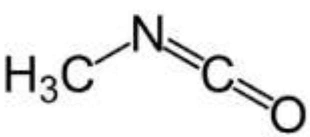
12 Inherently Safer Chemistry for Accident Prevention

- 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.

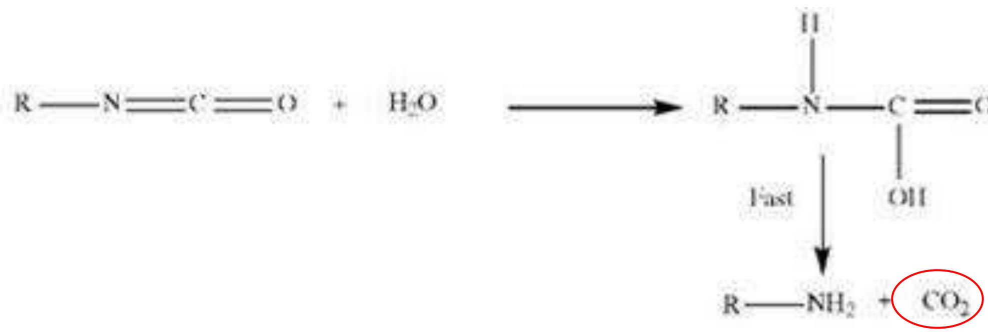
Tragedy in Bhopal, India - 1984

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 iniured.





- Clear, colorless, sharp smelling liquid
- Highly flammable
- Extremely toxic
- Volatile reaction with water in about 10 minutes



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

The major uses of GREEN CHEMISTRY

- Energy crisis
- Global Change
- Resource Depletion
- Food Supply
- Environment pollution

Energy

- The vast majority of the energy generated in the world today is from non-renewable sources that damage the environment.

  - Carbon dioxide
  - Depletion of Ozone layer
  - Effects of mining, drilling, etc
  - Toxics

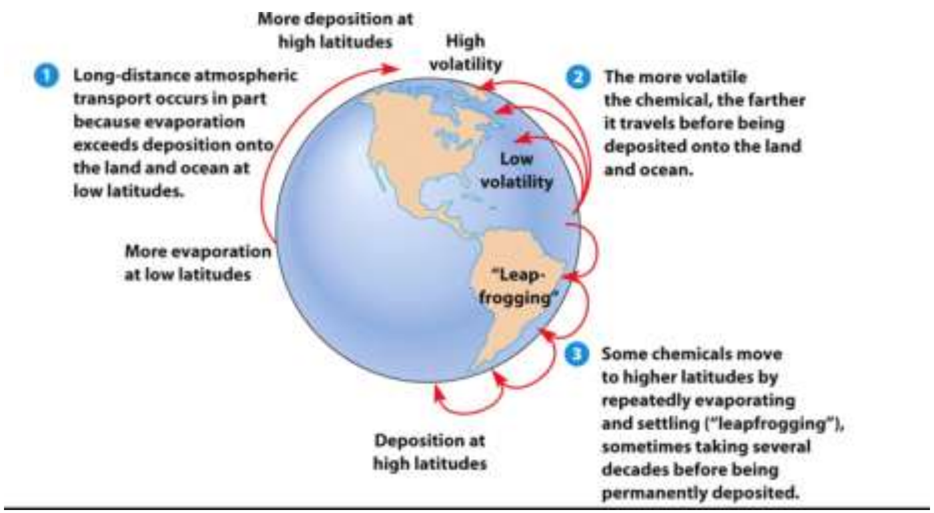
Energy

- Green Chemistry will be essential in
  - developing the alternatives for energy generation (photovoltaics, hydrogen, fuel cells, biomass fuels, etc.) as well as
  - continue the path toward energy efficiency with catalysis and product design at the forefront.

Global Change

- Concerns for climate change, oceanic temperature, stratospheric chemistry and global distillation can be addressed through the development and implementation of green chemistry technologies.

Global distillation: the process by which certain substances are transported from warmer to colder regions, which happens when chemicals and other pollutants that are released into the environment evaporate and in the form of vapour are then transported in colder areas where the vapour condenses and the pollutants are deposited as toxic rain or snow.



Resource Depletion

- Due to the over utilization of non-renewable resources, natural resources are being depleted at an unsustainable rate.
- Fossil fuels are a central issue.

Resource Depletion

- Renewable resources can be made increasingly viable technologically and economically through green chemistry.

  - Nanoscience & technology
  - Biomass
  - Solar
  - Carbon dioxide
  - Waste recycling and utilization

Food Supply

- Agricultural methods are unsustainable
- Future food production intensity is needed.
- Green chemistry can address many food supply issues

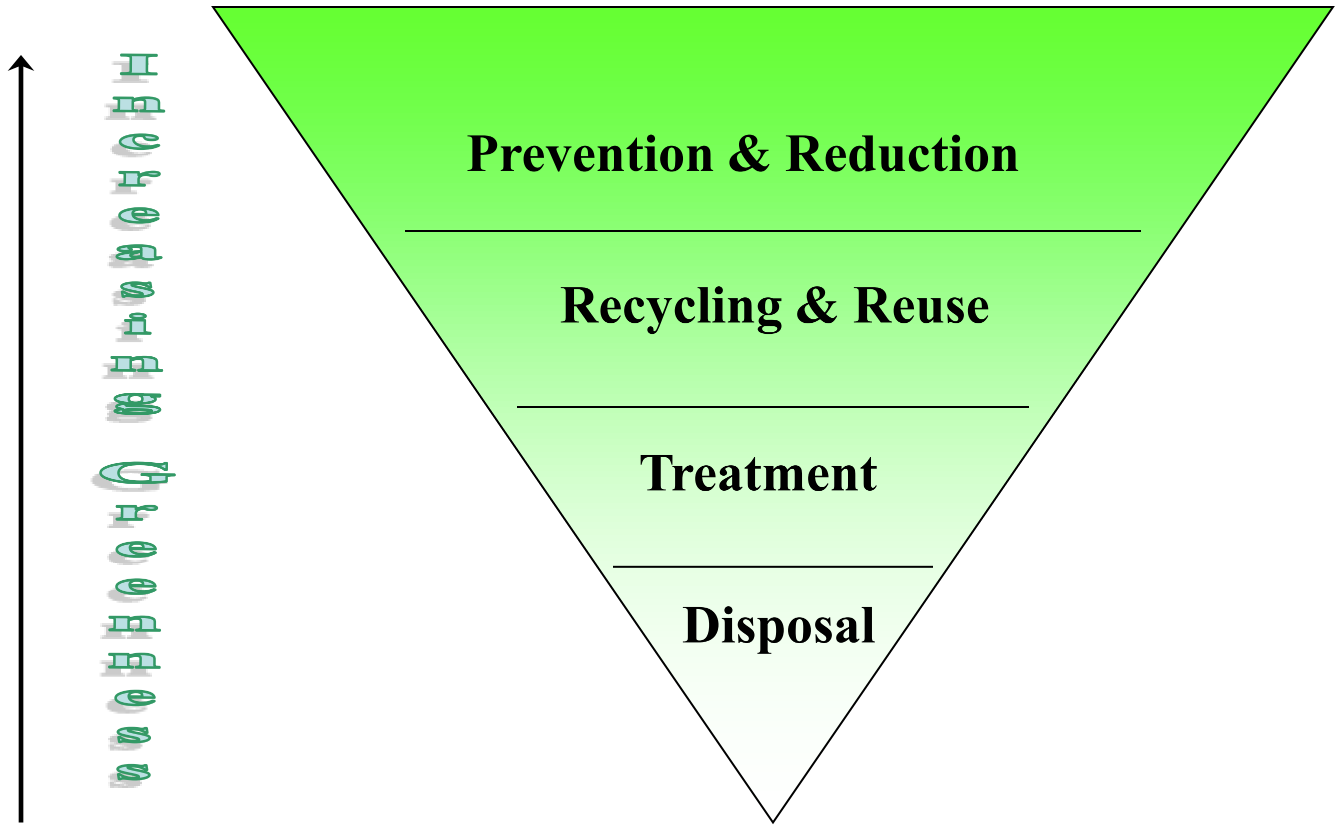
Food Supply

- Green chemistry is developing:
  - Pesticides which only affect target organisms and degrade to innocuous by-products.
  - Fertilizers and fertilizer adjuvants that are designed to minimize usage while maximizing effectiveness.
  - Methods of using agricultural wastes for beneficial and profitable uses.

Environment pollution

- Substances that are toxic to humans, the biosphere and all that sustains it, are currently still being released at a cost of life, health and sustainability.
- One of green chemistry's greatest strengths is the ability to design for reduced hazard.

Pollution Prevention Hierarchy



Conclusion

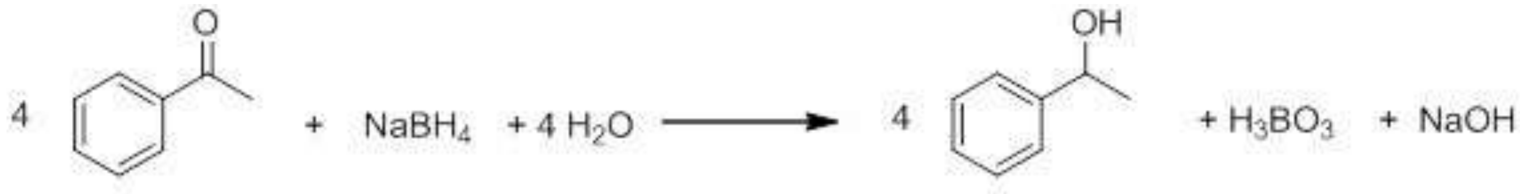
Green chemistry Not a solution to all environmental problems, But it is the most fundamental approach to prevent pollution.

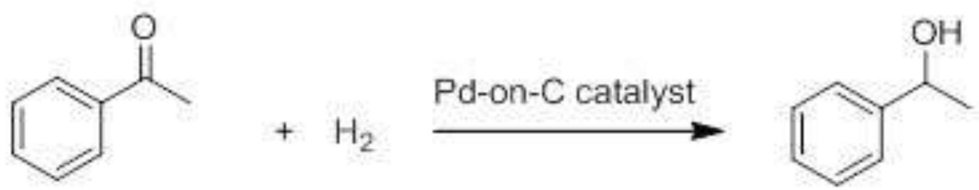
Presentation

• Oct. 09:	濮柳依	陈星回	周梓言
• Oct. 16:	赵与程	薛文杰	俞雅萍
• Oct. 23:	张欣妍	杨昕睿	方佳琳
• Oct. 30: :	徐驰瑞	葛俊辉	龚子惠
• Nov. 06	张思雨	贾牧言	窦鹏林
• Nov. 13:	华垒蕾	陆劭朴	董禹铜
• Nov.20:	肖林钰	邹荣开	许馨悦
• Nov.27:	周夏	石子玉	程荣松
• Dec. 04:	赵奕程	周阳	刘畅
• Dec. 11:	任思齐	袁昊	赵楦
• Dec. 18:	王子越	马少卿	熊浩宇

Home work

Calculate the atom economy the following reaction for the generation of 1-Phenylethanol?





That is all for today,

Thanks!