WHAT IS GREEN CHEMISTRY?

It is the design of chemical products and processes that reduce and eliminate the use and generation of hazardous substances.

THE FATHER OF GREEN CHEMISTRY

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Green Chemistry is about reducing

- Waste
- Materials
- Hazards
- Risks
- Energy
- Cost

Principles of Green Chemistry

Prevention. It is better to prevent waste formation than to treat it after it is formed.

Atom economy. Design synthetic methods to maximize incorporation of all material used into final product.

Less hazard. Synthetic methods should, where practicable, use or generate materials of low human toxicity and environmental impact.

Safer chemicals. Chemical product design should preserve efficacy whilst reducing toxicity.

Safer solvents. Avoid auxiliary materials - solvents, extractants - if possible, or otherwise make them innocuous.

Energy efficiency. Energy requirements should be minimized: conduct synthesis at ambient temperature and pressure.

Renewable feed stocks. Raw materials should, where practicable, be renewable.

Reduce derivatives. Unnecessary derivatization should be avoided where possible.

Smart catalysis. Selectively catalyzed processes are superior to stoichiometric processes.

Degradable design. Chemical products should be designed to be degradable to innocuous products when disposed of and not be environmentally persistent.

Real-time analysis for pollution prevention. Monitor processes in real time to avoid excursions leading to the formation of hazardous materials.

Hazard and accident prevention. Materials used in a chemical process should be chosen to minimize hazard and risk for chemical accidents, such as releases, explosions, and fires.

Principles of green chemistry

- Waste prevention
- Less hazardous chemical synthesis
- Safer solvent and auxillaries
- Use of renewable feedstocks
- Catalysis
- Real-Time Pollution prevention
- Atom economy
- Designing safer chemicals
- Design for energy efficiency
- Reduced derivatives
- Design for degradation
- Safer chemistry for accident prevention

BHOPAL GAS TRAGEDY

A PLANT ACCIDENT IN BHOPAL, INDIA, RELEASED METHYL ISOCYANATE. NEARLY 4000 PEOPLE DIED.

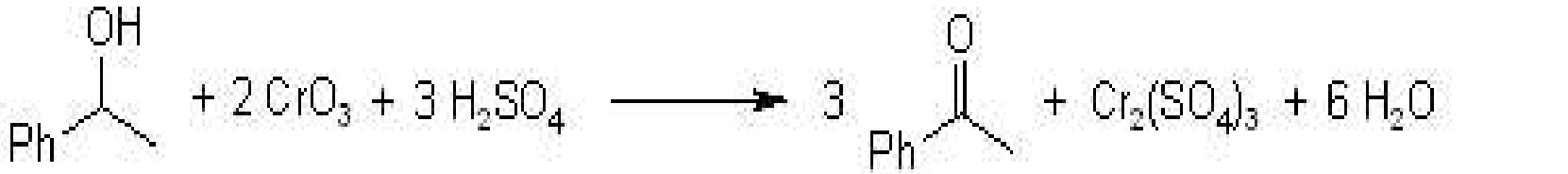
Examples of Green Chemistry

- Barry Trost's concept of atom economy for expressing efficiency of reaction
- New synthesis of Ibuprofen
- Use of waste carbon dioxide as a blowing agent instead of CFC's for foam polystyrene synthesis
- Development of carbon dioxide as a solvent for dry cleaning
- Development of oxidant activators for hydrogen peroxide in the manufacture of the paper
- Development of new insecticides

ATOM ECONOMY

$$\text{atom efficiency} = \frac{\text{molecular weight of desired product}}{\text{molecular weight of all substances formed}}$$

examples:



120 g / mol • 3 392 g / mol 18 g / mol • 6

$$\text{atom efficiency} = \frac{3 \cdot 120}{3 \cdot 120 + 392 + 6 \cdot 18} = 42\%$$

120 g / mol 18 g / mol

$$\text{atom efficiency} = \frac{120}{120 + 18} = 87\%$$

Tools of Green Chemistry

GREENER AND FUNCTIONAL SOLVENTS

Huge amounts of toxic, flammable and volatile organic solvents are used in chemical processes to prepare chemicals and materials. About 20 million tons of organic solvents are released to the atmosphere each year leading to solvent waste and environmental pollution. The use of greener solvents such as water, supercritical fluids, ionic liquids, non-toxic liquid polymers and their various combinations in chemical processes has become a major focus of research in academia and industry. A green solvent should meet some basic requirements such as low toxicity, ease of availability and recycling, and high process efficiency. It is known that the efficiency of a process usually depends strongly on the properties of the solvents used. Because of their special properties and functions, green solvents can be used to optimize chemical processes, decrease solvent usage and processing steps, and develop new routes and technologies that meet the requirements of sustainability.

GREEN ENGINEERING AND PRODUCTS

It should be emphasized that green chemistry covers engineering aspects and green products. Chemicals and materials are produced by industrial chemical processes, and therefore, clean, energy-efficient and mass-efficient processes and technologies are essential tools for achieving the goal of maximizing efficiency and minimizing wastes. Many current pharmaceuticals, fine chemicals, commodity chemicals and polymers are harmful. Products that are benign to human health and the environment need be designed and produced to replace hazardous products. Clearly, the exploration of synthetic routes, design of sustainable products and solvents, and exploration of new catalysts and chemical processes are closely related, and should be integrated. In addition, economic benefits are the central driver for the development of green chemistry and technology.

EFFICIENT SYNTHETIC ROUTES

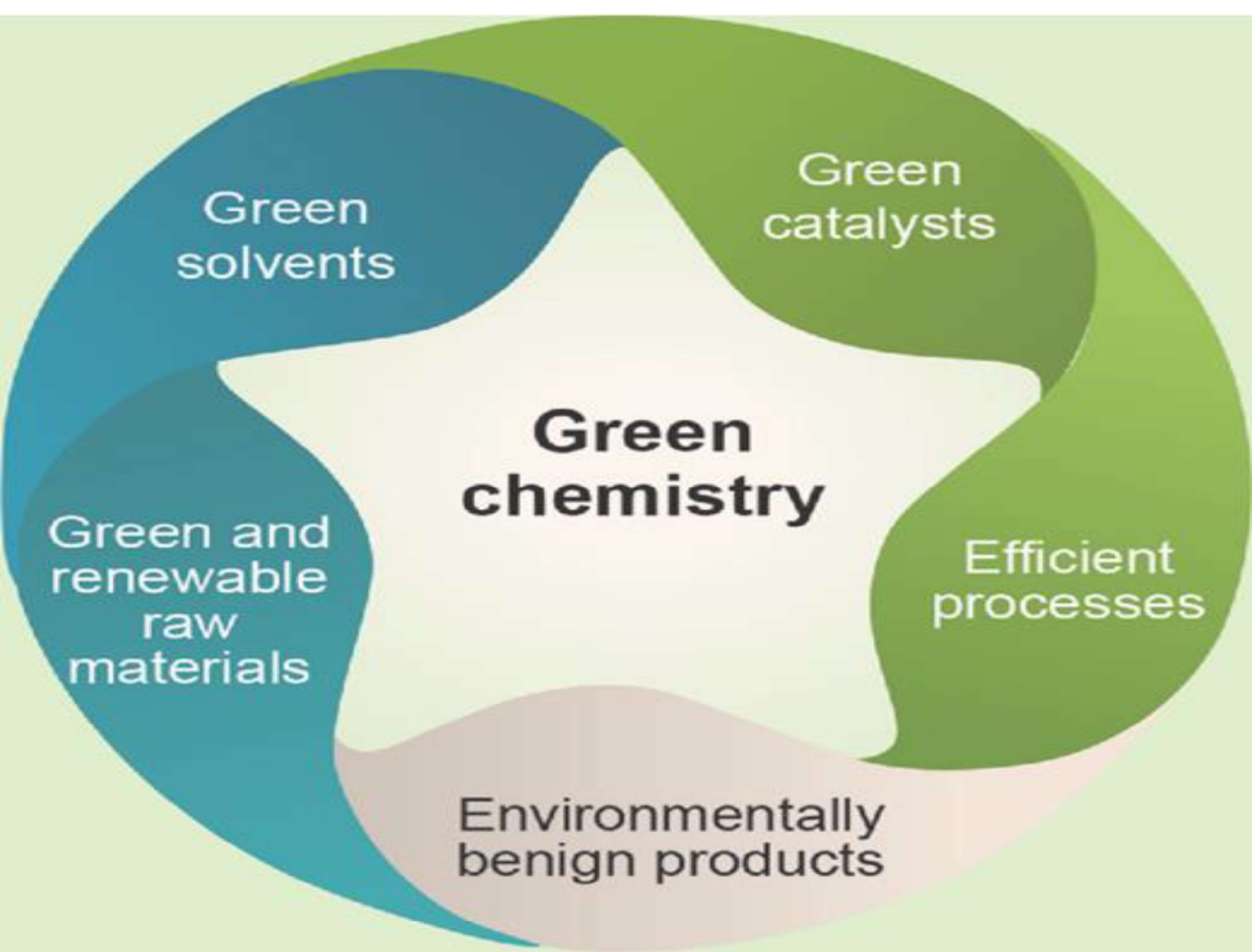
Most current chemical production processes lack efficiency in using feedstocks and produce large amount of wastes. Increasing atom economy is crucial for reducing both the depletion of raw materials and the generation of waste. Ideally, all the atoms in reactants should be transformed into the desired products. However, the achievement of 100% atom economy in all industrial chemical processes is not realistic. Another way to eliminate waste is integration of different reactions and processes, in which the by-product in one reaction is the feedstock of another. Exploration of atom-economic synthetic protocols and routes to increase the synthetic efficiency and reduce or eliminate wastes is a long-term task.

GREENER CATALYSIS

Catalysis plays a key role in the chemical industry because most chemical processes need catalysts to accelerate reactions, enhance selectivity and lower energy requirements. Current catalysts are often based on expensive, toxic, harmful or noble metals. Green catalysts should have some common characteristics such as high activity, selectivity, and stability, and ease of separation and reuse; they should be based on environmentally benign and widely available raw materials such as abundant metals, organic compounds and enzymes. The exploration and development of new synthetic routes and chemical processes rely strongly on progress in catalysis. The design and use of green catalysts and catalytic systems to achieve the dual goals of environmental protection and economic benefits is an important task, and is essential for the sustainability of the chemical industry.

USE OF GREEN AND RENEWABLE FEEDSTOCKS

Currently, our energy supply and the feed stocks for producing organic chemicals and materials are mainly based on fossil resources, which are not renewable and are diminishing. The use of renewable carbon resources, i.e. biomass and CO_2, in the chemical and energy industries is extremely important, and different routes and processes have been developed . However, we face thermodynamic, kinetic and technical challenges in the conversion of biomass and CO_2 into fuels and chemicals. Many current routes are technically feasible, but economically prohibitive, and only very small proportions of the resources are currently used. The development of efficient methods for converting biomass and CO_2 into useful chemicals and liquid fuels through energetically and economically viable industrial processes is of great importance, but is challenging. Moreover, the use of greener, cheaper, safer reactants and sustainable energy sources, such as oxygen, hydrogen peroxide and solar energy, in chemical processes is also an interesting area


Green solvents
Green catalysts
Green chemistry
Green and renewable raw materials
Efficient processes
Environmentally benign products

Goals of Green Chemistry

1. To reduce adverse environmental impact, try appropriate and innovative choice of material & their chemical transformation.
2. To develop processes based on renewable rather than non-renewable raw materials.
3. To develop processes that are less prone to obnoxious chemical release, fires & explosion.
4. To minimize by-products in chemical transformation by redesign of reactions & reaction sequences.
5. To develop products that are less toxic.

Goals of Green Chemistry

6. To develop products that degrade more rapidly in the environment than the current products.
7. To reduce the requirements for hazardous persistent solvents & extractants in chemical processes.
8. To improve energy efficiency by developing low temperature & low pressure processes using new catalysts.
9. To develop efficient & reliable methods to monitor the processes for better & improved controls.

ZERO WASTE TECHNOLOGY