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CBCS Sem-6 (Hons), DSE-A3 [Organic Chemistry]

GREEN CHEMISTRY

Introduction

- Green chemistry is also known as environmentally benign chemistry or sustainable chemistry .
- Paul Anastas is known widely as the 'Father of Green chemistry'. Anastas and John Warner, Who defined green chemistry as the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.
- Chemical developments also bring new environmental problems and harmful unexpected side effects, which result in the need for 'greener' chemical products.
- Green chemistry looks at pollution prevention on the molecular scale and is an extremely important area of chemistry due to the importance of chemistry in our world today and the implications it can show on our environment.
- The chemistry program supports the invention of more environmentally friendly chemical processes which reduce or eliminate the use and generation of hazardous substances.
- Anastas and Warner formulated the twelve principles of green chemistry in 1998. These serve as guidelines for chemists seeking to lower the ecologocal footprint of the chemicals they produce and processes by which such chemicals are made.
- The invention, design and application of chemical products and processes to reduce or eliminate the use and generation of hazardous substances.

What is Green Chemistry ?

1. Green Chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

   Or,

2. Green Chemistry is defined as invention, design, development and application of chemical products and processes to reduce or to eliminate the use and generation of substances hazardous to human health and environment.

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.

Twelve Principles of Green Chemistry (In brief) :

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

2) Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3) Wherever practicable, synthetic methodologies should be designed to use and generate substances that posses little or no toxicity to human health and the environment.
4) Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5) The use of auxiliary substances (e.g. solvents, separating agents etc.) should be made unnecessary wherever possible and innocuous when used.
6) 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.
7) A raw material feedstock should be renewable rather than depleting whenever technically and economically practical.
8) Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.
9) Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10) Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11) 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) Substances and the forms of the substance used in chemical reaction should be chosen so as to minimize the potential of chemical accidents, including releases, explosions, and fires.

TWELVE PRINCIPLES OF GREEN CHEMISTRY (In details)

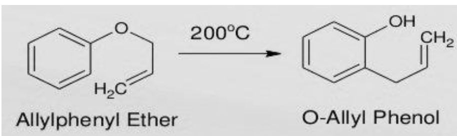
1. **Prevention of Waste or by-products** : It is better to prevent waste than to treat or clean up waste after it is formed.Therefore, " Prevention is better than cure."
2. **Atom Economy** : Atom economy (atom efficiency) describes the conversion efficiency of a chemical process in terms of all atoms involved (desired products produced).

   $$Atom\ Economy = \frac{Mol.\ wt\ of\ Desired\ product}{Mol.wt\ of\ all\ reactants} \times 100$$

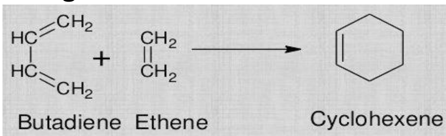
   For the reaction, atom economy should be maximum.

   Let us consider some common reactions like rearrangement, addition, substitution & elimination to find out which is more economical.

   - **Rearrangement Reactions :** These reactions involves only rearrangement of atoms that forms molecule. Hence, the atom economy of these reactions are 100%. e.g –



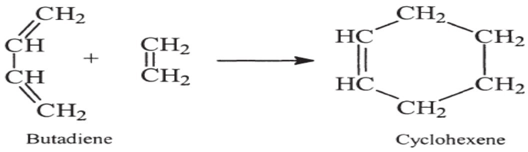
- **Addition Reactions :** These reactions involves only addition of two or more molecules without elimination that forms molecule. Hence, the atom economy of these reactions are 100%. e.g –



Next, the consider the addition of hydrogen to an olefin. Here also, all elements of the reactants are incorporated in the final product (propane).The reaction is a 100% atom economical reaction.

$$\underset{\text{Propene}}{H_3C\text{–}CH = CH_2} + H_2 \xrightarrow{Ni} \underset{\text{Propane}}{H_3C\text{–}CH_2\text{–}CH_3}$$

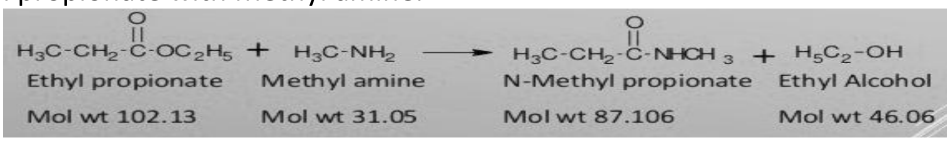
Similarly, Cycloaddition reaction and Bromination of Olefins are 100% atom economical reactions.



$$\underset{\text{Propene}}{H_3C\text{–}CH{=}CH_2} + Br_2 \longrightarrow H_3C\text{–}\underset{\underset{Br}{|}}{CH}\text{–}CH_2Br$$

1,2-Dibromopropane

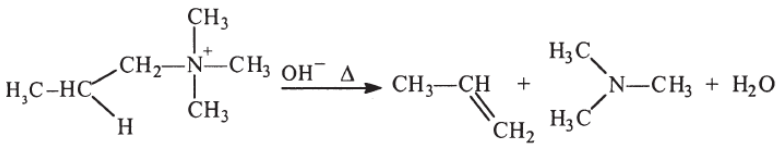
- **Substitution Reactions :** In these reactions one molecule substitute the some fragment and forms the product occupying that same position. H ence, the atom economy of these reactions should be maximum. e.g –
In substitution reactions, one atom or group of atoms are replaced by another atom or group of atoms. The atom or group of atoms that is replaced is not utilised in the final product. So, the substitution reaction is less atom-economical than rearrangement or addition reactions. Consider the substitution reaction of Ethyl propionate with Methyl amine.



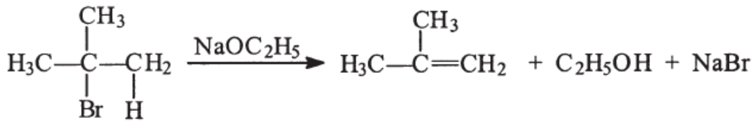
In this reaction, the leaving group (OC_2H_5) is not utilised in the formed amide. Also, one H-atom of the amine is not utilised. The remaining atoms of the reactants are incorporated into the final product.So, the total of atomic weights of the atoms in reactants that are utilised is 87.106g/mole, while the total molecular weight including the reagent used is 133.18g/mole. Thus, a molecular weight of 46.06g/mole remains unutilised in the reaction.
Therefore,

$$\%\ Atom\ Economy\ = \frac{87.106}{133.18} \times 100 = \ 65.4\ \%$$

- **Elimination Reactions :**
In an elimination reaction, two atom or group of atoms are lost from the reactant to form a π–bond. Consider the following Hofmann elimination



This elimination reaction is not very atom-economical. The % of atom economy is 35.3 %. In fact this is least atom-economical of all the above reactions.
Consider, another elimination reaction involving the dehydrohalogenation of 2-bromo-2-methylpropane with sodium ethxide to give 2-methylpropane.



2-Bromo-2-methylpropane 2-Methylpropane

This dehydrohalogenation (an elimination reaction) is also not very atom-economical. The % of atom economy or utilisation is 27 % which is even less atom-economical than the Hofmann elimination reaction.

3. **Minimization of hazardous products** : Wherever practicable, synthetic methods should be designed to use and generate substances that posses little or no toxicity to people or the environment.
   The most important principle of green chemistry is to prevent or at least minimize the formation of hazardous products, which may be toxic or environmentally harmful. The effect of hazardous substances if formed may be minimised for the workers by the use of protective clothing, engineering controls, respirator etc. This, however, adds to the cost of production. It is found that sometimes the controls can fail and so there is much more risk involved. Green chemistry, in fact, offers a scientific option to deal with such situations.

4. **Designing Safer Chemicals** : Chemical products should be designed to effect their desired function while minimising their toxicity.
   It is of paramount importance that the chemicals synthesised or developed (e.g. dyes, paints, adhesives, cosmetics, pharmaceuticals etc.) should be safe to use. A typical example of an unsafe drug is thalidomide (introduced in 1961) for lessening the effects of nausea and vomiting during pregnancy (morning sickness). The children born to women taking the drug suffered birth defects (including missing or deformed limbs). Subsequently, the use of thalidomide was banned, the drug withdrawn and strict regulations passed for testing of new drugs, particularly for malformation-inducing hazards. With the advancement of technology, the designing and production of safer chemicals has become possible. Chemists can now manipulate the molecular structure to achieve this goal.

5. **Safer Solvents & Auxiliaries** : "The use of auxiliary substances (e.g. solvents, separating agents etc.) should be made unnecessary wherever possible and innocuous when used."
   - Water should be used as a solvent.
   - If water is not usable then more ecofriendly solvents like supercritical CO_2 or ionic solvents.

- As far as possible synthesis is carried out without solvents.

An auxiliary substance is one that helps in manufacture of a substance, but does not become an integral part of the chemical. Many solvents used in traditional organic synthesis are highly toxic. The Green Chemistry approach to the selection of solvents has resulted in several strategies. One method that has been developed is to use supercritical carbon dioxide as a solvent. Supercritical carbon dioxide is formed under conditions of high pressure in which the gas and the liquid phases of carbon dioxide combine to a single–phase compressible fluid that becomes an environmentally benign solvent (temperature 31^{o}C, 7280 kPa, or 72 atms). Supercritical CO_2 has remarkable properties. It behaves as a material whose properties are intermediate between those of a solid and those of a liquid.The properties cab be controlled by manipulating temperature and pressur. Supercritical CO_2 is environmentally benign because of its low toxicity and easy recyclability. Carbon dioxide is not added to the atmosphere; rather, it is removed from the atmosphere for use in chemical processes. It is used as a medium to carry out a large number of reactions that would otherwise have many negative environmental consequences. It is even possible to perform stereoselective synthesis in supercritical CO_2. Some reactions can be carried out in ordinary water, the most green solvent possible. Recently, there has been much success in using near-critical water at higher temperatures where water behaves more like an organic solvent .Eckert and Liotta were able to run Friedel-Crafts reactions in near–critical water without the need for the acid catalyst $AlCl_3$, which is normally used in large amounts in these reactions. In the past 5 years, many new ionic liquids have been developed with a broad range of properties. By selecting the appropriate ionic liquid, it is now possible to carry out many types of organic reactions in these solvents. In some reactions, a well – designed ionic solvent can lead to better yields under milder conditions than is possible with traditional solvents.

6. **Design for Energy Efficiency** : Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized.
   If possible, synthetic methods should be conducted at ambient temperature and pressure.
   This can be achieved by-
   - Use of proper catalyst, enzymes
   - Use of micro organisms
   - Use of renewable materials

   In case the reaction is exothermic, sometimes extensive cooling is required. This adds to the overall cost. If the final product is impure, it has to be purified by distillation, recrystallisation or ultrafiltration. All these steps involve the use of energy. By designing the process such that there is no need for separation or purification, the final energy requirements can be kept at the bare minimum. Energy to a reaction can be supplied by photochemical means, microwave.
   The requirement of energy can be kept to a base minimum in certain cases by the use of a catalyst. For example in conversion of benzyl chloride into benzyl cyanide if we use phase transfer catalyst, the conversion goes to completion in a very short time.

$$C_6H_5CH_2Cl + \text{aq } KCN \longrightarrow C_6H_5CH_2CN + KCl$$

Benzyl chloride   Benzyl cyanide

Conventionally, we have been carrying reaction by heating on wire gauze, in oil bath or heating mantels. It is now possible that the energy to a reaction can be supplied by using microwaves, by sonication or photo chemically. Simple examples are –

(a) $$C_6H_5CONHC_6H_5 \xrightarrow[\text{MW, 12 MINS}]{} C_6H_5COOH$$

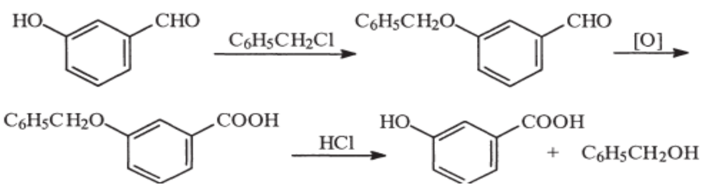
(b) $$RCOOH + ROH \xrightarrow[H_2SO_4,\text{Ultrasound}]{\text{Esterification}} RCOOR$$

7. **Use of Renewable Feedstock** : "A raw material or feedstock should be renewable rather than depleting whenever technically and ecomonically practicable."

   Non reversible or depleting sources can exhausted by their continual use. So these are not regarded as sustainable from environmental point of view. The starting materials which are obtained agricultural or biological processes are referred to as renewable starting materials. Substances like carbon dioxide (generated from natural sources or synthetic routes like fermentation etc) and methane gas (obtained from natural sources such as marsh gas, natural gas etc) are available in reasonable amounts and so are considered as renewable starting material. Methane, a constituent of biogas and natural gas can easily be converted into acetylene by partial combustion. Acetylene is a potential source of number of chemicals such as ethyl alcohol, acetaldehyde, vinyl acetate etc.

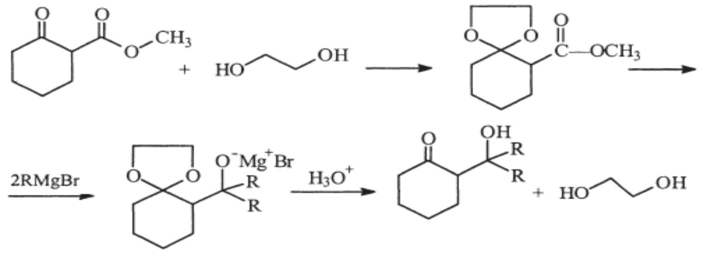
8. **Reduce Derivatives** : Unnecessary derivatization (use of blocking groups, protection/de-protection and temporary modification of physical or chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
   More derivatives involve –
   - Additional Reagents
   - Generate more waste products
   - More Time
   - Higher Cost of Products
   - Hence, it requires to reduce derivatives.

   A commonly used technique in organic synthesis is the use of protecting or blocking group. These groups are used to protect a sensitive moiety from the conditions of the reaction, which may make the reaction to go in an unwanted way if it is left unprotected. This procedure adds to the problem of waste disposal.
   In case an organic molecule contains two reactive groups and you want to use only one of these groups, the other group has to be protected, the desired reaction completed and the protecting group removed. For example



Reactions of this type are common in the synthesis of fine chemicals, pharmaceuticals, pesticides etc. In the above protection, benzyl chloride (a known hazard) and the waste generated after deprotection should be handled carefully.

Another reaction involving protection of a keto function by using 1,2- ethanediol is as follows:

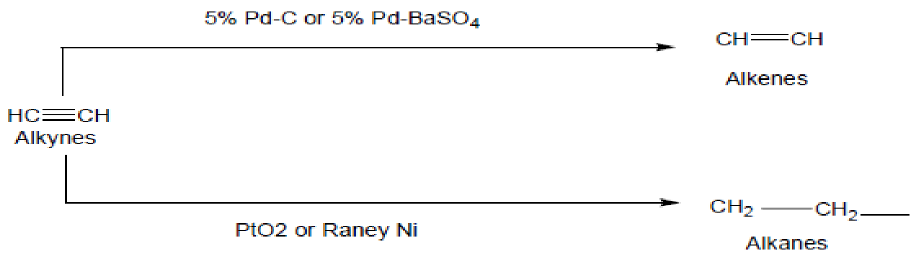


Thus, we see that the protecting groups that are needed to solve a chemoselectivity problem should be added to the reaction in stoichiometric amounts only and removed after the reaction is complete. Since these protecting groups are not incorporated into the final product, their use makes a reaction less atom-economical. In other words the use of protective group should be avoided whenever possible. Though atom-economy is a valuable criteria in evaluating a particular synthesis as 'green', other aspects of efficiency must also be considered.

9. **Catalysis** : Catalytic reagents (as selective as possible) are superior to stoichiometric reagents. e.g- Toluene can be exclusively converted into *p*-xylene (avoiding *o*-xylene & *m*-xylene) by shape selective zeolite catalyst.

   Catalyst make the -
   - Reaction faster
   - Decrease the energy requirement
   - Minimize waste

   The catalyst as we know facilitates transformation without being consumed or without being incorporated into the final product. Catalysts are selective in their action in that the degree of reaction that takes place is controlled, e.g. mono addition v/s multiple addition. A typical example is that reduction of triple bond to a double bond or single bond.



In addition to the benefits of yield and atom economy, the catalysts are helpful in reducing consumption of energy. Catalysts carry out thousands of transformation before being exhausted.

10. **Designing of degradable products** : 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.

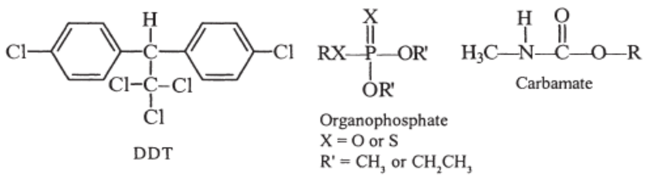
It is extremely important that the products designed to be synthesized should be biodegradable. They should not be persistent chemicals or persistent bio accumulators. It is now possible to place functional groups in a molecule that will facilitate its biodegradation. Functional groups which are susceptible to hydrolysis, photolysis or other cleavage have been used to ensure that products will be biodegradable. It is also important that degradation products do not possess any toxicity and detrimental effects to the environment. Plastic, Pesticides (organic halogen based) are examples which pose to environment.

Examples :

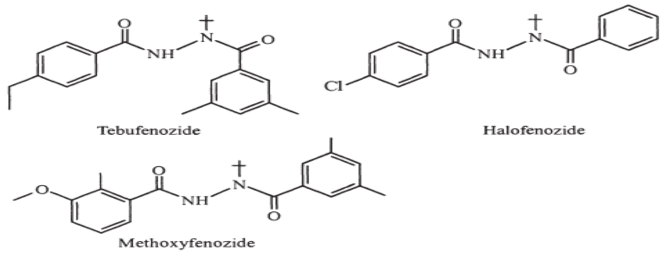
- Polyethylene, Polystyrene are not biodegradable but biodegradable polymer like Polyhydroxybutyrate-hydroxyvalarate (PHBV).
- Synthetic insecticides remains in the food grains, vegetables and do not degraded but natural insecticides (Chilli, neems etc.) get easily degraded after killing the insect

Insecticides

It is well known that farmers use different types of insecticides to protect crops from insects. The more widely used insecticides are organophosphates, carbamates and organochlorides. Of these, organophosphates and carbamates are less persistent in the environment compared to the organochlorides (for example aldrin, dieldrin and DDT). Though the latter are definitely effective but they tend to bioaccumulate in many plant and animal species and incorporate into the food chain. Some of the insecticides are also responsible for the population decline4 of beneficial insects and animals, such as honeybees, lacewings, mites, bald eagles etc.



Considering the above, it is of utmost importance that any product (e.g. insecticides) synthesised must be biodegradable. It is also equally important that during degradation the products themselves should not possess any toxic effects or be harmful to human health. It is possible to have a molecule (e. g. insecticide) which may possess functional groups that facilitate its biodegradation. The functional groups should be susceptible to hydrolysis, photolysis or other cleavage. Some of the diacylhydrazines (developed by Rohm and Hass Company) which have been found to be useful as insecticides are:



11. **New Analytical Methods** : “Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.”
Analytical techniques should be so designed that they require minimum usage of chemicals, like recycling of some unreacted reagent (chemical) for the completion of a particular reaction. Further, placement of accurate sensors to monitor the generation of hazardous by-products during chemical reaction is also advantageous.
Methods and technologies should be developed so that the prevention or minimization of generation of hazardous waste is achieved. It is necessary to have accurate and reliable reasons, monitors and other analytical methodologies to assess the hazardous that may be present in the process stream. These can prevent any accidents which may occur in chemical plants.

12. **Safer Chemicals For Accident Prevention** : “Analytical Substances and the form of a substance used in a chemical proces should be chosen to minimize the potential for chemical accidents, including releases, explosions and fires.”
    - The reagents and reactions should be risk free in the chemicals process to minimize the chemical accidents, explosions, fires & gas release.

The occurrence of accidents in chemical industry must be avoided. It is well known that the incidents in Bhopal (India) and Seveso (Italy) and many others have resulted in the loss of thousands of life. It is possible sometimes to increase accidents potential inadvertently with a view to minimize the generation of waste in order to prevent pollution. It has been found that in an attempt to recycle solvents from a process (for economic reasons) increases the potential for a chemical accident or fire.

Q1. What do you mean by Atom Economy ?

The concept of Atom Economy was developed by Barry Troast of Stanford University. Atom Economy is the amount of starting materials incorporated into desired product. The objective of it is to create synthesis in which most of the atoms of the reactants become incorporated into desired final product, so fewer waste by products are obtained.

$$\text{Atom Economy} = \frac{Mol.\ wt\ of\ Desired\ product}{Mol.wt\ of\ all\ reactants} \times 100$$

Needs of Green Chemistry

WHY DO WE NEED GREEN CHEMISTRY?

- Chemistry is undeniably a very prominent part of our daily lives.
- Chemical developments also bring new environmental problems and harmful unexpected side effects, which result in the need for 'greener' chemical products.
- A famous example is the pesticide DDT.
- **Green chemistry** looks at pollution prevention on the molecular scale and is an extremely important area of Chemistry due to the importance of Chemistry in our world today and the implications it can show on our environment.
- The **Green Chemistry** program supports the invention of more environmentally friendly chemical processes which reduce or even eliminate the generation of hazardous substances.
- This program works very closely with the twelve principles of **Green Chemistry.**

Goals or Aims or Objectives

OBJECTIVES

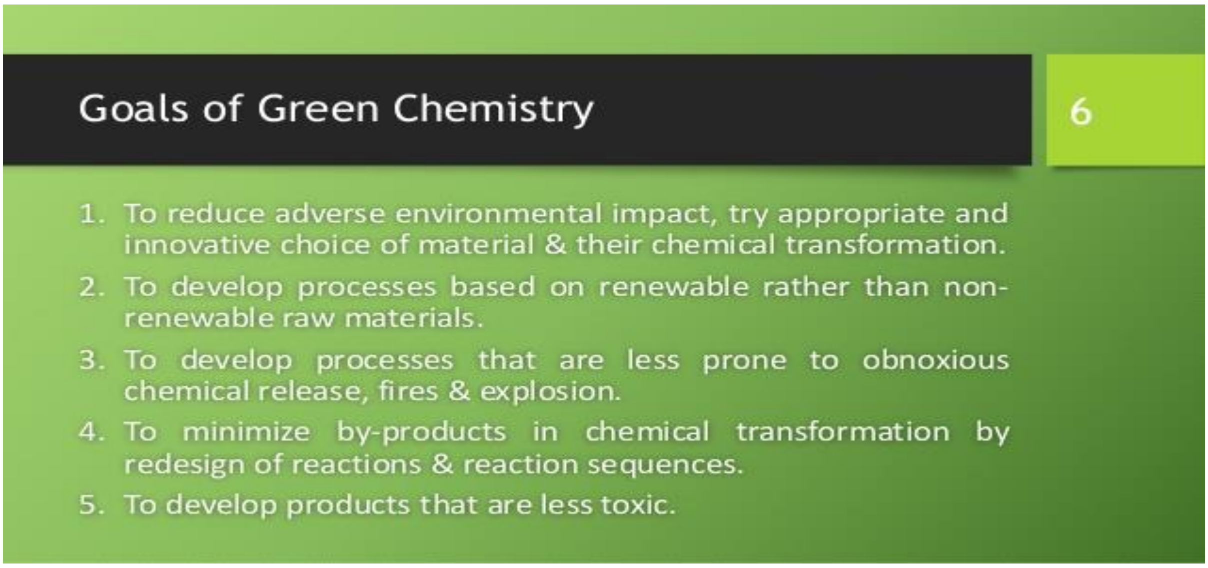
• To reduce the rate of growth of energy consumption while enhancing economic development;

• To facilitate the growth of the Green Technology industry and enhance its contribution to the national economy;

• To increase the capacity for innovation in Green Technology development and enhance competitiveness in Green Technology in the field;

• To ensure sustainable development and preserve the environment for future generations, and

• To increase public awareness and education on green technology and encourage its widespread use Green Technology.



Goals of Green Technology

The aims of green technology are myriads. The major objective of green technology is to meet the needs of society in ways without damaging or depleting natural resources on the planet. In addition, the opinion is to meet the present needs without making any compromise. Besides, it is required to find the right destination to get all about the goals of this kind of technology. The concentration of green technology is to make products which can be fully reclaimed or reused. In addition, steps are being taken to decrease wastes and pollution as one of the most indispensable aims of green technology via changing patterns of production and consumption. Moreover, it is necessary to improve alternative technologies to hamper any further damage to environment and health. The solution is precipitation in the implementation of these kind of technologies to benefit and protect the earth. The important goals of green technology introduce sustainable living, develop renewable energy, decrease production of waste, conserve the utilization of natural resources, creation of products which are reusable and recyclable, and inventing alternatives to the practices which adversely affect the human and environment.

GOALS OF GREEN TECHNOLOGY

The goals of green technology are many. To meet the needs of society in ways without damaging or depleting natural resources on earth is the main objective of green technology. The idea is to meet present needs without making any compromises. You have reached the right destination to know all about the goals of green technology.

Focus is being shifted on making products that can be fully reclaimed or re-used. By changing patterns of production and consumption, steps are being taken to reduce waste and pollution, as one of the important goals of green technology. It is essential to develop alternative technologies to prevent any further damage health and the environment. Speeding their implementation can benefit our environment and truly protect the planet. Explore the goals of green technology, introducing sustainable living, develop renewable energy and reduce waste.

Advantages or Disadvantages

Benefits or advantages of Green Technology

Following are the **advantages of Green Technology**:

➨It does not emit anything harmful for the environment.

➨It has become popular as consumers of the technology are becoming more environment conscious. This will give benefits to investors at long run in certain areas.

➨It requires less cost for maintenance. This reduces operating cost and hence overall cost on the long run.

➨As it uses renewable natural resources and hence we will never run out of vital resources such as water and electricity.

➨It will slow down effects of global warming due to reduction in CO_2 emissions.

Limitations or Challenges or disadvantages of Green Technology

Following are the **disadvantages of Green Technology**:

➨Initial investment or implementation cost is very high.

➨People are still not familiar with the technology and hence will take time to adopt it for larger population.

➨The technology is still evolving and many of the products are at R&D stage. Hence people are unaware of performance results.

➨Lack of skilled human resources are available to install or implement the green technology based products or systems.

➨In most of the countries policies have not been finalized for the green technology based systems.

Disadvantages or Challenges to Green Technology Adoption

In general, green technology is **more expensive** than the technology it aims to sub, because it accounts for the environmental costs which hare externalized in many conventional production processes. This is a novel technology and there is many things in it which is unknown. In addition, the associated improvement and training costs make it even more costly in comparison with other established technologies. The perceived profits regarding this technology are also pertain to other factors for instance supporting infrastructure, technology readiness, human resource capabilities and geographic elements. Adoption and circulation of these technologies can be limited by a number of other obstacles. Some may be institutional like the lack of an appropriate regulatory framework, and others can be technological, financial, political, cultural or legal in nature. Besides, from company's view, the barriers to adopting green technology are high implementing costs, lack of data and information, no or lack of alternative chemical or raw material inputs, uncertainty regarding performance impacts, lack of human resources and finally, lack of skilled personnel. In addition, overcoming these barriers is a complicated process. Promoting green growth needs identifying and removing these obstacles which prevent the large-scale dissemination of clean technology to improve countries.

Advantages of Green Processes and Technology

1. Does not release anything detrimental into atmosphere
2. Bring economic profits to certain areas

3. Need less maintenance

4. It is renewable which means will never run out

5. Slow the impacts of global warming by reducing CO_2 emissions

The advantage of using green energy sources is that it must be clean therefore there is no discharge or damage into the environment or atmosphere.

Disadvantages of Green Processes and Technology

Green processes and technology refers to making efforts to improve energy efficiency or reduce the pollution produced by your home, business and general living habits. The main purpose of this kind of processes and technology is to reduce the potential negative impact that energy consumption and pollution can have on the environment. While environmentally friendly living is a positive ideal, there are several possible disadvantages of Green processes and technology such as: high implementing costs, lack of information, no known alternative chemical or raw material inputs, no known alternative process technology, uncertainty about performance impacts, and lack of human resources and skills.

ADVANTAGES OF GREEN TECHNOLOGY

1. Does not emit anything harmful into the air
2. Can bring economic benefits to certain areas.
3. Requires less maintenance so you don't have to shell out alot of money to operate it
4. Renewable which means we will never run out.
5. Can slow the effects of global warming by reducing CO_2 Emissions.

DISADVANTAGES TO ADOPTING GREEN TECHNOLOGIES

- High implementing costs.
- Lack of information.
- No known alternative chemical or raw material inputs
- No known alternative process technology
- Uncertainty about performance impacts
- Lack of human resources and skills.[4]

Benefits or Advantages of Green Chemistry

Human health:

- Cleaner air: Less release of hazardous chemicals to air leading to less damage to lungs
- Cleaner water: less release of hazardous chemical wastes to water leading to cleaner drinking and recreational water
- Increased safety for workers in the chemical industry; less use of toxic materials; less personal protective equipment required; less potential for accidents (e.g., fires or explosions)
- Safer consumer products of all types: new, safer products will become available for purchase; some products (e.g., drugs) will be made with less waste; some products (i.e., pesticides, cleaning products) will be replacements for less safe products
- Safer food: elimination of persistent toxic chemicals that can enter the food chain; safer pesticides that are toxic only to specific pests and degrade rapidly after use
- Less exposure to such toxic chemicals as endocrine disruptors

Environment:

- Many chemicals end up in the environment by intentional release during use (e.g., pesticides), by unintended releases (including emissions during manufacturing), or by disposal. Green chemicals either degrade to innocuous products or are recovered for further use
- Plants and animals suffer less harm from toxic chemicals in the environment
- Lower potential for global warming, ozone depletion, and smog formation
- Less chemical disruption of ecosystems
- Less use of landfills, especially hazardous waste landfills

Economy and business:

- Higher yields for chemical reactions, consuming smaller amounts of feedstock to obtain the same amount of product
- Fewer synthetic steps, often allowing faster manufacturing of products, increasing plant capacity, and saving energy and water
- Reduced waste, eliminating costly remediation, hazardous waste disposal, and end-of-the-pipe treatments
- Allow replacement of a purchased feedstock by a waste product
- Better performance so that less product is needed to achieve the same function
- Reduced use of petroleum products, slowing their depletion and avoiding their hazards and price fluctuations
- Reduced manufacturing plant size or footprint through increased throughput

- Increased consumer sales by earning and displaying a safer-product label (e.g., Safer Choice labeling)
- **Green Technology satisfy the following criteria:**

a) It minimizes the degradation of the environment;

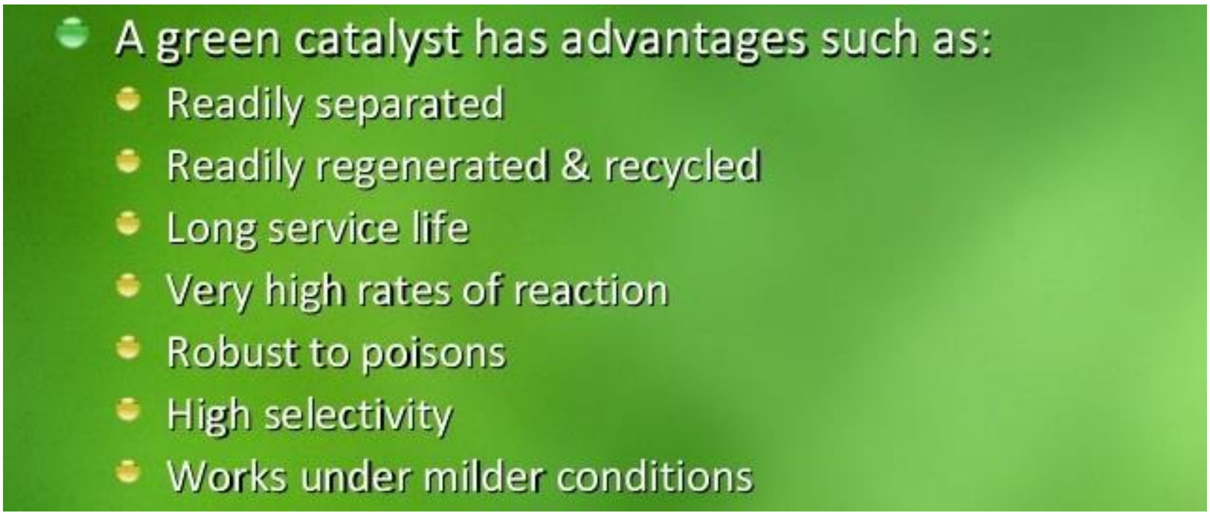
b) It has zero or low greenhouse gas (GHG) emission is safe for use and promotes healthy and improved environment for all forms of life;

c) It conserves the use of energy and natural resources;

d) It promotes the use of renewable resources.

Green chemistry:

- Prevents pollution at the molecular level
- Is a philosophy that applies to all areas of chemistry, not a single discipline of chemistry
- Applies innovative scientific solutions to real-world environmental problems
- Results in source reduction because it prevents the generation of pollution
- Reduces the negative impacts of chemical products and processes on human health and the environment
- Lessens and sometimes eliminates hazard from existing products and processes
- Designs chemical products and processes to reduce their intrinsic hazards



- Certain chemicals are used as green catalysts which reduce the incidence of toxic chemicals formed in a reaction by converting them to less toxic or harmless substances.
- Oxidation catalysts, called Fe-TAML® (tetra-amido macrocyclic ligand) activators, are made from elements found in nature and work with hydrogen peroxide to convert harmful pollutants into less toxic or harmless substances*.

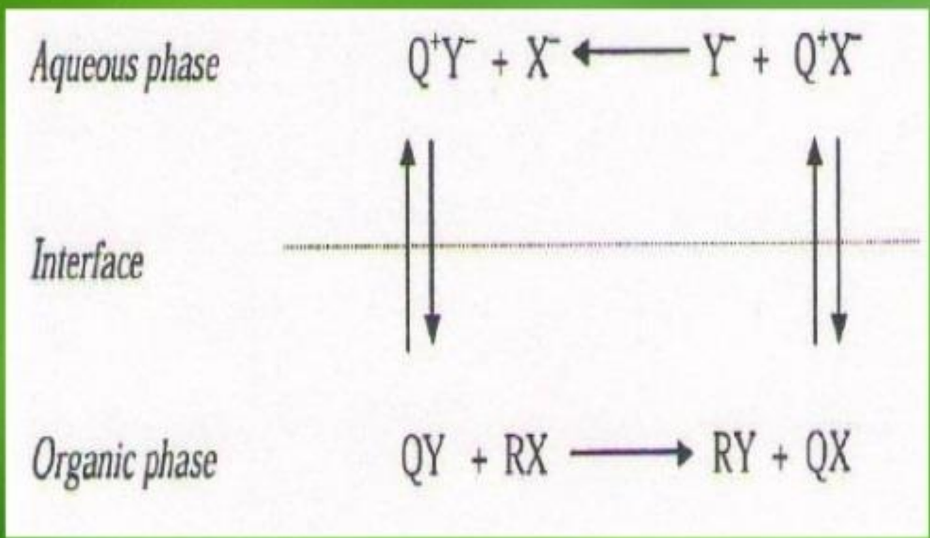
Biocatalysis:

- Enzymes or whole-cell microorganisms are used.
- Benefits include:
  - Fast reactions due to correct orientations
  - Orientation of site gives high stereospecificity
  - Substrate specificity
  - Water soluble
  - Naturally occurring
  - Moderate conditions
  - Possibility for tandem reactions

Phase Transfer Catalyst:

- A phase transfer catalyst is a catalyst which facilitates the migration of a reactant in a heterogeneous system from one phase into another phase where reaction can take place.
- Ionic reactants are often soluble in an aqueous phase but are insoluble in an organic phase unless the phase transfer catalyst is present.
- Advantages of PTC
  - Elimination of organic solvents
  - High yields and purity of products
  - Simplicity of the procedure
  - Highly scalable
  - Low energy cosumption and low investment cost
  - Minimization of industrial waste

- Mechanism of phase transfer by PTC:

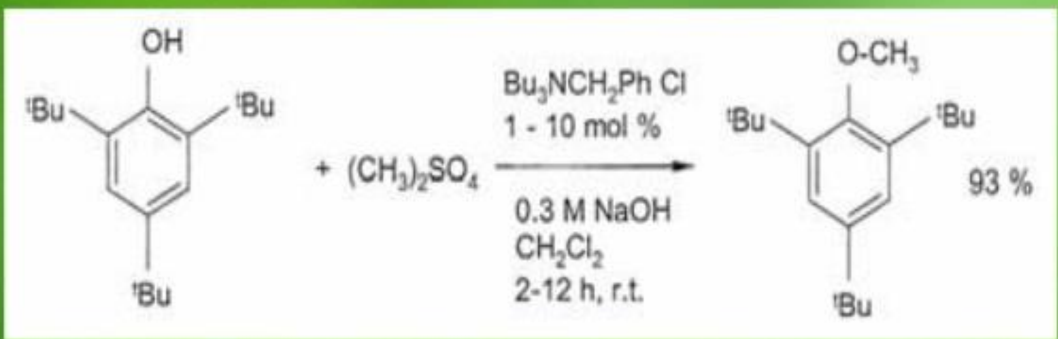


Applications of PTCs:

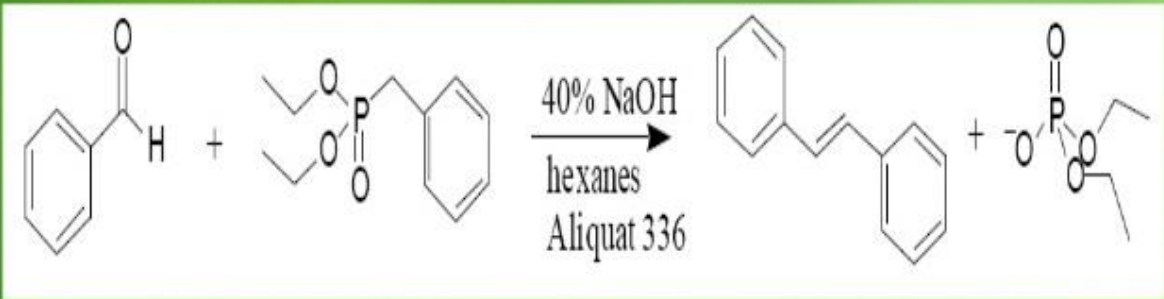
- In nucleophilic substitution reactions
- Synthesis of fine chemicals
- In perfumery and fragrance industry
- Is synthesis of drugs like dicyclonine, phenoperidine, oxaladine, ritaline etc.
- Provides liberty of use of cheaper and easily available raw materials like potassium carbonate and aqueous sodium hydroxide thereby obviating the need of severe anhydrous conditions, expensive solvents and dangerous bases such as metal hydrides and organometallic reagents.

Williamsons ether synthesis by PTC:

- High-yield etherification
- No need for excess pre-formed alkoxide
- Usually short cycle time and easy workup
- Non-dry mild reaction conditions



- Wittig reaction by PTC
- Aliquat 336 (N-Methyl-N,N-dioctyloctan-1-ammonium chloride) is used as PTC.



- Quarternary ammonium or phosphonium salts are most widely used PTCs.
  - Eg: methyltrioctyl ammoniumchloride (Aliquat 336 or Adogen 464),
  - Tetra-n-butylammonium bromide (TBAB)
  - Triethylbenzylammonium chloride (TEBA)
  - Cetyltrimethylammonium bromide (cetrimide)
  - benzyltrioctyl ammoniumchloride,
  - polyethylene glycoether,
  - crown ethers