भारतीय ज्ञान परंपरा

संस्कृति, दर्शन, शैक्षिक विचारधाराएँ और नवाचार

सम्पादक :
डॉ. दिनेश चन्द्र शर्मा

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17. GREEN CHEMISTRY FOR SUSTAINABLE DEVELOPMENT

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INTRODUCTION

In the last two hundred fifty years, starting after first chemical revolution, chemistry has improved and changed modern life with excellent amenities and services. Unfortunately this achievement has come at a price our collective human health global environment and non-renewable natural resources are threatened. Our bodies are contaminated with large number of synthetic chemicals, many of which are known to be toxic and carcinogenic while others remain untested for their health effects. They come to us from food, air, water and dust. We now know that many such chemicals enter the environment, not only from smoke-stacks, drainpipes, leaky storage tanks and waste sites but also as they migrate from furniture, textiles building materials, electronics, toys, personal care products, packaging and many more manufactured goods we encounter every day. As a result many of these chemicals are present in indoor air and dust. Many are in the food web and in our bodies

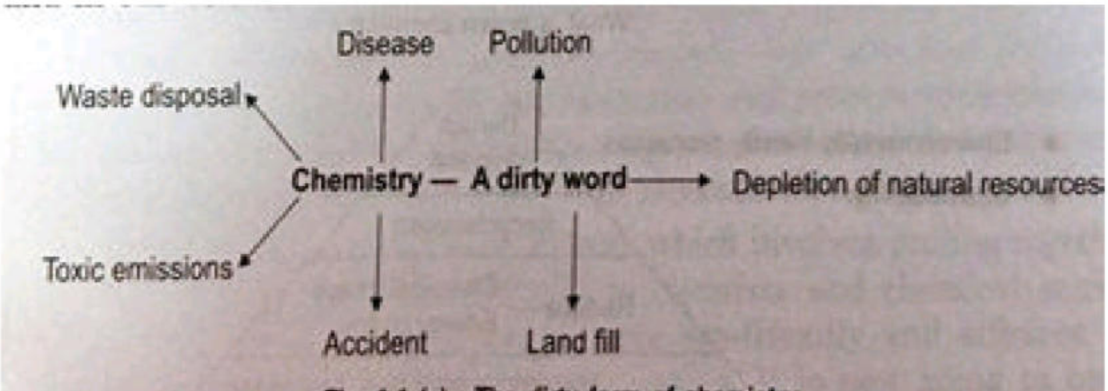


Fig. 1.1 (a) : The dirty form of chemistry.

Environment is a sphere around us which comprises of some physical and chemical components with which we are interacting and also are a part of it. Due to development in chemical science, the use of chemicals has become a quantity, same is the case with our environment. The chemical components in our environment are increasing day by day of which some can be degraded but most of them are undegradable. The addition of undegradable products that causes instability, disorder, harm and discomfort to the ecosystem, is termed as pollution. Pollution is creating a risk to the environment. Thus in order to reduce the risk of pollution, asystem should be introduced that must reduce the risk by not changing the effect but by changing the cause.

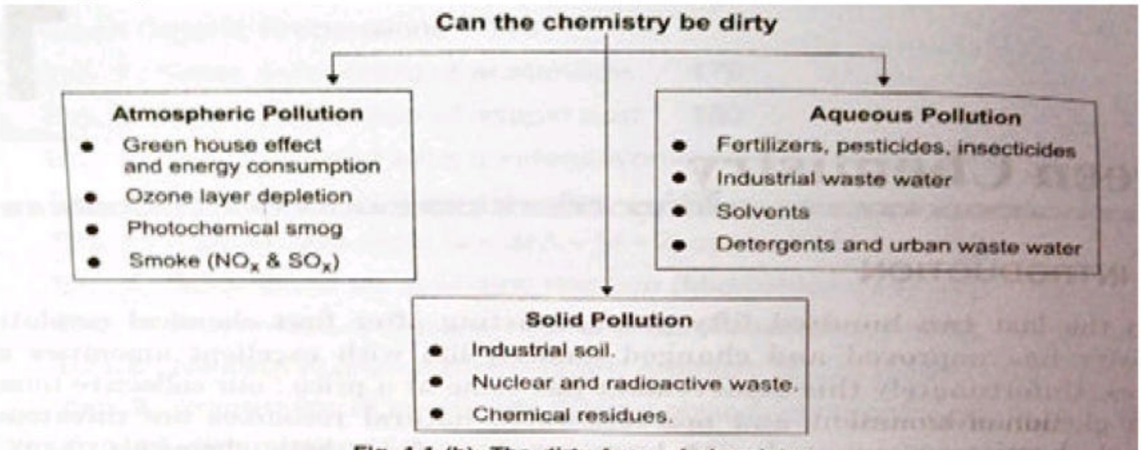


Fig. 1.1 (b). The dirty form of chemistry.

This led to a concept named "Green Chemistry". Green chemistry is an inventive science based on fundamental research towards the development of new sustainable chemical processes. It is a new approach to an old science. There is a great need to create new production system in order to prepare the younger generation to get a greener future. Thus green chemistry is cutting edge of the chemical industry today and can fundamentally change our lives for the better in the future assessing environmental concern today.

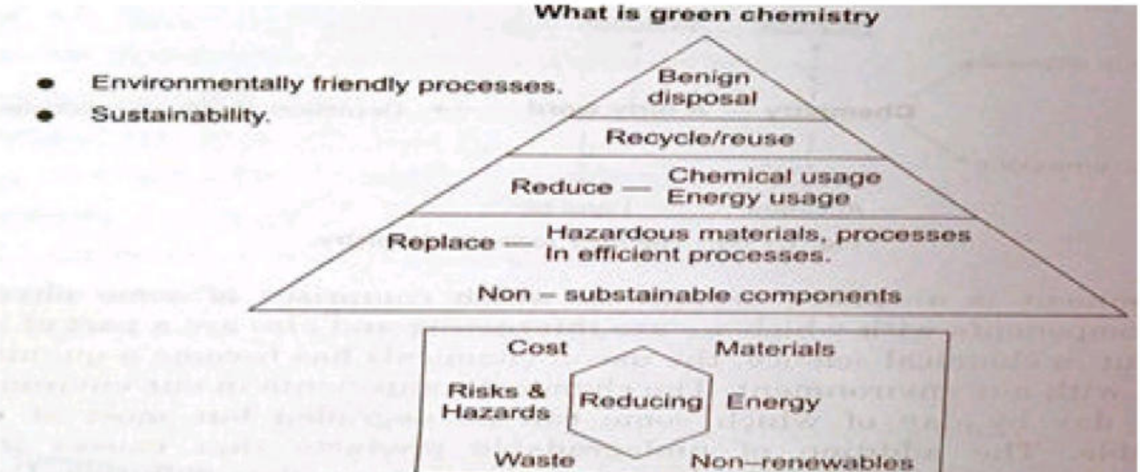


Fig. 1.2. The heart of green chemistry.

Green chemistry is a branch of chemistry which involves pulling together tools, techniques and technologies. It is helpful to chemists and chemical engineers in research development and production of more eco-friendly and efficient methods which may also have significant financial benefits. It is now going to become an essential tool in the field of synthetic chemistry.

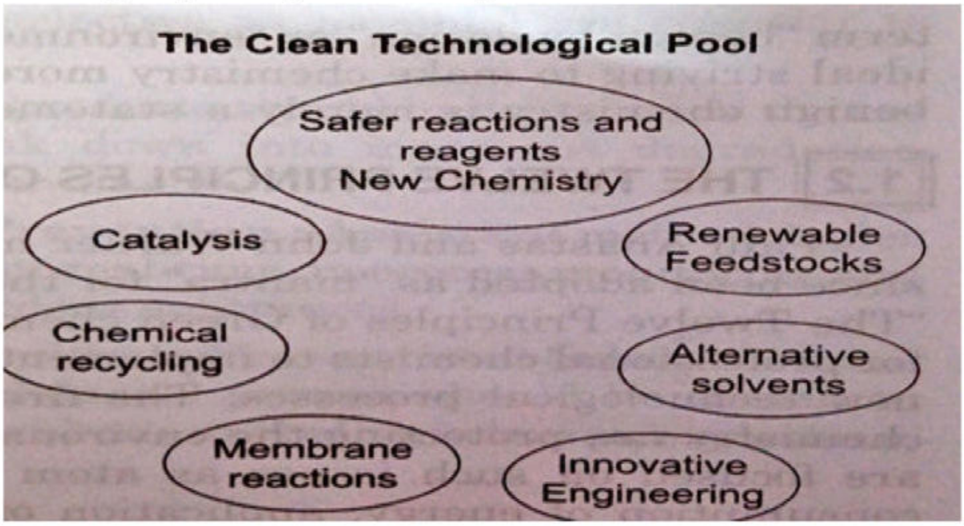
This new approach is also known as:

* environmentally benign chemistry.

* clean chemistry.

* atom economy.

* benign-by-design chemistry.



THE TWELVE PRINCIPLES OF GREEN CHEMISTRY

Paul Anastas and John Warner moved to produce a set of guidelines that have since been adopted as "mantra" for the design of environmentally benign process as The Twelve Principles of Green chemistry." These principles comprise instructions for professional chemists to implement new chemical compounds, new syntheses and new technological processes. The first principle describes the basic idea of green chemistry i.e., protecting the environment from pollution. The remaining principles are focused on such issues as atom economy, toxicity, solvent and other media, consumption of energy, application of raw materials from renewable sources and degradation of chemical products to simple nontoxic substances that are friendly for environment.

The twelve principles are:

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

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

3. Less Hazardous Chemical Syntheses: Wherever practicable, synthetic methods should be designated to use and generate substances that possess little or no toxicity to human health and the environment.

4. Design Safer Chemicals Chemical products should be designed to preserve efficacy of function while minimizing toxicity.

5. Safer Solvents and Auxillaries: The use of auxillary substances (solvents, separation agents etc.,) should be made unnecessary wherever possible and, when used, innocuous.

6. Design for Energy Efficiency: Energy requirements of chemical processes should be recognised for their environmental and economic impacts and should be minimised. Synthetic methods should be conducted at ambient temperature and pressure.

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

8. Reduce Derivatives: Unnecessary derivatisation (use of blocking groups, protection/deprotection, temporary modification of physical/chemical process) should be minimised or avoided if possible, because such steps require additional regents and

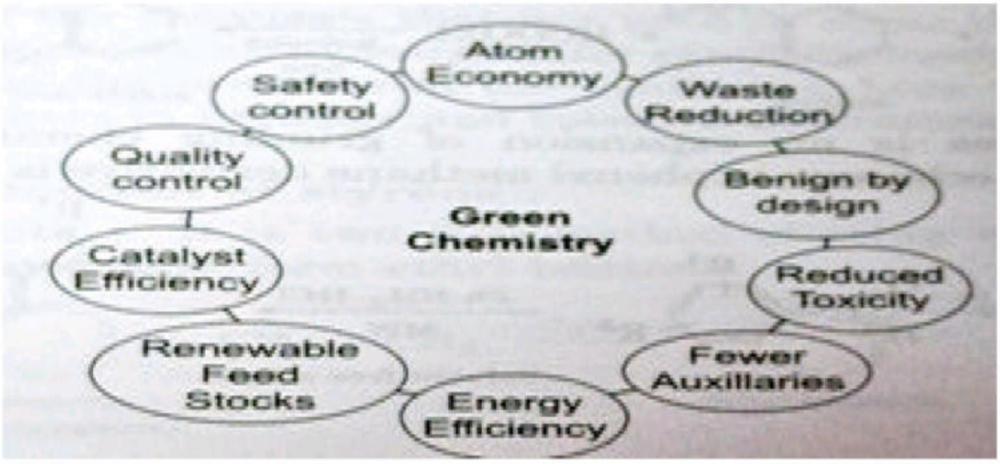
9. Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

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 fire.



Tang et.al. (2008) very cleverly and beautifully condensed the twelve principles of green chemistry to a single word "Productively".

Principles of Green Chemistry.

P - Prevent waste

R - Renewable materials

O- Omit derivitization steps

D - Degradable chemical products

C - Catalytic reagents.

T - Temperature and pressure ambient.

I- In-process monitoring.

V -Very few auxillary substances.

E -E-factor, maximise feed in products.

L- Low toxicity of chemical products.

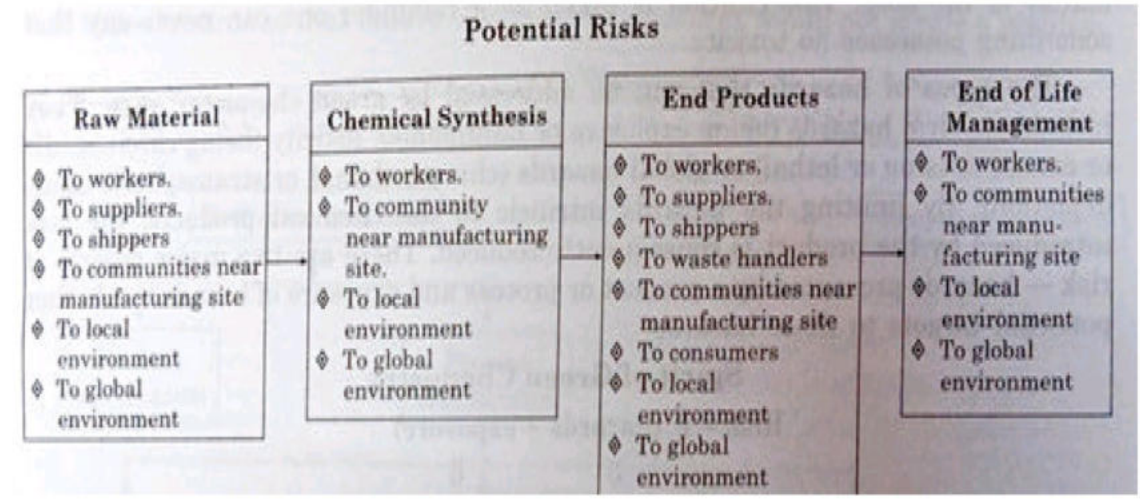
Y - Yes, it is safe -

Although in conducting a chemical process, efforts are always being made to fulfill the twelve principles but practically it is not feasible to satisfy all the conditions. Hence the word "Green" is used in comparative degree by comparing with "gray chemical" process

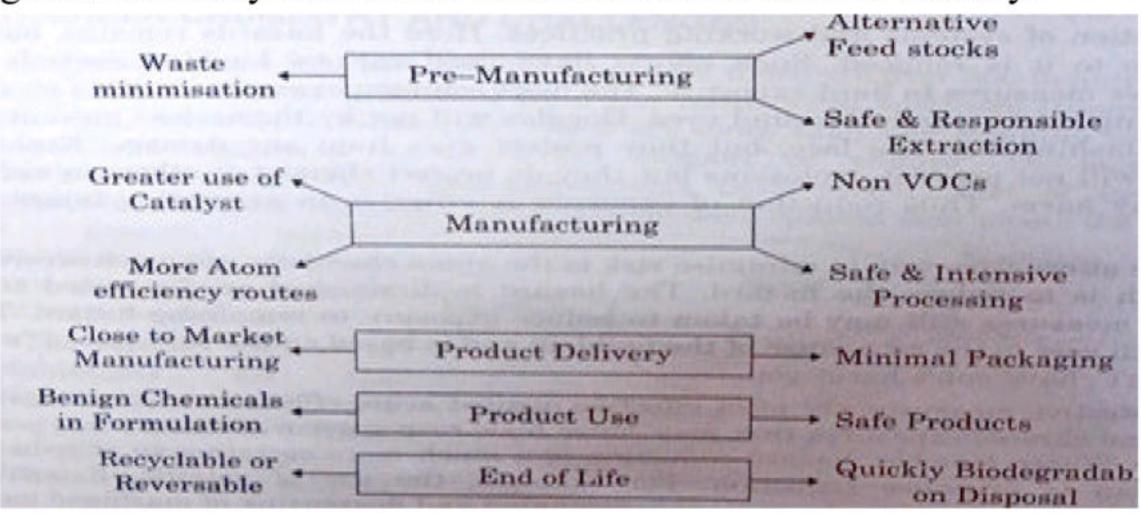
In this way a chemical process is greener than other chemical process (for the same chemical reaction) as it fulfills more conditions of twelve principles.

HAZARDS AND GREEN CHEMISTRY

Green Chemistry is an approach that aims to eliminate the usage and generation of hazardous substances by designing better manufacturing processes for chemical products. Specifically, the goal of making the finished product andby-products less toxic directs the decisions made during chemical production. The manufacturing process includes the aspect of initial selection of chemicals, the mechanism of chemical synthesis, the end product of the process and the management of toxic products generated during the production. It means that green chemistry principles should be applied to all aspects of the product life cycle, from its invention to the disposal, including the environmental fate after the use.



At the heart of green chemistry is the recognition that "hazard" is simply mnother property of a chemical substance. Properties of chemicals are caused by their molecular structure; they can be modified by changing that structure. One of the greatest strengths of green chemistry is its focus on the molecular basis of toxicity.



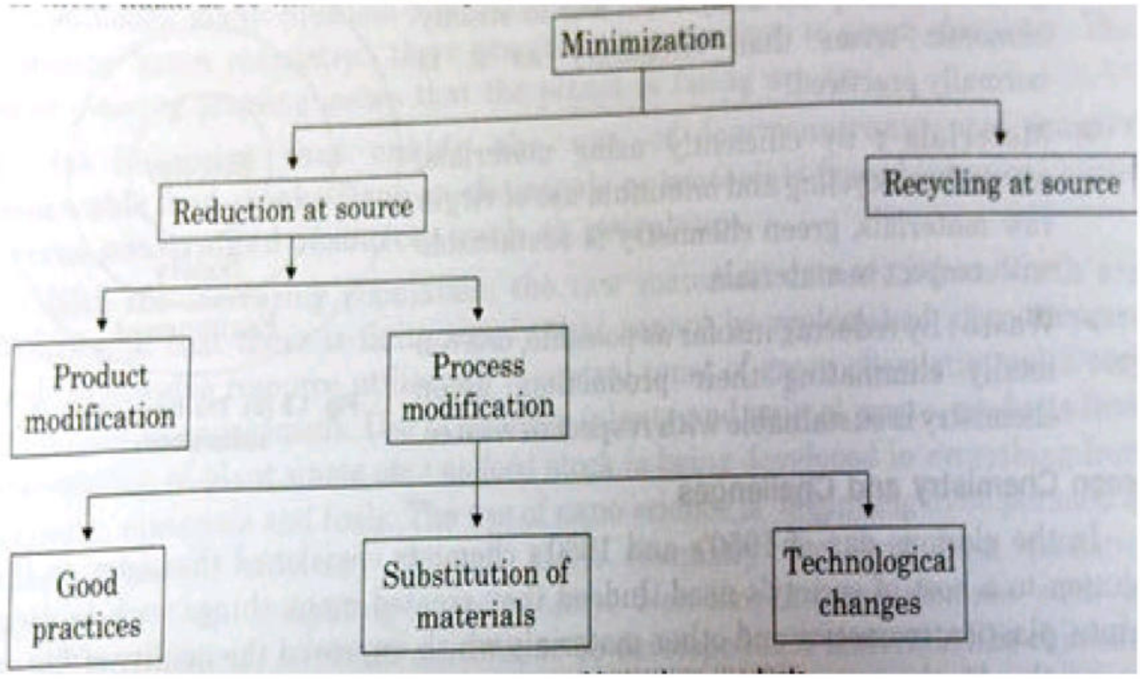
The types of hazards that can be addressed by green chemistry vary. They include physical hazards (being explosive or flammable), toxicity (being carcinogenie or cancer causing or lethal) or global hazards (climate change or stratospheric ozone depletion). By limiting the hazards intrinsic to the chemical products, the risk introduced by the product is consequently reduced. There are two major aspects of risk hazards presented by a product or process and exposure of humans and other potential targets to those hazards

Spirit of Green Chemistry

Risk = F (hazards × exposure)

$\Downarrow$ $\Downarrow$

Now Before



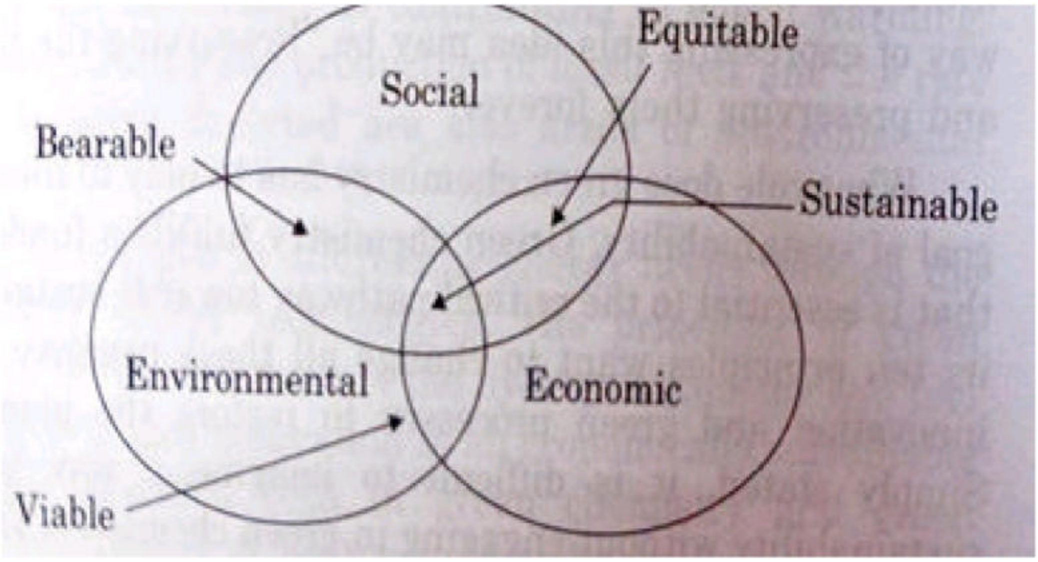
GREEN CHEMISTRY AND CHALLENGES

Sustainability: It is just one word but still there are over 300 definitions of it.

The word sustainability is derived from the Latin word sustinere (tinere to hold, susus-up). According to Dictionary, there are more than one meaning for sustain but mainly it is taken as to "maintain", "support" or "endure". The most quoted definition of sustainability and sustainable development, that of Brandtland Commission of United Nations: "substainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The three pillars of sustainability are the environmental, social and economic demands. These three pillars are expressed by three overlapping ellipses

which point out that these three pillar are not mutually exclusive and can be mutually reinforcing.



Another representation of substainability shows that how both economic and society are constrained by environmental limits, Green chemistry is sustainable chemistry. There are several important respects in which green chemistry is sustainable.

* **Economic:** At a high level of sophistication, green chemistry normally 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, green chemistry is sustainable with respect to materials.

* **Waste:** By reducing insofar as possible, or even totally eliminating their production, green chemistry is sustainable with respect to wastes and practices.

Although many chemists and some large and smaller companies are actively pursuing "green chemistry", there are still many barriers to green chemistry. The most pressing pressing issues that the planet is facing are as:

(a) Solutions that enable the use of low environmental impact renewable feed-stocks-Drop-in chemicals or materials from biological input versus constrained resources such as petroleum.

With the increasing population, the raw materials extracted from earth are depleting in that there is finite supply that cannot be replenished after they are used. Renewable resource utilisation is central tenet of green chemistry and a very active area of engagement. Use of biomass (plants and animal waste, products from fermentation of plant waste etc.) as feed stock is being developed in everything from polyester, materials and fuels. The use of nano-science is beginning to be pursued to achieve material efficiency through green chemistry that will have potential applications from computing sustainability. Non-conventional biomass such as seafood by-products e.g., chitin continue to be developed into materials like chitosan. However, an overarching theme may be that green chemistry strives to turn materials and energy sources that may have once been viewed as waste into value added renewable materials.

(b) Solutions that increase energy, water and raw material efficiency minimising the use of constrained resources.

Energy consumption poses economic and environmental costs in virtually all synthetic and manufacturing processes. Therefore energy requirement should be minimised. Currently the energy supply of world is largely based on the combustion of carbon. The extraction and collection of carbon through mining, drilling, processing etc. has well documented environmental consequences. The production of carbon dioxide and other

gases has been cited as contributing to global warming. The generation of associated toxics during the production of fossil fuels and the rate at which this finite resource is being depleted are also areas of environmental concern.

generation of toxic and bio-accumulating substances.

(c) Solutions to reduce the use of hazardous chemicals in materials and processes.

There are now enough data for the toxicological and for the long term ecotoxicological properties of most of the high volume chemicals, reagents, solvents, catalyst etc. are used for industry.

Synthesis, separation of product, cleaning, drying, analysis and recycling etc. are some of the processes where solvents are used. Solvent in the chemical industry is one of the major problems concerning worker's health and safety and environmental pollution because most of the solvents used are volatile organic solvents, out of them some are banned and some others are restricted due to toxic nature. Changing solvents and processes is not an easy task. There are many alternatives but can be more expensive, time consuming or difficult to implement under the established order of chemical methodologies. In the recent years, under the influence of green chemistry principles, some green solvents have been used such as ionic liquids, super critical carbon dioxide etc. A green solvent must ideally have high boiling point a low vapour pressure, non-toxic inexpensive, dissolve a great range of organic compounds and of course be recyclable. All these things put together tend to narrow the possibilities of finding a compound or a class of compounds that can effectively be called as green solvent. However, many efforts from research groups all over the world have enabled the appearance of some good alternatives of organic solvents as stated above.

(d) Solutions for waste prevention:

Waste prevention is better than having to treat or clean up wastes. In the carlier years the waste treatment cost was very low as wastes were simply discarded into water ways, into the grounds or in the air as stack emissions. With the passage and enforcement of environmental laws after 1970, cost of waste treatment increased steadily. The clean up of pollutants including asbestos, dioxins, pesticide manufacture residues, perchlorate and mercury are costing very high to various concerns. Hence chemical industries will require a level of innovation and new technology with an increasing emphasis on the reduction of waste. Thus

"Enviro-economics" will become the driving force for new product and processes.

(e) To develop chemistry that enables end-of-life recycling or maximise the potential for closed loop system:

A major source of waste in the fine chemicals industry is derived by the use of mineral acids and Lewis acid which end up via a hydrolytic work up, as waste stream. They cannot easily be recycled.

Their widespread replacement by recyclable solid acids such as zeolites, acidic clay etc. could afford a dramatic reduction in waste (Fig. 1.9).

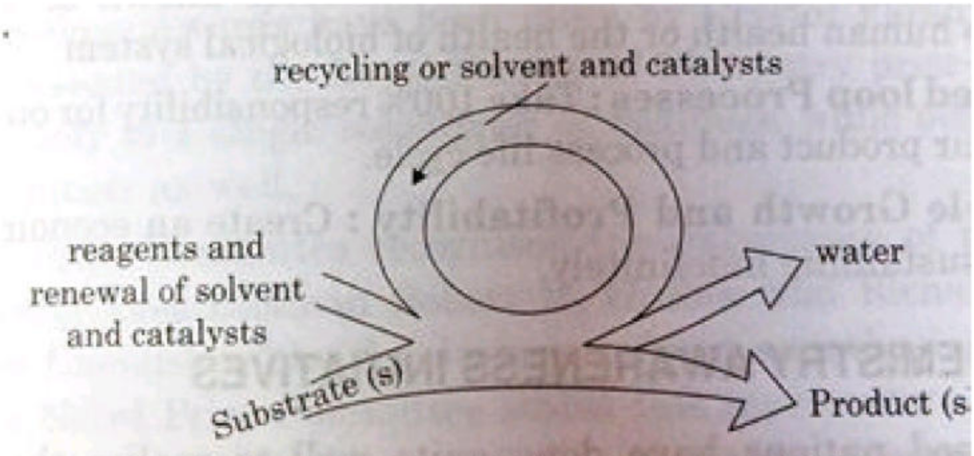


Fig. 1.9. Close loop system for solvents and catalyst.

(f) Population and Education:

Population is such type of challenge to sustainability that it drives many other challenges as well.

"Teaching must be in harmony with practice" i.e., education is specially important in the popularisation of green chemistry. Despite the progress made in recent years, however, there are still barriers which prevent a further diffusion and acceptance of green chemistry. "Like for any new technology, innovation, there are always barriers and resistance to full acceptance." In the case of green chemistry it s sometimes difficult to find economically variable "safer" alternatives to a certain product or process. In many cases, there is lack of agreement of what is considered safer". On the business supply chain side, it takes always time to switch from something old to something new; issues such as new product re-design, for instance, can be difficult and long.

2020 Sustainability Goals

* Zero waste eliminate the concept of waste in products, process, materials and energy.

* Zero Toxic Substances eliminate substances known or suspected to be harmful to human health or the health of biological system.

* 100% closed loop Processes: Take 100% responsibility for our products at all stages of our product and process life cycle.

* Sustainable Growth and Profitability: Create an economy the planet is capable of sustaining indefinitely.

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