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Role of green chemistry in reducing the environment hazards

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Abstract
The green chemistry revolution is gaining momentum now a days. The applications of green chemistry for environmental protection have become more obvious. In industrialized societies with good, well-enforced regulations and measures to reduce environmental pollution and exposure to harmful chemicals have been implemented. A small increase in environmental protection requires relatively a large investment both in money as well as effort. In this context, the grand challenge faced by industry and academia is reinventing the use of materials. To address this challenge, collaboration from an interdisciplinary group of stakeholders is necessary. The major approach is to reduce exposure to materials that are hazardous to health and the environment.

Keywords: green chemistry, environmental hazards, pollution

1. Introduction
Green chemistry can be defined as the application of chemical science to the society in a sustainable, safe and non-polluting manner. When processed in a wrong manner, the production, processing, use and disposal of chemical products may cause harm to the society. Chemistry has a key role to play in maintaining and improving our quality of life, the competitiveness of the chemical industry and the natural environment. This role for chemistry is not generally recognized by government or the public. In fact chemicals, chemistry and chemists are actually seen by many as causes of the problems [1]. The evolution of societal concerns regarding toxicity and environmental hazardous are embedded in a set of guiding principles of Green Chemistry. Basically, green chemistry harnesses the knowledge about chemical technology which can be applied for the effective production, use and disposal of chemicals in a way that minimizes consumption of materials, exposure of living organisms and damage to the environment. The drive towards clean technology in the chemical industry with an increasing emphasis on the reduction of waste at source
will require a level of innovation and new technology that the chemical industry has not seen in many years. Mature chemical processes, that are often based on technology developed in the first half of the 20th century, may no longer be acceptable in these environmentally conscious days. ‘Enviro-economics’ will become the driving force for new products and processes [1]. The appliction of green chemistry becomes the most efficient when it is cost effective i.e. when all of the costs related to practice of chemistry, including hazards and potential environmental damage are taken into account Fig 1 [1].

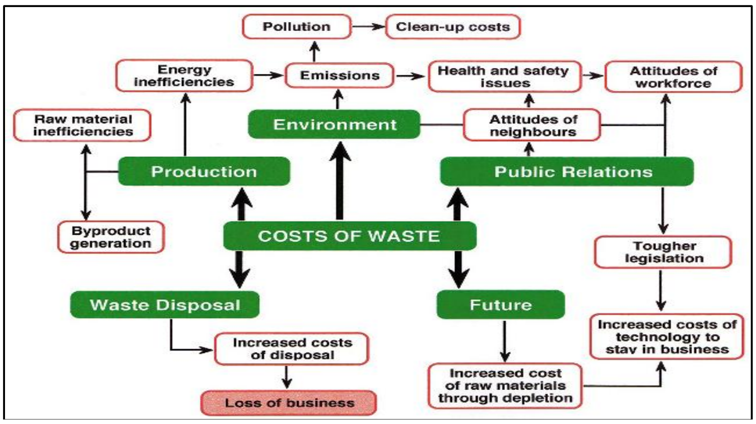

Fig 1: The costs of waste

Some important aspects which make green chemistry sustainable are [2].

- 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 or even totally eliminating their production, green chemistry is sustainable with respect to wastes.

2. Environmental challenges

Over the past half century, production trend is shifting from a predominance of commodity chemicals to specially chemicals. Most of the chemical industry is capital-intensive and thus is typically slow to adapt to new technologies. The dynamics of advance in the chemical industry are generally concerned with increasing scale, reducing costs, and increasing demand that spurs process innovation rather than break through product innovations. The challenge for chemists and others is to develop new products, processes and services that achieve the societal, economic and environmental benefits that are now required. This requires a new approach which sets out to reduce the materials and energy intensity of chemical processes and products, minimise or eliminate the dispersion of harmful chemicals in the environment, maximise the use of renewable resources and extend the durability and recyclability of products in a way which increases industrial competitiveness. Some of the challenges for chemists include the discovery and development of new synthetic pathways using alternative feedstocks or more selective chemistry, identifying alternative reaction conditions and solvents for improved selectivity and energy minimisation and designing less toxic and inherently safer chemicals. In chemical synthesis, the ideal will be a combination of a number of environmental, health and safety, and economic targets [1]. The pattern of process innovation is punctuated by occasional discontinuities of enabling technology followed by long periods of incrementalism [3]. Process innovation in the chemical sector is often risky, expensive, difficult, requires a broad combination of skills, and takes a long time [4]. In order to frame expectations regarding the adoption rate of Green Chemistry, at an industry level, the comparative rates of evolution of industries are insightful. According to [5], petrochemical industry has a new product technology cycle of 10-20 and 20-40 years for major process change. The pharmaceutical industry stands midway with a product cycle of 7-15 years and process cycle of 5-10 years [6]. The context of R&D and innovation in chemistry can be seen as benefiting from huge economic drivers, leveraged by a fairly small number of people, with diverse opportunities in small-scale initiatives [7]. The theory and practice of Green Chemistry is associated with a reorientation in the paradigm for conducting science-based investigations [8]. Furthermore, private investment in R&D has become dominant (about 65%), and its interest seems to be shifting increasingly to ‘‘work conducted to achieve practical benefits without consideration of advancing the frontiers of knowledge’’[9]. Above perception has led to a drive for the formation of Government - Industry Partnerships [5, 10].

3. The enviromental impact and green chemistry

Green Chemistry can be viewed as a design hub standing midway between the societal purpose directly engaged by environment and the evolving science based on alternative approaches to chemistry. Green Chemistry can be made to reduce the enviromental hazards by employing the following principles [1, 5].

3.1 Prevent waste

It is better to prevent waste than to treat or clean the same. Green Chemistry is pollution prevention at the molecular level. Regardless of the scale, using benign and safe materials and processes is always beneficial as even an ounce of effort in this regard will be quite beneficial. Major issue in this regard is that the costs of disposal of hazardous spent materials usually exceeds the per volume price of the raw materials as input. For Example, Disodium aminodiacetate (DSIDA) is a key intermediate in the manufacture of Roundup, the environmentally friendly herbicide [1]. The traditional manufacturing route to DSIDA was based on old Strecker chemistry and suffered from numerous serious environmental and health and safety problems like the use of the highly toxic hydrogen cyanide which requires special handling and gives rise to operator, environmental and local community risks, the exothermic generation of unstable intermediates requires special care to avoid runaway reactions [1]. On the other hand, the new DSIDA manufacturing process is cleaner and safer. It is based on the catalytic dehydrogenation of diethanolamine and has the advantages like: being less toxic and less volatile starting materials, endothermic and inherently safer chemistry; after removal of the catalyst, no further purification is required before the intermediate is used in the next stage of the herbicide manufacture; a new active and reusable solid catalyst which has applications wider than in this process [1].

3.2 Less hazardous synthesis

Synthetic methodologies should be designed to use and generate substances that possess little or no toxic effects both to human health and the environment. Manufacturing procedures should ensure that contamination from these process do not appear in the final product. But the process itself still presents a number of hazards. Redesigning existing transformations to incorporate less hazardous materials is at the heart of Green Chemistry [5].

3.3 Safer chemicals

Chemical products should be designed to preserve efficacy of function while reducing toxicity. In other words efficacy/ toxicity ratio should increase. The use of carcinogenic red dyes, endocrine disrupting plasticizers, and ozone depleting refrigerants should be reduced. The chemical community has become quite sophisticated in identifying specific mechanisms of action for a variety of negative endpoints [2].

The use of chemicals called organotin compounds in ships to prevent accumulation of barnacles and marine plants, should be reduced. Organotin compounds, such as TBT, are considered to be amongst the most toxic chemicals ever released into the marine environment. Even when present in the marine environment at very low concentrations, they have been shown to produce demonstrable negative impacts upon marine life [5].

3.4 Safer solvents and auxiliaries

The use of auxiliary substances like solvents, separating agents, etc. should be made unnecessary wherever possible and, innocuous when used. Often one has a form of chemical tunnel vision when designing synthetic transformations and even more inconsequential afterthought is reaction and purification media that will be used. Elegant chemistry that requires high dilution in chlorinated solvents can be quite problematic [5]. Chromatographic separations using enormous amounts of elution solvent can be the single largest environmental impact of a transformation.

For example, 4-Isobutylacetophenone is a key intermediate in the manufacture of the bulk active pharmaceutical ibuprofen [1]. The conventional method of preparation is based on a Friedel-Crafts acylation, which uses greater than stoichiometric quantities of $AlCl_3$. To produce 1000 tonnes of 4-isobutylacetophenone, 760 tonnes of $AlCl_3$ are required and a corresponding amount of aluminium waste in the form of aluminous water is generated when the product–catalyst complex is broken down by quenching with a large volume of water [1]. In addition, large amounts of acidic gaseous emissions have to be scrubbed from the off-gas stream. Later stages in the process involve cyanide and elemental phosphorus making the whole manufacturing process extremely hazardous and wasteful Fig. 2 [1].

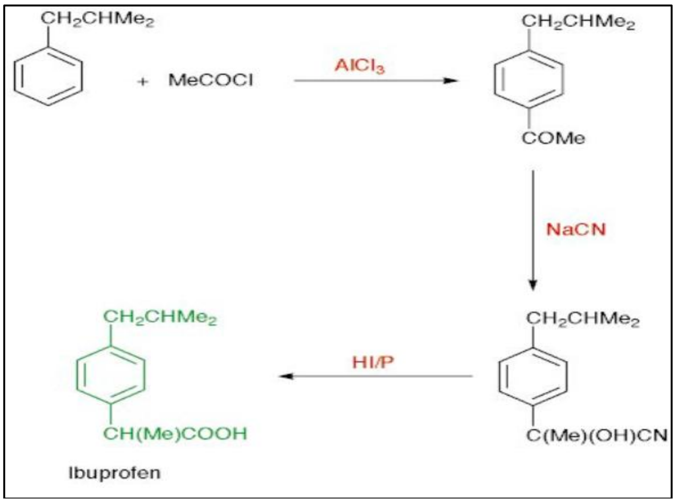

Fig 2: Traditional manufacturing route to 4-isobutylacetophenone.

3.5 Energy efficiency

Energy inputs can amount to a substantial component of the overall environmental transformation. Each chemical reactivity is governed by the laws of thermodynamics and kinetics. Every transformation requires an input of energy to overcome the activation energy of the transition state. Hence the energy requirements for environmental and economic impacts should be recognized and efforts should be made to minimize these energy requirements [5]. Synthetic methods should be conducted at ambient temperature and pressure and highly exothermic reactions must be cooled in order to be controlled. Pollution reduction can be achieved through the use of catalytic technologies in the generation of clean fuels and chemicals. Traditional preparation of the catalysts used generate large amounts of wastewater, utilize large amounts of energy and oftentimes generate nitrate and sulfate emissions which contribute to acid rain [2].

3.6 Catalysis

Catalytic reagents are superior to stoichiometric reagents. In order to make transition state energies more accessible in a chemical transformation, the use of catalysts can be quite beneficial. There are countless examples of stoichiometric reactions that might have catalytic alternatives. Provided the catalyst employed is not orders of magnitude more toxic than the stoichiometric reagents they replace, their use will be quite beneficial. Acid catalysis is the most widely used type of catalysis with applications in all sectors of the chemical, pharmaceutical and allied industries, although the largest scale use is in the petrochemical industries where the processes are largely quite efficient and the use of solid acids is well established. Traditionally most liquid phase organic reactions have been catalysed by strong Brønsted acids such as H_2SO_4 and HF and by soluble Lewis acids such as $AlCl_3$ and BF_3. Though these acids have many important advantages: they are cheap, hreadily available and very active, yet, they also suffer from some serious drawbacks; they are difficult to separate from the organic products and their use leads to large volumes of hazardous waste [1].

The green chemistry goal for such reactions should be to remove all elements from the accounts other than those involved in the organic chemistry and, of course, to push the organic chemistry towards 100% selectivity to the desired product. A number of new, more environmentally friendly acids for liquid phase organic reactions, notably solid acids (which are generally easier and less energy and resource consuming to recover than soluble acids), are beginning to find their way into industrial usage. These include zeolites, clays and other mixed metal oxides, inorganic–organic composite materials, functionalised polymers and supported reagents [9, 11] as well as lanthanide triflates [12].

3.7 Design for degradation

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. The earth's natural environment is full of ecological cycles where the waste of one process becomes the feedstock of another. In society's quest for durable and stable materials in the past, materials have been designed that are robust and resist entering into any degradative cycle. Landfills across the planet are filling up with more and more material that will not undergo any form of degradation [5]. One must better understand these cycles and incorporate them into the design of future materials so as to give us strong stable materials that are around for as long as they are needed and no longer.

3.8 Real-time analysis for pollution prevention

In order to process the efficient monitoring and control prior to the formation of hazardous substances, two aspects should be given main emphasis: time and materials. For the first aspect, real-time analytical techniques must be developed for use in large-scale manufacturing processes [5]. Also there is a need to improve analytical techniques to consume less materials with the help of new chromatographic methods that use less solvents or do not require complex mixtures of solvents. Though, analytical chemistry has played an essential role in organic synthetic chemistry, helping to understand what is happening within reactions and also helping to identify and characterize isolated compounds, yet it has also involved excessive solvent usage, high-energy requirements and often large sample sizes [5]. Process analytical chemistry has recently shifted towards smaller, more precise instrumentation and in-line analysis, which has helped to decrease the solvent usage and therefore drastically decrease waste.

4. Conclusions

The drive towards clean technology in the chemical industry and the emergence of green chemistry is the need of the hour. There is specific need to work on improving efficiency/toxic ratio. In future, the successful chemical manufacturing companies will be those which can exploit the economic, legislative and public image advantages that a clean technology approach to chemical manufacturing can provide. The chemical researchers and educationalists should emphasise and appreciate the value of green chemistry in innovation, application as well as recognising its role in minimising the environmental hazardous. The major challenge in this context is the lack of technology in reinventing the reuse or disposal of waste materials. For addressing this problem, collaboration from the society,industry, academia and the Goverenment is necessary.

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