

Green Chemistry: A Veritable Approach to an Environmentally Friendly Process and Practice in the Teaching and Learning of Chemistry.

Okechineke, Benjamin Chukwunonso

Science Education and Chemistry Department

Alex Ekwueme Federal University, Ndufu - Alike Ikwo (Funai), Ebonyi State, Nigeria.

E-mail: okechinekebenjamin@gmail.com

Abstract

Green Chemistry, which is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances, is placed in the frontier areas of research and has been focused for consideration recent research. The current emphasis on green chemistry reflects a shift away from the grey approach (cleaning up of generated waste) to environmental hazards that deal with waste treatment, control and pollution prevention. Rather than accepting waste generation and disposal as unavoidable, green chemistry seeks new technologies, processes, practices and products that are cleaner, eco-friendly, environmentally friendly, benign and economically competitive; by providing green paths for different synthetic routes using non-hazardous solvents and environmental-friendly chemicals both in the laboratory and industries. The major aim of this article is to establish as a fact that green chemistry has been an acceptable approach to sustainably environmental friendly process in chemistry practices. The paper traced briefly, the history, general concept, scope and principles of green chemistry. It also examined the different between 'green' and 'grey' chemistry, while green solvents and their applications were highlighted. Recommendations like the campaign towards the adoption of green processes in the industries were made.

Key words: Green Chemistry, Benign/Environmental friendly process and product.

Introduction

The last few decades of the 20th century witnessed growing concerns over the impact of industries on the global environment. This includes acid rain, greenhouse gases increase, fertilizer in water bodies, and a hole in the ozone layer (ozone layer depletion). However in spite of an enormous investment over the last 50 years to ensure that the production of chemicals does not have a malign effect on the environment, the public and the very consumers, there is no doubt that there are still mistakes and these are generally well publicized, even though significant changes in the operation of the chemical industry are designed to reduce these impacts on the environment. (Van Aken, Streckowski, & Patiny, 2006).

According to Linthorst (2009), "Industrial vomits fill our skies and seas, pesticides and herbicides filter into our foods; twisted automobile carcasses, aluminum cans, broken bottles, and synthetic plastics; lamenting that we don't even know what to do with our radioactive wastes – whether to pump them into the earth, shoot them into outer space, or pour them into the oceans, in that our technological powers increase, but the side effects and potential hazards escalate" (p.55). The researcher therefore said that the acceptance of chemical industry not to adversely affect the environment for future generations has been the driving force behind the development of *greenchemistry*. And this can be summed up in one word: *sustainability*. Sustainable processes and practices meet the needs of the present without compromising the ability of future generations to meet their own needs. Meanwhile this is not a separate branch of chemistry, but an approach that permeates every stage of process development without as well being multi – disciplinary in nature.

Brief history of green chemistry

The development of green chemistry in Europe and the United States was linked to a shift in environmental problem-solving strategies: a movement from command and control regulation and mandated reduction of industrial emissions at the “end of the pipe”, toward the active prevention of pollution through the innovative design of production technologies themselves. The set of concepts now recognized as green chemistry coalesced in the mid-to late-1990s, along with the broader adoption of the term which prevailed over competing terms such as ‘clean’ and ‘sustainable’ chemistry. (Metus, Clark, Anastas, & Zimmerman, 2012, p. 10892).

Green chemistry's roots in the Pollution Prevention Act of 1990

To stop creating pollution in the first place became America's official policy in 1990 with the Federal Pollution Prevention Act.

The law defines **source reduction** as any practice that:

- Reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal.
- Reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

The term "source reduction" includes:

- Modifications to equipment or technology
- Modifications to process or procedures
- Modifications, reformulation or redesign of products
- Substitution of raw materials
- Improvements in housekeeping, maintenance, training, or inventory control
- Section 2 of the Pollution Prevention Act establishes a pollution prevention hierarchy, saying:
- The Congress hereby declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible;
- Pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible;
- Pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; an
- Disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.
- (Woodhouse, & Breyman, 2005, p.199, and Linthorst, 2009, p. 55).

Scope of green chemistry

Green chemistry spans across most areas of chemistry including organic, biochemistry, inorganic, polymer, toxicology, environmental, physical, industrial, etc. while the principles of green chemistry can be applied broadly to areas like synthesis, catalysis, reaction conditions, analysis and monitoring, extractions, separations, computational chemistry and process modeling. Also, an emerging area of increasing importance in green chemistry is that of analytical, pharmaceutical, etc. and all its associated activities.

Concepts and Aim of Green Chemistry.

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal.

Green chemistry, also called sustainable chemistry, is an area of chemistry and chemical engineering focused on the designing of products and processes that minimize the use and generation of hazardous substances. (Sharma, Ashu, & Singh, 2008, pp. 68-92).

Green Chemistry or Sustainable Chemistry is defined by the Environmental Protection Agency as “the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances.” It is also important to note that green chemistry is different from environmental chemistry. Because according to Noyori (2005, p. 2), environmental chemistry is the scientific study of the chemical and biochemical phenomena that occur in natural places. It should not be confused with green chemistry, which seeks to reduce potential pollution at its source.

The aim of green chemistry is to reduce chemical related impact on human health and virtually eliminate contamination of the environment through dedicated, sustainable prevention programs. 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) At the same time, green chemistry can save companies money by reducing the need for costly chemicals, reagents and solvents, lowering insurance and legal costs, reducing waste disposal costs (which can exceed \$5 per kg for some toxics), and saving energy. (Anastas & Williamson, 1988, p. 15).

Therefore, since green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances, it applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal. Green chemistry is also known as sustainable chemistry.

Green chemistry's 12 principles

These principles demonstrate the breadth of the concept of green chemistry:

1. **Prevent waste:** Design chemical syntheses to prevent waste. Leave no waste to treat or clean up.
2. **Maximize atom economy:** Design syntheses so that the final product contains the maximum proportion of the starting materials. Waste few or no atoms.
2. **Design less hazardous chemical syntheses:** Design syntheses to use and generate substances with little or no toxicity to either humans or the environment.
3. **Design safer chemicals and products:** Design chemical products that are fully effective yet have little or no toxicity.
4. **Use safer solvents and reaction conditions:** Avoid using solvents, separation agents, or other auxiliary chemicals. If you must use these chemicals, use safer ones.
5. **Increase energy efficiency:** Run chemical reactions at room temperature and pressure whenever possible.
6. **Use renewable feedstock:** Use starting materials (also known as feedstock) that are renewable rather than depletable ones. The source of renewable feedstock is often agricultural products or the wastes of other processes; the source of depletable feedstock is often fossil fuels (petroleum, natural gas, or coal) or mining operations.
7. **Avoid chemical derivatives:** Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
8. **Use catalysts, not stoichiometric reagents:** Minimize waste by using catalytic reactions. Catalysts are effective in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and carry out a reaction only once.
9. **Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
10. **Analyze in real time to prevent pollution:** Include in-process, real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
11. **Minimize the potential for accidents:** Design chemicals and their physical forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment. (Anastas & Williamson, 1988, p. 18).

Green chemistry benefactions:

- 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.
- Green chemistry aims to design and produce cost-competitive chemical products and processes that attain the highest level of the pollution-prevention hierarchy by reducing pollution at its source.

For those who are creating and using green chemistry, the hierarchy looks like this:

1. Source Reduction and Prevention of Chemical Hazards.
 - a. *Designing chemical products to be less hazardous to human health and the environment.*
 - b. *Making chemical products from feedstock, reagents, and solvents that are less hazardous to human health and the environment.*
 - c. *Designing syntheses and other processes with reduced or even no chemical waste.*
 - d. *Designing syntheses and other processes that use less energy or less water.*
 - e. *Using feedstock derived from annually renewable resources or from abundant waste.*
 - f. *Designing chemical products for reuse or recycling.*
 - g. *Reusing or recycling chemicals.*
2. Treating chemicals to render them less hazardous before disposal.
3. Disposing of untreated chemicals safely and only if other options are not feasible.

Chemicals that are less hazardous to human health and the environment are:

1. Less toxic to organisms
2. Less damaging to ecosystems
3. Not persistent or bio accumulative in organisms or the environment
4. Inherently safer to handle and use because they are not flammable or explosive

(Collins, 2001, p. 48).

How green chemistry differs from grey chemistry (cleaning up pollution).

Green chemistry reduces pollution at its source by minimizing or eliminating the hazards of chemical feedstock, reagents, solvents, and products.

This is unlike cleaning up pollution (also called remediation), which involves treating waste streams (end-of-the-pipe treatment) or cleanup of environmental spills and other releases. Remediation may include separating hazardous chemicals from other materials, then treating them so they are no longer hazardous or concentrating them for safe disposal. Most remediation activities do not involve green chemistry. Remediation removes hazardous materials from the environment; on the other hand, green chemistry keeps the hazardous materials out of the environment in the first place.

If a technology reduces or eliminates the hazardous chemicals used to clean up environmental contaminants, this technology would qualify as a green chemistry technology. One example is replacing a hazardous sorbent [chemical] used to capture mercury from the air for safe disposal with an effective, but nonhazardous sorbent. Using the nonhazardous sorbent means that the hazardous sorbent is never manufactured and so the remediation technology meets the definition of green chemistry. (Sharma, et al, 2008).

Green Chemistry Application.

Green chemistry has different industrial applications in Designing Safer Chemicals Production, Food & Flavor Industry, and Green Technologies in the Pharmaceutical Industry, Paper & Pulp Industry, Polymer Industry, Sugar & Distillery Industries, Textile and Tannery Industry and Green Chemistry in Agrochemicals.

Green Reagents

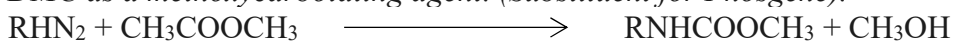
Green reagent is one that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products.

- Chemistry is undeniably a very prominent part of our daily lives.
- Chemical developments also bring new environmental problems and harmful unexpected side effects, as a result (of this), there is need for “greener” chemical products.
- Green reagents have minimal side effects and low pollutability.

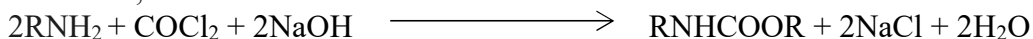
A famous example for environmental pollutant is the pesticide DDT (dichlorodiphenyltrichloroethane) and can be replaced with a benign dimethyl carbonate (DMC).

Examples;

DMC as a methoxycarbonylating agent. (Substituent for Phosgene).



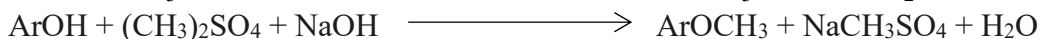
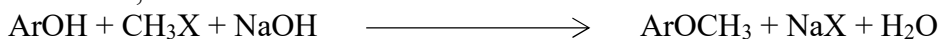
Instead of;



DMC as a methylating agent.



Instead of;



Conventional methylation reactions employ methyl halides or methyl sulphates. The toxicity of these compounds and their environmental consequences render these syntheses somewhat undesirable.

Polymer supported reagents;

Besides DMC, there are group of reagents which though are ordinary reagents, are bound to polymer support. The main advantage of using these reagents is that any excess of the reagent can be recovered by filtration and used again also the isolation of the products is very easy.

Another is polymer supported peracids – used for the epoxidation of alkenes in good yields.

Also, polymer supported Chromic acid (HCrO_4). This is commercially available and has been used to oxidize primary and secondary alkanols to carbonyl compounds and also oxidizes allylic and Benzylic halides to aldehydes and ketones.

Polymeric Organo Tin Dihydride reagent as a reducing agent.

The use of this involves ease of operation and reaction work up and avoids toxic vapors, characteristic of tin hydride. The polymer supported organotin dihydride reagent has been used for the conversion of aldehydes and ketones to alcohols in 80-90% yields and the reduction of halides to hydrocarbons. The use of organotin hydride for the reduction of alkyl and aryl halides in the presence of the other functional groups is generally superior to Lithium aluminum hydride (LiAlH_4).

This can also be used for the selective reduction of only one functional group of a symmetrical difunctional aldehyde (Terephthaldehyde).

Polystyrene Carbodiimide

Polystyrene Carbodiimide is useful for the synthesis of anhydrides. It can also be used for Moffat oxidation of alcohols to aldehydes and ketones.

Polystyrene anhydride

Acetylation of aniline with polystyrene anhydride gives benzanilide in 90% yields. Similarly, ethylbenzoate is obtained in 90% yield by acylation of ethanol.

Polystyrene Wittig reagent

The polymeric Wittig reagent reacts with carbonyl compounds to give the usual products.

Polymeric Phenyl Thiomethyl Lithium reagent

The Polymeric Phenyl Thiomethyl Lithium reagent is useful for lengthening of side chain of alkyl iodide in good yield.

Merit of Green Chemistry

- It minimizes the number of steps involves in the synthesis of a chemical compounds.
- It reduces the number by –products released.
- It promotes the liberation of non-toxic compounds.

Demerits

- It is not applicable for the synthesis of all chemical compounds

Recommendation

Sequel to the recent discoveries of industrial process hazards associated with grey (conventional) chemistry, as well as the non-toxicity and sustainability of benign chemistry and its practices, the chemistry and industrial processes of Nigeria needs;

- A curriculum review to incorporate green chemistry principle into senior secondary school chemistry curriculum, to acquaint the students of this noble idea at young age.
- Sensitization, advocacy and mobilization of support of Green Chemistry
- Re-engineering in order to strategically reposition Nigeria to provide a conducive and habitable benign environment while developing technologically.

Conclusion

The discovery of the principles and application of green chemistry is a relief to humanity, whose environment is already polluted by the industrial wastes. Working with this innovative approach will certainly improve the development of Science Education and Chemistry.

References

- Anastas, P.T., & Williamson, T.C. (1998). *Green Chemistry: Frontiers in benign chemical syntheses and processes*. Oxford University Press.
- Collins, T. (2001). Towards sustainable chemistry Science. *Essay on Science and society*. 291, 5501. pp. 48-49. doi:10.1126/science.291.5501.48
- Linthorst, J.A. (2009). “An overview: Origins and development of green chemistry”. *Foundations of Chemistry* 12: 55. Doi:10.007/s10698-009-9079-4
- Metus, K.J.M., Clark, W.C., Anastas, P.T., & Zimmerman, J.B. (2012). Barriers to the Implementation of Green Chemistry in the United States. *Environmental Science & Technology Journal*, 46(20), 10892-10899. doi:10.1021/es3021777.
- Noyori, R. (2005). Pursuing practical elegance in chemical synthesis. *Journal of Chemical Communications (14)*, 1807-1811. doi.10.1039/B502713F.
- Sharma, S.K., Ashu C., & Singh R.V. (2008). Gray Chemistry verses green chemistry: challenges and opportunities. *Journal of chemistry*, 1(1), 68-92. Retrieved from <http://pdfs.semanticscholar.org>
- Van Aken, K., Streckowski, L., & Patiny, L. (2006). Eco Scale; a semi-quantitative tool to select an organic preparation based on economical and ecological parameters. *Beilstein Journal of Organic Chemistry*. 2(1), 3. Doi:10.1186/1860-5397-2-3. PMC1409775. PMID 16542013.
- Woodhouse, E.J., & Breyman, S. (2005). Green Chemistry as social movement. *Science, Technology & Human Values*. 30 (2): 199-222. doi:101177/01622439042.71726.