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An Analysis upon Various Technological and Sustainable Developments in Green Chemistry: Challenges and Opportunities

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Abstract – The chemical industry plays a fundamental role in sustaining the world economy and underpinning future technologies and scientific advances in new materials, less toxic products, renewable energy sources, environmental protection, industrial processes with energy efficiency and renewable raw materials. Green Chemistry (GC) or Sustainable Chemistry aims, under greater societal expectations, for a sustainable global future of the planet Earth, for the design of chemical products that eliminate the use of hazardous substances for man and the environment. In this respect Green Chemistry fields initiated in the 1990s are rapidly developing technological innovations providing the most environmentally suitable solutions for a sustainable development of future science and technology. GC offers enhanced chemical process economics, concomitant with a reduced environmental burden. GC can be applied to design environmentally benign synthetic protocols, to produce life-saving medicines, environmentally friendly agrochemicals, new enzymes for biocatalytic chemical processes, innovative renewable energy sources, energy efficiency in chemical reactions, and innovative materials while minimizing environmental impact.

Chemistry and its application plays vital role in many industries such as medicine. Green chemistry is tool for innovation which includes business, education and economy to build a sustainable future. Hence, we should now concentrate on innovation in green chemistry to reduce the environmental damage and eliminate the use and generation of hazardous substances. There are various innovations in green chemistry such as renewable feed stocks, use of catalysts in experiments, proper disposal of waste, design of safer chemicals and auxiliaries, design for degradation and reactions with more efficient syntheses and high efficiency formulation. This conceptual paper addressing innovations in green chemistry and steps need to be taken by various industries to incorporate green chemistry for a sustainable development.

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INTRODUCTION

Green chemistry is described as the movement towards more environmentally acceptable chemical product and processes. It comprises of research, education and commercial application of chemicals. Green chemistry can be applied through environment friendly old or new technologies (Bjorn Lamborg, 2001). Although nowadays green chemistry is accepted as a vital development in a way we practice chemistry and sustainable development but it is only applied in a small fraction of actual chemistry. It is also very important to understand that Green chemistry technologies is not only should be practice in development countries.

In 1980s there was a research conducted by developed countries such as Japan, UK and France and later in 1990s when United States Environmental Protection Agency (US EPA) proposed the term "Green Chemistry", there were various research in industrial field application among many countries including China and India (El-Agraa, 2004). This rapid field of science governed by twelve specific chemical principles which move processes and products towards an economy based on renewable feedstocks which prevent deliberation of toxicity at the molecular level. The chemical processes and products are designated to eliminate waste, minimize energy use, be less hazardous and degrade safely upon disposal.

In a short term, green chemistry has been focused heavily focused on developing new and environment friendly chemical processes using many technologies. Globalization era will demand increasing emphasis on product but it is important that the manufacturing should be through green chemistry methods. Green chemists and engineers employ biological systems and life cycle to create chemicals that lead to foundation of our economy.

There are numerous application of Green Chemistry in industry such as plastics, renewable energy technologies, pesticides, textile manufacturing, water purification, pharmaceuticals and basic chemical feedstocks. It is believed that, overtime Green Chemistry will change a chemistry as a whole towards an economy based on sustainable renewable energy, green jobs, bio-based productions. Hence, in this article, the researchers will start to explore the innovations behind the movement towards green and sustainable chemistry.

As sustainable development has been accepted by the government, industries and the public, green chemistry plays a vital role in maintaining and improving the quality of life, the competitiveness of the chemical industry and the natural environment. The challenges faced by the chemist and others are basically concerned on societal, economic and environmental benefits. This requires a new approach that minimizes or eliminates harmful chemicals from environment, maximize the use of renewable resources, extend the durability and recyclability of products- which in a way increases industrial competitiveness (Clark, 1998).

Other than this, lack of awareness and training in school, universities and industries and the management perception that green chemistry is a cost without benefits becoming the major obstacles of green chemistry.

Although there are few challenges, but the rapid growing interest in green chemistry especially in industries and academic institution are being partly witnessed by the growth in relevant conferences that are regularly held in USA, Europe and Asia (Clark, 1998). This are good examples that shows the awareness about green chemistry begins to improve. In addition, marketing sustainability as a key strategy to enhance the awareness in green chemistry. The transition to green chemistry can be done by helping to create the demand for green chemistry among workers, managers, manufacturers, retailers, users, investors, consumers, students and public. This is because in some situation, this community may willingly to pay a premium price for green products and manufactures that do not uses green chemistry will be seen as unethical or environmental damaging factor (Meyer, 2001).

Today’s civilization is not sustainable for future generations. Broad, global access to the fruits of technology and acceptable standards of development is also inequitable. The WHO’s 2005 Millenium progress report, for example, estimates that the richest 15% of the world’s population consumes 91% of medicines (cf. above URL). China and India have made enormous strides in transitioning towards “first-world” economies. This has been accomplished, however, at huge costs to respective national health and safety and with global environmental impacts. A good deal of the production capacity that drives economic development in India and China results from the moving the manufacturing of goods to lower cost centers of production.

Thus, production for export drives a substantial amount of economic development. This practice must be coupled with the best exercise of green technologies, however, to prevent emerging economies from becoming the dumping ground for global waste. The requirements that we make of Green Chemistry are to enable substantial progress towards equitable standards of living in a manner that is sustainable for future generations. Playing such a game of “catch up” is arduous and (evidenced by China/India) risky.

Trends and rapid developments of the global economic and technological growth in the 20th century, forced scientists and technologists to realize that further development of human civilization and the fulfillment of socio-economic needs of the present generation will be only possible if the natural resources are properly managed and the relationship between economic growth and caring for the environment of the present and future generations is consciously maintained.

Ten years after the 1972 United Nations Conference on the Human Environment (Stockholm), most of the global environmental challenges had clearly not been adequately addressed. Particularly, the problems poverty in developing and Third World countries through more productive and industrialized economies, the global and local environmental pollution, and the non-sustainable use of natural resources. Environmental pollution threats, ranging from atmospheric pollution in cities, municipal solid waste, acid rain, deforestation and desertification, the reduction of ozone layer and signs of climate change were overlooked. The idea of sustainable eco-development was presented for the first time in 1987 in the report of the World Commission on Environment and Development of the United Nations.

In the report, it was stated that the further development of human civilization and the fulfillment of socio-economic needs of the present generation will be only possible if the natural resources are properly managed and the relationship between economic growth and caring for the environment of the present and future generations is consciously maintained, while the long-term effects of industrial activities are also considered. The global chemical industry plays a fundamental role in important scientific and technological fields associated with the future of sustainable development in developed and developing countries. From the beginning, the leaders of the major chemical industries participated in the debate on the actions and changes needed to achieve goals of Sustainable Development and identified their share of responsibility towards these goals. Chemists and engineers are embracing sustainability challenges in order to minimize potential environmental and health implications of their technologies. The American Chemical Society (ACS) in the 1990s promoted sustainability, green chemistry, and green engineering, combined with incentives for the adoption of sustainable technologies and new regulatory strategies.

The term Green Chemistry (or Sustainable Chemistry) was coined by Paul Anastas in 1991 within the framework of the U.S. Environmental Protection Agency (EPA) program. As a result, the comprehensive US Green Chemistry Program was established in 1993 which involved the cooperation among many governmental agencies and research institutions, international scientific cooperation as well as worldwide activities in the field of education and information dissemination.

GREEN CHEMISTRY : CURRENT AND FUTURE ISSUES

The term green chemistry was first used in 1991 by P. T. Anastas in a special program launched by the US Environmental Protection Agency (EPA) to implement sustainable development in chemistry and chemical technology by industry, academia and government. In 1995 the annual US Presidential Green Chemistry Challenge was announced.

Similar awards were soon established in European countries. In 1996 the Working Party on Green Chemistry was created, acting within the framework of International Union of Applied and Pure Chemistry. One year later, the Green Chemistry Institute (GCI) was formed with chapters in 20 countries to facilitate contact between governmental agencies and industrial corporations with universities and research institutes to design and implement new technologies.

The first conference highlighting green chemistry was held in Washington in 1997. Since that time other similar scientific conferences have soon held on a regular basis. The first books and journals on the subject of green chemistry were introduced in the 1990s, including the Journal of Clean Processes and Products (Springer-Verlag) and Green Chemistry, sponsored by the Royal Society of Chemistry. Other journals, such as Environmental Science and Technology and the Journal of Chemical Education, have devoted sections to green chemistry. The actual information also may be found on the Internet.

The concept of green chemistry has appeared in the United States as a common research program resulting from interdisciplinary cooperation of university teams, independent research groups, industry, scientific societies and governmental agencies, which each have their own programs devoted to decreasing pollution.

Green chemistry incorporates a new approach to the synthesis, processing and application of chemical substances in such a manner as to reduce threats to health and the environment. This new approach is also known as:

- Environmentally benign chemistry
- Clean chemistry
- Atom economy
- Benign-by-design chemistry

Green chemistry is commonly presented as a set of twelve principles proposed by Anastas and Warner. The principles comprise instructions for professional chemists to implement new chemical compounds, new syntheses and new technological processes.

Development of analytics and environmental monitoring leads to better knowledge of the state of the environment and the processes that take place in it. Due to the introduction into an analytical practice new methodologies and new measuring techniques for identification and determination of trace and micro-trace components in samples with complex compositions have enabled the discovery of the following important facts:

- acidifying the particular elements of the environment,
- the existence of stratospheric ozone depletion phenomenon,
- designation of long term trends in changes of trace components in atmospheric air,
- increase of concentration level of so called persistent organic pollutant (POPs), i. e. compounds belonging to dioxins (PCDD, PCDF), polychlorinated biphenyls (PCBs) and others,
- examination of pollutant bioaccumulation in tissues of organisms on different steps of the trophic chain.

This branch of analytical chemists creates many challenges.

The most important are as follows:

- low and very low concentration levels of analytes,

- the existence of time and space fluctuations of analytes in the investigated media,
- a broad range of concentration of analytes belonging to the same group of compounds,
- the possibility of the presence of interfering compounds, frequently with similar chemical structure and properties.

The irony is that the analytical methods used to assess the state of environmental pollution may in fact be the source of emission of great amount of pollutants negatively influencing the environment. This is connected with the necessity of using considerable amounts of chemical compounds in successive steps of applied analytical procedures. Sampling and especially preparation for their final determination is frequently connected with the forming of large amounts of pollutants (vapours, wastes of reagents and solvents, solid waste). Therefore, it is necessary to introduce the rules of green chemistry into chemical laboratories on a large scale. There is an urgent necessity to evaluate the used analytical methods not only in respect for the reagent, instrumental costs and analytical parameters but also on the basis of their negative influence on the environment. A good tool for such evaluation may be Life Cycle Assessment (LCA). It can be stated that green analytical chemistry is the essential element of green chemistry. The constant development of a new solventless technique is a good example of the activities in this field.

GREEN CHEMISTRY AND GREEN ENGINEERING PRINCIPLES

From the beginning Paul Anastas and John Warner emphasized the new principles of Green Chemistry and the new ―philosophy‖ that has to be followed to achieve the sustainable eco-development of the chemical industry in the future. The following list of 12 principles outlines an early conception of what would make a greener chemical, process, or product.10,11

1. **Preventiont** 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 Chemicals.** Syntheses wherever practicable, should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals** with desired function while minimizing their toxicity.
5. **Safer Solvents** and auxiliaries substances (e.g., solvents, separation agents, etc.) for workers and the environment.
6. **Design for Energy Efficiency**. Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized.
7. **Use of Renewable Feedstocks**. Raw materials or feedstock should be renewable rather than depleting.
8. **Reduce Derivatives**. Unnecessary derivatization (blocking groups, protection/deprotection, temporary modification, etc) should be minimized or avoided if possible.
9. **Catalysis and new catalytic reagents** (enzymes, as selective as possible) are superior to stoichiometric reagents.
10. **Design Products 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 chemical process should be chosen to minimize the potential for chemical accidents.

FIELDS OF GREEN CHEMISTRY WITH NEW TECHNOLOGICAL DEVELOPMENTS

In the last decade Green Chemistry and Green Engineering have advanced for a great variety of research and technology fields providing cutting-edge research and practical applications for a wide spectrum of chemical products and technological innovations. The most important research and technological fields of GC and GE include solutions. Among other things, reduction of global warming and use of CO_2 as a raw material for chemical synthesis, microwave, electrochemical and ultrasound synthetic methods, solvent free reactions (or water as a solvent), phytoremediation, waste management and wastewater, eco-friendly dyes and pigments, innovative food products, catalysis and biocatalysis, biopolymer technology, renewable materials, renewable energy sources, etc. Although there are many fields of innovation for GC and GE products we list below some of the basic.15-17

a. Biocatalysis and biotransformation's processes for practical synthetic reactions

b. Directed evolution. New enzymes for organic synthesis

c. Green chemistry and synthetic processes in the pharmaceutical industry

d. Hydrogen production via catalytic splitting of water

e. Green and renewable energy sources

f. Green chemistry and agricultural technologies benign to environment

g. Green chemistry. Multicomponent reactions

h. Green flow chemistry and continuous processes in chemical industry

i. Green chemistry and biodegradable polymers

j. Green chemistry and organic solar cells

k. Solvent and solvent selection in industrial synthesis

Except for the above, there are also numerous other technological; fields of Green Chemistry and Green Engineering that have been advanced in the last years. Already, some these innovative inventions have been applied and improved sustainability, reduced environmental pollution and released less hazardous chemical products.

GREEN CHEMISTRY, A PHARMACEUTICAL PERSPECTIVE

Green Chemistry definitions change based upon focus. To answer this elusive question it may in fact be best to first consider what Green Chemistry is not. Green Chemistry is often described within the context of new technologies. But Green Chemistry is not beholden to ionic liquids, microwave chemistry, supercritical fluids, biotransformation, fluorosis phase chemistry, or any other new technology. Green chemistry is outside of techniques used but rather resides within the intent and the result of technical application.

Some view Green Chemistry as something process chemists do already...good process chemistry. While often enabling "greener" synthesis, good process chemistry is not equivalent to Green Chemistry. A robust, efficient, and cost-effective chemical process is likely accepted as good process chemistry. The same process examined more rigorously with regard to the twelve principles of Green Chemistry1 invariably brings to light potential improvements relative to environmental performance. Processes evolve and become "greener" relative to earlier iterations, but only an ideal process embodies Green Chemistry itself. Green Chemistry is not simply good process chemistry; it is the highest efficiency potential that exists for each chemical process, serving as both an inspiration for and a measure of the best process chemistry.

Others feel Green Chemistry is a purely environmental agenda, and a condemnation of industrial chemistry or of scientists. This picture neglects the direct relationship between Green Chemistry principles and highly efficient and environmentally benign chemistry. Green Chemistry is a concept for scientists envisioned by scientists for higher efficiency, not a mandate or a condemnation from outside of the scientific community.

In short, Green Chemistry is neither a new type of chemistry nor an environmental movement, a condemnation of industry, new technology, or "what we do already". Green Chemistry is simply a new environmental priority when accomplishing the science already being performed...regardless of the scientific discipline or the techniques applied. Green Chemistry is a concept driven by efficiency coupled to environmental responsibility.

Green Chemistry insists that our synthetic objectives are achieved while assuming additional considerations related to the unnecessary environmental burden created during operations. If using a toxic reagent, one should inquire if a less toxic reagent might accomplish similar ends. A literature search may provide no current alternative with similar efficiency and reduced toxicity, but many do not realize that the simple act of inquiry toward reduced toxicity already indicates a new priority and intent, a higher level of awareness and environmental stewardship, and is Green Chemistry! In some cases a safer reagent will exist. Application will improve the process environmental profile and reduce risk related to working with a toxic reagent while maintaining or improving synthetic efficiency. Some believe an environmental priority will add time and cost. Just the opposite, time and cost are reduced by incorporating higher synthetic efficiency the first time, and new methods can be applied toward parallel and future endeavors to enhance overall productivity.

The definition of Pharmaceutical Green Chemistry should include "The quest for benign synthetic processes that reduce the environmental burden"...but it must also include..."within the context of enabling the delivery of our current standard of living." Pharmaceutical Green Chemistry seeks to eliminate unnecessary environmental impact, but we must enable delivery of life saving medicines and also show value for our stakeholders. Green Chemistry principles do not condemn this but rather encourage that these goals be met through our absolute best performance.

Application of the twelve principles of Green Chemistry can deliver higher efficiency and reduced environmental burden during chemical synthesis. Most of these principles apply directly to pharmaceutical chemistry, but some do not. For instance, designing for degradation can be inappropriate for an active pharmaceutical ingredient (API) that relies upon its precise chemical structure for the desired biological activity and that also must demonstrate adequate stability and acceptable shelf life. Renewable feedstocks are certainly preferred for long-term chemical manufacture but are difficult to achieve with a rapidly changing family of products. Green Chemistry as portrayed by the twelve principles acts as a guide but does not wholly apply to Pharmaceutical Green Chemistry.

Roger Sheldon's E-factor10 is frequently used to highlight the relative inefficiency of pharmaceutical manufacture as opposed to that of petroleum manufacture. This comparison has flaws, however, due to varying product complexity depending upon the particular industry. For example, petroleum scientists collaborate to design unique facilities providing specific engineering solutions to address the physical properties of relatively simple molecules for large-scale manufacture. In contrast, pharmaceutical scientists must generate a diverse array of exceptionally complex targets with little or no specialized engineering adaptation. This high molecular complexity accompanied by limited engineering flexibility translates to a significant responsibility for efficiency placed directly upon the pharmaceutical chemist.

Therefore, the primary driver of Pharmaceutical Green Chemistry becomes the synthetic and analytical chemist. Pharmaceutical green chemists must strive for the correct choice of starting material, ideal number and order of chemical steps, the appropriate use of solvents and reagents, and efficient strategies for isolation and purification. They must achieve a balance for highest efficiency, safety, and robustness, within the existing industry engineering constraints and with concern for the environment. Methodology should be state of the art, and the techniques should be synergistic, accounting for combined synthetic performance as well as individual compound toxicity. Replacing a toxic solvent with a benign solvent that ultimately decreases process throughput is not Green Chemistry! Processes must be examined holistically to ensure maximum efficiency. Particular attention should be paid to solvents, however, as 80% of waste generated during manufacture of a typical API is related to solvent use.

Patent life determines the relative success or failure for a new drug, thus time to market must be minimized. Moreover, industry regulation to ensure quality and safety of pharmaceuticals results in significant effort and expense to incorporate and justify process improvements late in the product timeline. Therefore, repeated use of established methodology that minimizes timeline and regulatory risk can become attractive. This perceived risk management might be the greatest inhibitor of Pharmaceutical Green Chemistry. Complacency must be shed, and green chemists must be willing to challenge tried and true techniques in favor of improved techniques for greater synthetic efficiency. The seemingly higher risk implicit in this quest must be embraced, because Pharmaceutical Green Chemistry will translate to higher synthetic efficiency and better chemical processes, which will in turn reduce impact upon the environment.

The potential of Pharmaceutical Green Chemistry will only be realized if scientists are empowered and rewarded based upon higher expectations of efficiency. It is a competitive advantage to reduce the cost of manufacture beyond mere acceptability, and greener chemistry reduces cost. It is encouraging that metrics14 have been developed which may help business leadership to better understand and reward greener chemistry. It should be clear though that while Pharmaceutical Green Chemistry can be measured by metrics of environmental health and safety, the real driVer of Pharmaceutical Green Chemistry is synthetic efficiency.

Embracing concepts of Green Chemistry will be an effort worth pursuing, not only for the sake of economic efficiency and environmental impact but also toward a sustainable future. As pharmaceutical chemists, we have many choices with regard to how we synthesize molecules. These choices must deliver economic viability, but a responsibility also exists that we incorporate environmental consideration toward this ultimate goal of sustainability. Our responsibility should be viewed as a privileged opportunity, an extension of our heritage as chemists, and represents an emerging new frontier of exploration. Chemistry is the "ultimate cult of the new", and chemical literature captures a history of innovation and an inclination toward elegance. There could be no more elegant an endeavor than to better address issues of pharmaceutical science within the higher context of environmental stewardship.

GREEN CHEMISTRY AND ENVIRONMENTALLY FRIENDLY TECHNOLOGIES

The "green chemistry" concept was introduced in the early 1990s in a special program launched by the US Environmental Protection Agency (EPA) and soon adopted by mass-media as the new approach of chemistry in opposition to the pollute-and-then-clean-up approach considered the common industrial practice.[1]Their early definition of the subject is still widely quoted:

"'Green Chemistry' is the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products". However in practice 'Green Chemistry' is nowadays taken to cover a much
broader range of issues than the definition suggests. As well as using and producing 'better' chemicals with less waste, 'Green Chemistry' also involves reducing other associated environmental impacts, in particular reducing the amount of energy used in chemical processes. In 1995 President Bill Clinton established the Presidential
Green Chemistry Challenge Awards to recognize chemical technologies that incorporate the principles of sustainable chemistry into chemical design, manufacture and use.

EPA identified the following main areas for green chemistry:

* Use of alternative synthetic pathways (examples, are natural processes such as photochemistry and biomimetic synthesis or alternative feedstocks that are more innocuous and renewable such as biomass).

- Alternative reaction conditions (examples are use of solvents that have a reduced impact on human health and the environment), or increased selectivity and reduced wastes and emissions.

- Design of eco-compatible chemicals (less toxic than current alternatives or inherently safer with regard to accident potential).

Ideally, the application of green chemistry principles and practice renders control, regulation, clean-up and remediation unnecessary and the resultant environmental benefit can be expressed in turns of economic impact, It is science based non regulatory and economically
driven approach to achieving the goals of environmental protection. The major difference between a green chemistry approach to environmental issues and more traditional approaches is that green chemistry utilizes the creativity of the scientists and engineers to develop novel and benign approaches to processes from the start rather than relying on regulatory restrictions after the process
has been discovered to be toxic or polluting. Green chemistry is a tool for chemists, chemical engineers and others who design materials to help move society toward the goal of sustainability. Design at the molecular level allows decisions to be made that impact how materials will be processed, used and managed at the end of their life. Green chemistry principles were first published in the 1998 book "Green Chemistry: Theory and Practice," by Paul T. Anastas and John C. Warner, as a means to make the concepts of green chemistry accessible to the scientific community. It is now being explored and used by many countries including UK, Canada, Australia and Germany.
Being one of the leading producers of pesticides and pharmaceutics, India has also realized the need to go green. Green chemistry methodologies can be viewed through the framework of the 'Twelve Principles of Green Chemistry"

CONCLUSION

Green chemistry is not a new branch of science. It is a new philosophical approach that through application and extension of the principles of green chemistry can contribute to sustainable development. Presently it is easy to find in the literature many interesting examples of the use of green chemistry rules. They are applied not only in synthesis, processing and using of chemical compounds.

Many new analytical methodologies are also described which are realized according to green chemistry rules. They are useful in conducting chemical processes and in evaluation of their effects on the environment. The application of proper sample preparation techniques, allows us to obtain precise and accurate results of analysis.

To combine the technological progress with the safeguard of the environment is one of the challenges of the new millennium. Chemists will play a key role in the realization of the conditions for a sustainable development and green chemistry may be their winning strategy.

Green chemistry addresses such challenges by inventing novel reactions that can maximize the desired products and minimize by-products, designing new synthetic schemes and apparati that can simplify operations in chemical productions and seeking greener solvents that are inherently environmentally and ecologically benign.

The goal of green chemistry is to create a better, safer and efficient environment by reducing waste and eliminate the hazardous materials in chemicals. Our future challenges in society, environmental, economic and resources demand for efficient and environmental-friendly chemical processes and products. Therefore, through our paper, we have addressed a few innovations, challenges, opportunities and step need to be taken for a sustainable development through green chemistry.

Furthermore, the success of green chemistry depends on the training and education of a new generation of chemists. Student at all levels have to be introduced to the philosophy and practice of green chemistry.

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