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Review paper for a green chemistry

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Abstract:

As the Green Chemistry1, 2 movement has gained momentum, definitions of Green Chemistry have been dominated predominantly by academic viewpoints. Green Chemistry concepts, however, apply to an incredible diversity of scientific endeavor, which has invariably led to differences between and amongst both academia and industry regarding what constitutes Green Chemistry.

Speaking primarily of the pharmaceutical industry and considering the advances achieved toward promoting Green Chemistry globally,3 it is surprising how diverse the answers can be when executives, engineers, biologists, and chemists are asked the seemingly simple question "What is Green Chemistry?" Perhaps this should be expected considering that individual priorities change based upon a specific endeavor, altering the focus of Green Chemistry and consequently the message, making general definitions difficult. A common impression obtained appears to be that many do not accurately know or fully understand the true motivations, drivers, and deciding factors that serve to inspire and define Green Chemistry, and in particular Pharmaceutical Green Chemistry. This commentary seeks to shed light upon key aspects with regard to the philosophy of Pharmaceutical Green Chemistry.

Keywords:

Green chemistry, sustainable development, environmental benignity, renewable feedstock's, industrial applications

1. Green chemistry:

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,4 microwave chemistry,5 supercritical fluids,6 biotransformation,7 fluorous phase chemistry,8 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 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.

2. Green chemistry principal:

Green chemistry, also known as sustainable chemistry, is an approach to designing chemical products and processes that reduce or eliminate the use and generation of hazardous substances. The principles of green chemistry guide researchers and industry professionals in developing innovative solutions that are environmentally benign, economically viable, and socially responsible. Here's an explanation of the twelve principles of green chemistry, as outlined by Anastas and Warner:

2.1. Prevention:

It's better to prevent waste generation than to treat or clean up waste after it's formed. This principle encourages the design of processes to minimize the production of hazardous substances.

2.2. Atom economy:

Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product, thereby reducing waste generation.

2.3. Less hazardous chemical syntheses:

Whenever possible, synthetic methods should use and generate substances that possess little or no toxicity to human health and the environment.

2.4. Designing safer chemicals:

Chemical products should be designed to have minimal toxicity while maintaining their desired functionality. This principle encourages the use of substances that are inherently safer and less harmful.

2.5. Safer solvents and auxiliaries:

The use of auxiliary substances (such as solvents and separation agents) should be minimized or eliminated to reduce waste generation and the risk of accidents or pollution.

2.6. Design for energy efficiency:

Energy requirements should be minimized during the synthesis of chemicals and products. This principle promotes the development of processes that are energy-efficient and reduce greenhouse gas emissions.

2.7. Use of renewable feedstock's:

Whenever feasible, raw materials should be obtained from renewable resources to reduce dependence on non-renewable fossil fuels and mitigate environmental impacts associated with resource extraction.

2.8. Reduce derivatives:

Unnecessary derivatization (e.g., converting one functional group to another) should be avoided to minimize waste generation and improve process efficiency.

2.9. Catalysis:

Catalytic reagents (substances that promote chemical reactions without being consumed) should be used to minimize the use of stoichiometric reagents, which can generate waste.

2.10. Design for degradation:

Chemical products should be designed to break down into innocuous substances after use to prevent persistence and accumulation in the environment.

2.11. Real-time analysis for pollution prevention:

Analytical methodologies should be developed to allow for real-time monitoring and control of chemical processes to minimize pollution and waste generation.

2.12. Inherently safer chemistry for accident prevention:

Chemical accidents should be prevented through the use of inherently safer design principles, such as minimizing the use of hazardous substances and reducing process complexity.

3. Designing for a green chemistry future:

The scientific question facing the chemical sector when designing for the future Earth is not whether products of the chemical industry will be necessary, because they surely will be. Rather, the question is, what will be the character, nature, and production processes of synthetic chemicals needed for a sustainable civilization? Chemistry has a long history of inventing essential and beneficial products and processes with extraordinary performance; however, this technological progress has often been realized using a narrow definition of function, which does not account for adverse consequences. Today's chemical sector follows a linear path (Fig. 1, left), in which feedstock's, mostly fossil and finite in nature, are pushed through a production chain that relies on reagents that are designed to be highly reactive but are often also unintentionally persistent and/or toxic, which is consequential for worker exposure as well as accidental or intentional release (e.g., methyl isocyanate release in Bhopal, India, and dioxin spills in Times Beach, Missouri, and Seveso, Italy). Many of these processes generate waste (often itself toxic, persistent, and bioaccumulating), at rates higher than the intended product, particularly as product complexity increases (e.g., 5 to 50 times for specialty chemicals and 25 to 100 times for pharmaceuticals)

(1) Similarly, the resulting chemical products are often designed for their intended use while relying on circumstantial controls to limit exposures to hazards that have often not been

assessed, potentially owing to the historic lack of tools and models, as evidenced by the multitude of unintended adverse consequences

(2) Given the need for the many functions provided by the products of the chemical industry, the question, as we look to the future, must include two goals: How do we

(i) Keep and greatly expand upon the advances in performance while

(ii) Limiting or eliminating the detrimental impacts that threaten the sustainability of human and planetary wellbeing? Answering this question is an important and urgent scientific challenge. There is a plethora of achievements in the fields of "green chemistry" and "green engineering" that have demonstrated that more performance and functionality from our chemical products and processes can be realized while decreasing adverse impacts. These successes need to be made systematic and not anecdotal. To succeed, not only do the conditions and circumstances by which we make and use chemical products need to be altered but the inherent nature of the chemical products and reagents themselves across the entire value chain from feedstock to application also needs to be changed (Fig. 1). This requires changing the nature of the very definition of "performance" from function alone to function and sustainability, which can only be realized through thoughtful design of the intrinsic properties of the molecules and their transformations.

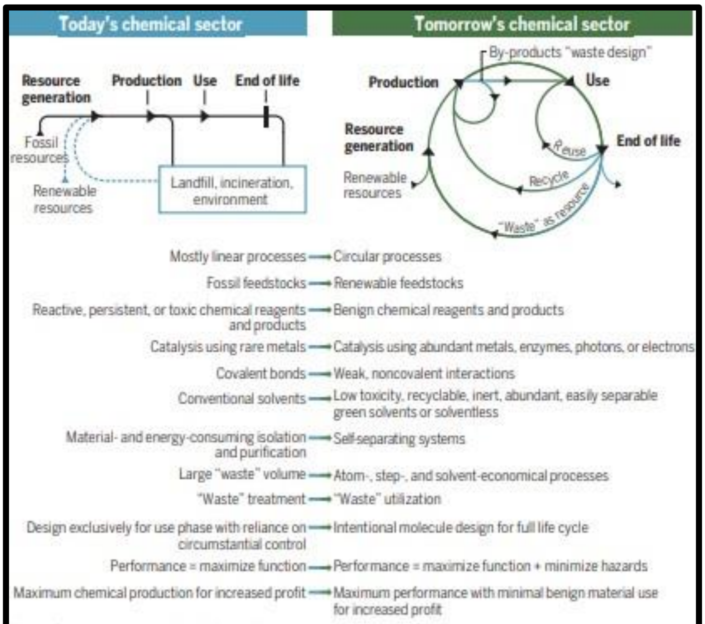
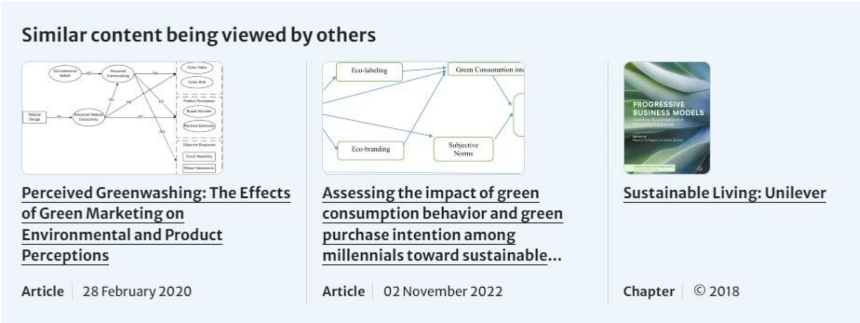


Fig. 1. Characteristics of today's and tomorrow's chemical sectors.

Figure. 1: Characteristics of today's and tomorrow's chemical sectors

3.1. Current scenario:

This article provides an overview of the origins and development of green chemistry. Aiming to contribute to the understanding of green chemistry, basically from a historical point of view, this overview argues that contextual influences and the user friendliness of the term are drivers for the explosive growth of green chemistry. It is observed that political support for its development has been significant, in which the Pollution Prevention Act of 1990 was a formal political starting-point, but informally the origins of green chemistry go back to before 1990. US EPA played an important role in all this, but did not solely contribute to the growth of green chemistry.



4. Conclusion:

Einstein is famously quoted as saying "problems cannot be solved at the same level of awareness that created them" (45). The new tools and approaches we need include attaining mastery of weak-force interactions as a design tool, as we have realized with covalent bonds; designing complex, no ideal mixtures rather than synthesizing a single molecule to achieve function; understanding the molecular scale at the complete dynamic reality rather than as a simple, static snapshot; understanding and controlling long-range interactions for chemical reactivity at localized structures; and progressing from mathematical analysis of a series of experiments toward statistical mining of large and diverse datasets. As it is in nature, the concept of "waste" must disappear from our design frameworks, such that we instead think in terms of material and energy flows. Hazards to the inhabitants and systems of the biosphere by our chemical products and processes should be viewed as a critical design flaw and performance defined in terms of both primary functionality and sustainability

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