

## Green Chemistry and Sustainability: A Mutual Connection

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### Abstract

For the chemists, practicing Green Chemistry is essential nowadays to avoid the drawbacks and limitations of the traditional laboratory practices followed. For this purpose, 12 Green Chemistry principles are suggested for the scientific community. Each principle basically concerns with the environment protection avoiding unwanted products of a chemical process. Emergence of these principles have one of the greatest goals, the sustainability, which becomes a burning topic in recent days. Green chemistry significantly works for a greater interest of sustainable development by applying its principles. This is now widely accepted. As such, the concept of Green Chemistry and sustainability has found immense importance in the recent days among the researchers. In this chapter, we will discuss how Green Chemistry principles has significantly influence the sustainability goal; and works for the betterment of the future generation.

### Keywords

Green Chemistry, Sustainability, Design, Environment

### Introduction

Green Chemistry has been emerged as a powerful alternative to the traditional chemical process that have been widely applied in different chemical transformations in academia, research laboratories as well as in the industries. It basically refers to the design of chemicals with viable processes which can either reduce or eliminate the use and generation of numerous hazardous substances. The pioneer work on Green Chemistry was done by Paul Anastas and John Warner in the publication *Green Chemistry Theory and Practice*.<sup>1,2</sup> Green Chemistry focusses on reducing pollution at the source by minimizing or eliminating the hazards of chemical feedstocks, reagents, solvents as well as products.<sup>3,4</sup> It is defined as the “design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances”.<sup>1,5,6</sup> Global awareness of Green Chemistry has grown significantly which support sustainability objectives like avoiding waste, maximizing resource usage, and lowering environmental consequences.

According to the notion of sustainable development, current needs should be met without sacrificing the capacity of future generations to meet their own.<sup>7,8</sup> An approach to development

known as sustainable development aims to strike a balance between social inclusion, economic progress, and environmental preservation.<sup>9</sup> Natural resources are becoming more and more in demand due to the population growth of the world and the ongoing industrialization process. This leads to a large deal of environmental deterioration and puts tremendous strain on our natural and social ecosystems.<sup>10</sup> As such, necessary steps must be taken by the human to protect the future generation. In this context Green Chemistry principles have emerged as a pioneer concept to design a sustainable future protecting the environment and minimising the resource depletion.

The Green Chemistry approach works in such a way to achieve sustainability at the molecular level.<sup>11</sup> To achieve this goal, it has been applied to all industry sectors from aerospace, automobile, cosmetic, electronics, energy, household products, pharmaceutical, to agriculture.<sup>12,13</sup>

Herein, a brief overview has been given to understand the relation of Green Chemistry with the concept of sustainability.

### **The 12 principles of Green Chemistry:**

The 12 principles of Green Chemistry as proposed by Anastas and Warner are mentioned below.<sup>1,14</sup> They serve as a framework for designing new chemical products and processes, encompassing all facets of the process life-cycle, from the toxicity and biodegradability of products and reagents to the raw materials utilized to the transformation's efficiency and safety.<sup>11,15</sup>

#### **i) Prevention**

It is better to prevent waste than to treat or clean up waste after it has been created.

#### **ii) Atom Economy**

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

#### **iii) Less Hazardous Chemical Syntheses**

Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

#### **iv) Designing Safer Chemicals**

Chemical products should be designed to preserve efficacy of function while reducing toxicity.

#### **v) Safer Solvents and Auxiliaries**

The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and, innocuous when used.

**vi) Design for Energy Efficiency**

Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

**vii) Use of Renewable Feedstocks**

A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.

**viii) Reduce Derivatives**

Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided, if possible, because such steps require additional reagents and can generate waste.

**ix) Catalysis**

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

**x) 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.

**xi) 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.

**xii) Inherently Safer Chemistry for Accident Prevention**

Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

For designing a process practicing Green Chemistry principle, it is not possible to address all the principles at a time. But efforts should be given for the application of these principles in certain steps of the synthesis process.<sup>15,16-19</sup>

**Sustainable development:**

The concept of sustainability was mainly driven by the increasing environmental destructions and concerns about resource depletion as well as the pollution originated by the chemicals. The triple-bottom-line theory of the three domains *viz.* social, economic and

environmental, is the foundation of sustainability. This theory made it clear that in order to carry out development, the economy, society and the environment must all be balanced.<sup>20</sup> By ensuring that the use of natural resources and the human cycle does not diminish the worth of life and lessen environmental inequalities; sustainability is the design of human and industrial systems.<sup>21</sup> Environmental sustainability, which is the prime requirement at this time, can be achieved by lowering different kinds of emissions, wastes (either solid or liquid), environmental hazards, the use of toxic products and resources; by enhancing human health.<sup>22</sup> Sustainable progress was defined as growth that satisfies present demands without jeopardizing the ability to meet the needs of the future generation. The two main concepts are (i) the idea of "needs" to sustain human life and (ii) the idea of limitations resulting from the technical and social association conditions of the capacity of the environment to meet present and future demands.<sup>23</sup>

### **How Green Chemistry meets the sustainability goal?**

It is clear that, sustainable development is “meeting the needs of present without compromising the ability of future generation,” according to the UN. Green chemistry is concerned with using science and technology to promote sustainability. Environmental impact assessment models and methods have been developed in order to better understand and address the problem of environmental contamination. Several of these methods and models have proven effective in forecasting the effects of particular substances in particular environmental conditions. These models have been extremely helpful in developing emission control and compliance strategies by connecting air and water quality characteristics to point and nonpoint sources. But some of the methods and models didn't concentrate on pollution control; instead, they were largely focused on determining how much pollutants could be released into the environment with a reasonable impact. Environmentally conscious manufacturing, eco-efficient production, and pollution prevention became more popular, and the idea of end-of-pipe approaches to waste management decreased.<sup>24-</sup>

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The idea of design is the most crucial component of green chemistry and design cannot be done by chance; it is a declaration of human intention. It encompasses originality, preparation, and methodical ideation. The “design rules” known as the 12 Principles of Green Chemistry assist scientists in achieving the deliberate objective of sustainability.<sup>3,11,28-30</sup>

From the 12 principles of Green Chemistry and the concept of sustainability, we can conclude some points to interpret their interconnectivity. If we concentrate on the environmental

aspect, Green Chemistry basically deals with the prevention of pollution as well as reduction of wastes. Sustainability at the same aspect promotes long term environmental health. Green Chemistry focusses on the safer design of reaction protocol as well as the disposal of wastes at the onset. It promotes the renewable feedstocks and energy efficient reaction protocols. Sustainability, in this regard, concentrate on the safe disposal of raw materials. It ensures the responsible use of the resources. Consequently, it is observed that Green Chemistry supports sustainable lifecycle management. The techniques designed by it can help to meet the sustainability goals. Furthermore, Green Chemistry exclusively works on reducing toxicity and hazards of the products developed. It encourages for new and cleaner technologies. At the same time, sustainability requires safe products and drives change towards circular economy and green industries. This also shows the interconnectivity of both the concepts. Green Chemistry enables the creation of safer and sustainable product. As such, it is a practical pathway for sustainable innovation.

### **Conclusions**

From the above discussion, it is seen that Green Chemistry and sustainability are undistinguishably linked. More effective and safe scientific methods for chemical processes and product manufacturing are needed to address the sustainability of resources as well as the environment. These issues are addressed by Green Chemistry, which provides a broad and diverse research scope that enables the development of new synthetic methodologies which are naturally benign to the environment and to the ecosystem. It also focusses on the development of novel reaction protocols that can maximize the desired products and minimize the wastes and byproducts. The fusion of Green Chemistry principle with the sustainability concept effects the economy of the chemical industry. As such, research and development efforts must prioritise a goal that will serve as a potent instrument for promoting sustainable innovation. Putting its 12 principles into practice, Green Chemistry gradually contributes to the creation of a more environment friendly sustainable world by addressing the latest environmental issues and effects our contemporary era.

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