WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
SJIF Impact Factor 8.084
Volume 11, Issue 15, 449-464. Review Article ISSN 2277– 7105

GREEN CHEMISTRY

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Article Received on
09 September 2022,
Revised on 30 Sept. 2022,
Accepted on 20 Oct. 2022
DOI: 10.20959/wjpr202215-26030

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ABSTRACT

Green chemistry is a term used to describe a series of chemical engineering principles and practices that aim to improve environmental quality and safety. The principles of green chemistry are often used in the development of new chemical products, both industrially and in the laboratory. Some of the key areas that are typically addressed with green chemistry include the use of sustainable materials, the reduction of waste, and the elimination or minimization of toxicants. In addition, green chemistry has been shown to be an effective strategy for developing more environmentally friendly processes and products. Green chemistry is a field of chemistry that seeks to improve the environmental friendliness of chemical processes. It does this by identifying and reducing environmental pollutants, by recycling or reforming materials, or by using alternative methods of synthesis.

KEYWORDS: green chemistry, green chemistry principles, 12 principles of green chemistry, what is green chemistry, principles of green chemistry, green chemistry definition, green chemistry define, green chemistry impact factor, examples of green chemistry, green chemistry examples, john warner green chemistry, acs green chemistry, renewable starting materials green chemistry, green chemistry journal.

INTRODUCTION

Green Chemistry has 12 core principles that cover a number of ways of reducing environmental and health impacts from chemical manufacturing, and specify the priorities of research to develop green chemistry technologies.[1]

Essentially, green chemistry is characterised as the reduction of the accompanying environmental damages from materials production, as well as corresponding minimization

and appropriate disposal of the waste generated in various chemical processes.[2] Green Chemistry is an approach to chemical science which effectively uses renewable sources of raw materials, reduces waste, and avoids the use of toxic and hazardous reactants and solvents during chemical products production and applications.[3] Green chemistry also seeks to increase the efficiency of the production of chemical products through changes to how chemicals are designed, manufactured, and used.[4] Green Chemistry (also known as Sustainable Chemistry) is defined as designing chemical products and processes to reduce or eliminate the use of hazardous and toxic substances or their production.[5]

Green Chemistry is designed to eliminate the use and generation of dangerous substances through developing better processes to produce chemical materials, producing minimal waste, while real-time tracking the processes in operation.[6] The green chemistry approach could save schools money by reducing the amount of toxic chemicals that they have to buy, and also reducing their need to dispose of it as hazardous waste. In green chemistry, teachers evaluate the relative risks of chemicals used in conventional chemistry experiments, and choose materials that are less toxic in order to demonstrate green chemistry principles.[7] To counteract this stereotype, a central aim of green chemistry is to mitigate risks to humans and the environment resulting from the synthesis, production, and application of chemical products by developing cleaner, closed-loop procedures.[3]

If, as some suggest, green chemistry is simply using chemicals to solve sustainability problems, such as those addressed by UN sustainable development goals (e.g., climate change, energy production, water purification, food production, or drug manufacturing),

then, without adhering to the principles of green chemistry, there is the potential for the greatest number of tragic unintended consequences.[8] The idea of green chemistry was originally developed in response to the Pollution Prevention Act of 1990, which stated that US national policies should address pollution through enhanced design (including economically beneficial changes to products, processes, raw materials usage, and recycling) rather than through remediation and waste.[9] American chemist Paul Anastas, one of green chemistry's main founding fathers, claimed that it was possible to prevent pollutants from being produced by improving the way chemicals are synthesized.[1] Green chemistry took the EPAs (Electronic Protocols Application Software) mandate one step further, and created a new reality for chemistry and engineering, asking chemists and engineers to design chemicals, chemical processes, and commercial products in ways that, at the very least, avoided creating toxics and waste.[10]

Chemists are instructed to use these 12 principles as a checklist to evaluate a particular chemical process or technology during design and scaling-up phases. Attempts are made to not only quantify the environmental friendliness of the chemical process, but to consider other variables, such as chemical yield, price of the reaction components, chemical handling safety, equipment requirements, energy profiles, and the ease of working and cleaning products.[13]

History of Green Chemistry

In green chemistry, the goal is to create chemical products and processes that are safer, more environmentally friendly and less toxic. The history of green chemistry can be traced back to the early 1990s, when scientists began to realize that many of the chemicals used in industry were harmful to human health and the environment.[14]

One of the first steps in green chemistry was to develop ways to test chemical products for safety before they were released into the environment. This led to the development of testing methods such as hazard assessment, risk assessment, and impact assessment.[15]

Another important step in the development of green chemistry was the recognition that many chemicals are both harmful and poorly understood. This led to the creation of research programs focused on understanding how specific chemicals interact with each other and with biological systems.[16]

Today, green chemistry is widely accepted as a way to create safer, more environmentally friendly products. It has also helped to reduce the use of harmful chemicals worldwide.

Principles of Green Chemistry[11]

There are a few general principles that underpin green chemistry, though the specific details of how they're applied will vary depending on the particular scenario. Here are a few of the most important ones.

1. Prevention: It is better to prevent waste formation than to treat it after it is formed.

2. Atom economy: Design synthetic methods to maximize incorporation of all material used into final product.

3. Less hazard: Synthetic methods should, where practicable, use or generate materials of low human toxicity and environmental impact.

4. Safer chemicals: Chemical product design should preserve efficacy whilst reducing toxicity.

5. Safer solvents: Avoid auxiliary materials - solvents, extractants - if possible, or otherwise make them innocuous.

6. Energy efficiency: Energy requirements should be minimized: conduct synthesis at ambient temperature and pressure.

7. Renewable feedstocks: Raw materials should, where practicable, be renewable.

8. Reduce derivatives: Unnecessary derivatization should be avoided where possible.

9. Smart catalysis: Selectively catalyzed processes are superior to stoichiometric processes.

10. Degradable design. Chemical products should be designed to be degradable to innocuous products when disposed of and not be environmentally persistent.

11. Real-time analysis for pollution prevention. Monitor processes in real time to avoid excursions leading to the formation of hazardous materials.

12. Hazard and accident prevention. Materials used in a chemical process should be chosen to minimize hazard and risk for chemical accidents, such as releases, explosions, and fires.

Fig. 1: 12 Core Principles Of Green Chemistry.[12]

What Is Green Chemistry?

Green Chemistry covers chemical reagents, reactions, and products, and the design, production, use, and disposal of chemical agents. Green chemistry is described as using a series of principles in chemical product design, production, and usage that help reduce or eliminate hazardous chemicals used or created.[17] Green chemistry reduces pollution at the source by minimizing or eliminating the hazards of chemicals feedstocks, reactants, solvents, and products. Green chemistry seeks to develop and manufacture economically advantageous chemical products and processes that achieve the highest levels in the hierarchy of pollution prevention, by reducing contamination at the source.[18]

Green Chemistry is an approach to chemical science that effectively uses renewable feedstocks, reduces waste, and avoids the use of toxic and hazardous reactants and solvents in chemical products manufacturing and applications.[19] Green chemistry is a branch of chemistry focusing on developing products and processes that eliminate or minimize the use and production of harmful chemicals.[17] Green chemistry also seeks to increase the efficiency of the production of chemical products through changes in how chemicals are designed, manufactured, and used.[20] Green chemistry the goal of making the entire

industrial chain of chemical products and chemicals green has contributed, and will continue to contribute, to sustainable chemical industrial development.[21]

We are capable of developing environmentally sound chemical processes and products, which would, first and foremost, prevent pollution.[22] If the technology reduces or eliminates hazardous chemicals used in cleaning environmental contaminants, that technology will qualify as green chemistry technology.[4] American chemist Paul Anastas, a major founding figure in green chemistry, has said that it may be possible to avoid producing pollutants by improving how chemicals are synthesized. In the 1990s, Paul Anastas and John Warner postulated 12 principles for green chemistry, which are still used today, which depend upon minimization or avoidance of toxic solvents in chemical processes and analyses, as well as avoiding waste products produced from those processes.[18]

New methods and technologies capable of reducing the use and generation of dangerous substances at all stages of chemical analyses are a major focus of the so-called green analytical chemistry (Paul Anastas, 1999, Sanseverino, 2000, Nolasco et al., 2006, Guardia and Armenta, 2012).[23] The idea of green chemistry was originally developed in response to the Pollution Prevention Act of 1990, which stated that US national policies should address pollution through better design (including economically efficient changes to products, processes, use of input materials, and recycling) rather than through processing and disposal.[24] Green Chemistry takes the EEPAs mandate one step further, and establishes a new reality for chemistry and engineering, asking chemists and engineers to design chemicals, chemical processes, and commercial products so as, at the very least, to avoid creating toxics and waste.[22] To turn that stereotype around, a central objective of green chemistry is to mitigate risks to humans and the environment of chemical syntheses, production, and applications of chemical products by designing cleaner, closed-loop processes.[19]

Understanding Pharmaceutical Green Chemistry

In this review paper, we will summarize a few successful examples using Green Chemistry principles for guiding process development and green solvent application within the pharmaceutical industry15-19.[25] Green Chemistry first gained momentum in 1990s, aiming at making products using chemical processes that reduced waste, saved energy, and employed alternatives to dangerous substances.[26] Green chemistry is the design of chemical

products and processes that reduce or eliminate the use or production of dangerous substances.[18]

Green chemistry applies throughout the entire lifecycle of the chemical product, including its design, manufacturing, use, and final disposal. Green chemistry seeks to develop and manufacture economically viable chemical products and processes that achieve the highest levels in the hierarchy of pollution prevention, by reducing pollution at the source.[18] Green chemistry is generally defined as designing chemical processes and products in such a way that they minimise the use and/or production of hazardous materials.1 Green chemistry is further clarified through a series of principles intended to provide a coherent framework for designing chemicals that have reduced inherent hazards.[27]

A review of these issues will give the reader a sense of how green chemistry is an innovative, science-based approach to sustainability, warranting widespread adoption across the pharmaceutical industry and its supply chains.[27] In 1998, Paul Anastas and John Warner co-authored a book outlining the 12 principles forming the foundation for green chemistry, including a number of ways in which chemical manufacturing can reduce environmental and human impacts.[28]

Through Pfizer green chemical initiatives, rooted in the 12 principles of green chemical science outlined by Paul Anastas and John Warner, we are committed to promoting the selection and use of chemicals that are more environmentally friendly, eliminating waste, and conserving energy.[29] The Pharmaceutical Roundtable of the American Chemical Society Green Chemistry Institute (ACS GCI) aims to advance green chemical science and engineering in companies engaged in API R&D and manufacturing of medicines.[30] Its activities include maintaining a research agenda and producing guidelines and standards for a variety of chemical processes, and it hosts an annual Green Chemistry Challenge Award, designed for innovative science-based solutions to real world environmental problems.[31]

Fig. 2: Mclean/Shutterstock.Com.

While green chemistry has been a major component of process development at Amgen for years, the efforts recently moved back to the fore as a core component of the companys environmental sustainability plan 2027, which seeks carbon neutrality alongside major reductions in water use and waste generation.[26] By applying green chemistry principles of atom economies (i.e., synthetic methods must be designed to maximize incorporation of all materials used in a process into the final product) to pharmaceutical R&D, few by products are produced, thus minimising costs in storage and disposal.[28] Many principles of green chemistry may enable processes to become more efficient, such as by reducing the number of reaction steps, or using less energy or materials ("Green Chemistry Principles for Sustainability"). Green-chemistry also promotes the use of recycled solvents.[32] However, recent guidelines for the N-nitrosamine contamination have highlighted how these practices often lead to cross-contamination, and are currently discouraged.[34] In conclusion, while many of these green initiatives would increase efficiency, minimize costs, and minimize streams of waste, they frequently conflict with existing guidance for the quality, for example, with the guidance on the ICH Q11, the guideline on the contamination from N-nitrosamines.[33]

Green Chemistry Application Pharmaceutical

In this review paper, we will summarize a few successful examples using Green Chemistry principles for guiding process development and green solvent application within the pharmaceutical industry15-19.[25] In the last ten years, many major pharmaceutical companies have moved towards using green chemistry practices in their drug discovery, development, and manufacturing.[34] The growing numbers of green methodologies developed by scientists at the university level and industry researchers has allowed companies to market these ideas.[35]

Green Chemistry builds upon EPAs goals, encouraging chemists and engineers to develop chemicals, processes, and products that avoid creating toxins and waste.[13] Green chemistry reduces pollution at the source by minimizing or eliminating hazards from chemicals feedstocks, reactants, solvents, and products. Green chemistry seeks to develop and manufacture economically advantageous chemical products and processes that achieve the highest levels in the hierarchy of pollution prevention, by reducing contamination at the source.[18]

Green chemistry is the design of chemical products and processes that reduce or eliminate the use of, or the production of, dangerous substances.[18] Defining it as the design of products and processes that minimize the production and use of dangerous substances, green, sustainable chemistry has been demonstrated to be feasible over the past quarter-century. This makes green and sustainable chemistry very important to the future sustainability.[36]

Green chemistry applies throughout the entire lifecycle of the chemical product, including design, manufacturing, usage, and final disposal.[18] By applying atomic-economy principles of green chemistry (i.e., the synthesis methods must be designed in such a way that they maximise incorporation of all materials used in the process into the final product) to pharmaceutical research and development, few byproducts are produced, thus minimising the costs of storage and disposal.[28] Many principles of green chemistry may enable processes to become more efficient, such as by reducing the number of reaction steps, or using less energy or materials (see "Green Chemistry Principles for Sustainability").[34]

Simply formalizing the chemical reaction on the benchtop, or an industrial chemical process, as a system, without considering the molecules systems and lifecycle impacts, frustrates the

goal of systems thinking in green chemistry.[36] In 1998, Paul Anastas and John Warner co-authored a book outlining the 12 principles forming the foundation for green chemistry, including a number of ways chemical manufacturing can be reduced both environmentally and in terms of the impact on humans.[28] As seen, changing a drug products system towards larger drug molecules such as oligonucleotides involves some environmental trade-offs, but it is plausible that over time, the high intensity of the processes associated with those larger molecules could be reduced by changes in the technology for synthesizing, the adoption of semi-synthetic approaches, and better practices for managing water.[36]

Little is known about the effects on humans of sustained, prolonged exposure to lower concentrations of pharmaceuticals, which is why it is necessary to pursue green, sustainable chemical approaches to changing how chemical and pharmaceutical industries operate.[36] Although solvents are not the only means for producing green pharmaceuticals, considerations about solvents will be frequent in the history of the drug processes developed throughout this review.[37] Attempts are made to not only quantify greenness of a chemical process, but to consider other variables, such as the chemical yield, price of the reaction components, chemical handling safety, equipment requirements, energy profiles, and the ease of manufacturing and product purification.[13]

Green Chemistry Is Gaining Global Recognition

Green chemistry has been recognized by many as a way to improve the safety and environmental sustainability of chemical production.[35] While it is not a new concept, recent advances in technology have made green chemistry more practical and efficient. Here are a few reasons why green chemistry is gaining global recognition.

1. Green chemistry can help reduce environmental stressors - By using green chemistry principles, chemicals can be produced in a more environmentally friendly way that reduces stress on the environment.

2. Green chemistry can improve safety - By using safer chemicals, green chemists can ensure that the products they create are safe for human and environmental use.

3. Green chemistry can improve sustainability - By producing chemicals in a more sustainable way, green chemists can reduce the environmental impact of their work.

4. Green chemistry can improve product quality - By using well-defined and standardized procedures, green chemists can ensure high-quality products regardless of the chemical source.

Greener Pharmaceutical Chemistry Is Important To The World

Green Chemistry is the engineering of chemicals products and processes to reduce or eliminate the use of hazardous substances or their production.[11] Green chemistry first gained momentum in the 1990s, aiming to produce products using chemical processes that reduce waste, conserve energy, and utilize alternatives to dangerous substances.[29] Green chemistry redefines chemical process designs and offers environmental benefits through reduced waste, elimination of costly chemical processing, and reduced energy and resource usage. A philosophy that has been introduced into the chemical industry only recently, green chemistry promotes careful design of chemical production processes in order to minimize toxic components used, as well as to minimize the waste and use of energy.[22]

The green chemical approach aims to engineer materials that form the foundations of our society and our economy--including those that produce, store, and transport our energy in ways that are human friendly and environmentally sustainable, as well as having inherent resilience.[40] The green chemical ideas were originally developed in response to the pollution prevention act of 1990, which stated that US national policies should address pollution through better design (including economically beneficial changes to products, processes, raw materials usage, and recycling) rather than through treatment and disposal.[42] Two years later, in the United States, California lawmakers introduced the Green Chemistry Initiative, which also promoted using alternatives to dangerous chemicals in industrial production. The book set forth principles that would help to minimise the environmental impacts of chemical manufacturing, and identified areas in which green chemistry could be applied, one of them being pharmaceutical production.[40]

If a technology reduced or eliminated hazardous chemicals used in cleaning up environmental pollutants, that technology would qualify as green chemical technology. Many green chemistry principles may allow processes to be more efficient, such as by reducing the number of steps in the reaction, or using less energy or materials ("Green Chemistry Principles for Driving Sustainability"). Green-chemistry also promotes the use of recycled solvents.[5] However, recent guidelines for the N-nitrosamine contamination have highlighted how these practices often lead to cross-contamination, and are currently discouraged.[13] In conclusion, while many of these green initiatives would increase efficiency, minimize costs, and minimize streams of waste, they frequently conflict with

existing guidance for the quality, for example, with the guidance on the ICH Q11, the guideline on the contamination from N-nitrosamines.

For example, researchers working on etelcalcetide (which is being evaluated as a treatment for a complication of chronic kidney disease) won their companys Green Chemistry Award for developing a process that reduced their use of organic solvents by more than 400,000 litres and shortened the time to produce the project. In 2017, for instance, the US environmental protection agency (EPA) awarded amgen its green chemistry challenge award for developing, in collaboration with beachem, a green process to produce, one of Amgens nephrology medicines, with a 71% decrease in solvent use, five-fold increased capacity and a 40% estimated decrease in operating time.[25] The dedicated Chemistry Division is committed to introducing a broad array of advances, ranging from eliminating potentially harmful waste products, to using green solvents and reagents (substances or compounds that cause a chemical reaction).[27]

Green Chemistry And Sustainable Development

Sustainable development is about creating an environment in which people can live and work in a way that does not destroy the planet or its resources.[40] One of the most important ways to achieve this is through the use of green chemistry.[41]

Green chemistry is a set of principles and methods used in the chemical industry that are designed to create products that are environmentally friendly.[42] The principles of green chemistry include using chemicals that are less harmful to the environment, using waste materials instead of creating new chemicals, and using natural processes when possible.[39]

By using green chemistry techniques, manufacturers can create products that are safer for humans and the environment, and they can reduce their dependence on chemical pesticides and other hazardous materials. In addition, green chemistry can help to reduce the cost of manufacturing products, and it can improve efficiency by reducing waste production.[43]

sustainable development is a way of living that meets the needs of the present without compromising the ability of future generations to meet their own needs.[38] The concept of sustainable development has been around for a while, but it has recently come to the forefront as the world begins to realize that we are running out of resources and that we need to do something about it.[23]

One way that we can try to live more sustainably is by using green chemistry. Green chemistry is a set of principles and practices that help us produce products with fewer negative environmental effects. For example, it may involve using sustainable materials or developing products in ways that reduce or reuse waste products.[41]

There are many benefits to using green chemistry, including reducing pollution, conserving resources, and ensuring that products are safe and effective. In addition, green chemistry can help us develop products that are more environmentally friendly than traditional ones. So, while sustainable development is an important goal, green chemistry can help us get closer to our goals faster.[42]

Progress In Green Chemistry

One of the most significant advances in green chemistry has been the development of new methods for synthesizing small molecules. These methods use less energy and are more efficient than traditional methods, which can result in significant reductions in waste and pollution.[40]

Another key advance has been the development of new catalysts and synthetic routes to small molecules. These catalysts can convert pollutants into harmless substances or they can be used to create new molecules that are useful for green chemistry processes.[43]

Finally, green chemistry is continuing to develop methods for detecting and mitigating environmental risks. These methods are essential for ensuring that products and processes are safe and compliant with environmental regulations.[38]

All in all, green chemistry is making tremendous progress and there is no sign of it slowing down any time soon!

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