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OVERVIEW OF GREEN CHEMISTRY AND SUSTAINABLE FUTURE

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ABSTRACT

Green chemistry has risen as a significant lesson that reclassifies the way chemical forms & items are outlined, pointing to maintainability, proficiency, and negligible natural effect. Not at all like conventional hones that regularly include poisonous reagents and dangerous byproducts. With high vitality utilization, green chemistry emphasizes anticipation, more secure choices, & asset productivity. The mental roots of green chemistry lie in the natural mindfulness developments of the 1960s, emphatically impacted by Rachel Carson's Silent Spring, which uncovered the antagonistic impacts of aimless chemical applications. In the 1990s, Paul Anastas and John C. Warner formally set up the teaching by showing the 12 Standards of Green Chemistry. These standards act as an around-the-world rule, empowering researchers, analysts, and businesses to grasp more feasible and eco-friendly homes. In conclusion, green chemistry is more than an elective approach; it is a progressive worldview that equalizes logical progression with environmental duty.

KEYWORDS: Green Chemistry, Sustainability, 12 Principles, Environmental Responsibility.

INTRODUCTION

Green chemistry represents a forward-looking approach to chemical science that emphasizes the design of products and processes that are safe, efficient, and environmentally responsible. Instead of depending on dangerous or toxic chemicals, it emphasizes renewable resources and environmentally safe methods that minimize or remove threats to people and nature. The central goal is to align chemistry with the principles of sustainability, ensuring that innovations contribute positively to both present and future generations. Unlike traditional environmental chemistry, which mainly studies and measures the causes of pollution and ecological damage, green chemistry provides practical solutions by creating sustainable alternatives and safer technologies. Its goal is to support sustainable development, ensuring that scientific progress leads to healthier lives and a balanced natural cycle for future generations. Modern chemical manufacturing faces two major challenges: improving economic efficiency and ensuring environmental sustainability.

Green chemistry

Green chemistry is the approach of designing chemical processes and products that are safe for individuals and the environment. It aims to avoid pollution by reducing or eliminating harmful substances and designing materials that safely break down into non-toxic components after use.

History

The roots of environmental awareness can be traced back to 1962, when Rachel Carson's book Silent Spring revealed the negative consequences of chemical use on ecosystems. During the 1970s, the creation of the U.S. Environmental Protection Agency (EPA) marked a major advancement in environmental protection efforts.[1,2]

The following year, the International Union of Pure and Applied Chemistry (IUPAC) established a working group dedicated to green chemistry.

Paul Anastas, along with John C. Warner, developed the well-known Twelve Principles of Green Chemistry. These principles outline strategies to reduce or eliminate hazardous substances in the design, production, and use of chemical products.[3-11]

Concerns about the environment first appeared on the global stage at the 1949 United Nations Scientific Conference on the Conservation and Utilization of Resources (UNSCCUR) in the United States. In the early 1960s, Rachel Carson's book Silent Spring sparked a worldwide environmental movement by drawing attention to the dangers of chemical pollution.[12,13] Research in chemical and ecological engineering has introduced sustainable approaches, but achieving real environmental benefits also requires supportive industrial practices and effective policies.[14-16]

Principal of green chemistry

The twelve principles of green chemistry, introduced by Paul Anastas, emphasize minimizing or eliminating hazardous substances throughout the design, synthesis, manufacturing, and use of chemical products.

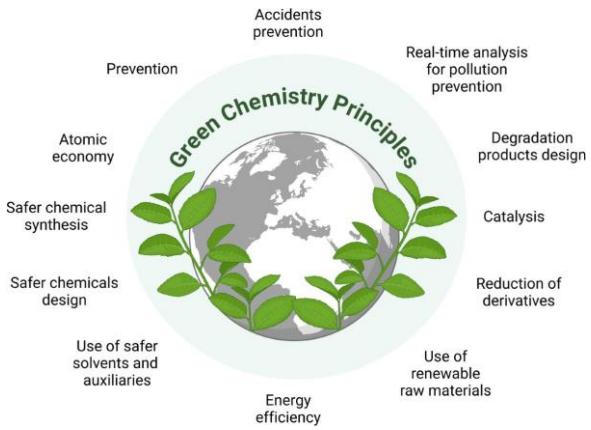


Figure-1.1.

Prevention of waste and By-Products: Preventing waste at the source is more effective than managing or cleaning it up after it has been created. It is better to avoid or control the creation of hazardous, toxic, explosive, persistent, or wasteful chemicals rather than relying on cleaning or treatment afterward.[17]

Example: 1. Prevent the manufacturing of nuclear and non-nuclear weapons, explosives, and dangerous biochemicals in a variety of industrialized and developing nations since they contribute to a variety of environmental pollutions.[18] 2.Check for and/or stop the overuse of natural resources like coal and petroleum, as these fuels produce toxic gases during combustion that lead to acid rain and global warming.[19]

A successful example is the greener production of sertraline, where switching to ethanol as the only solvent cut solvent use from 250 liters to just 25 liters per kilogram of product.[20]

Atomic economy

Manufactured approaches ought to guarantee that the most extreme extent of all materials utilized in the response is consolidated into the craved item. The concept of iota economy is closely related to the thought of squandering anticipation, as it emphasizes the effective utilization of crude materials so that they contribute specifically to the last compound or maybe than getting to be by-products.[21]

% of atomic = M.mass of products x 100 Efficiency M. mass of reactant

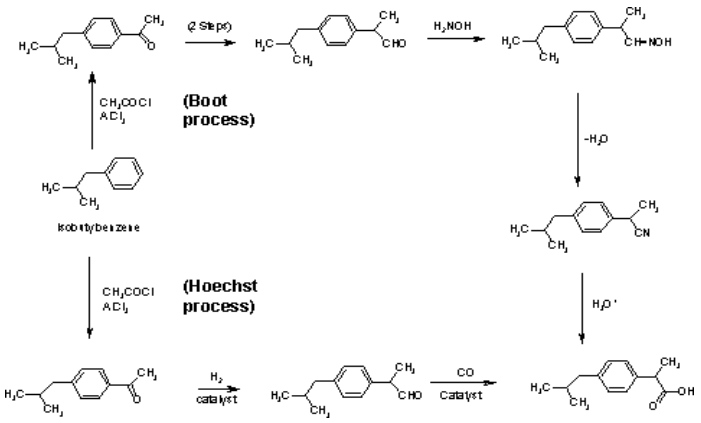


Figure-1.2.

Comparison of the Boots Process and the "Green" Hoechst Ibuprofen Synthesis Process.[22]

Less Hazardous Chemical Synthesis

Risk = f(Hazard, Exposure) Case study: thalidomide

Original purpose: Used to relieve nausea during pregnancy.

Consequence: Led to major developmental abnormalities in infants exposed during pregnancy.

Response: The drug was withdrawn and its use banned in many countries.

Takeaway: Thorough pre-market testing and long-term safety evaluation are essential before releasing chemicals for widespread use progress toward safer chemicals.

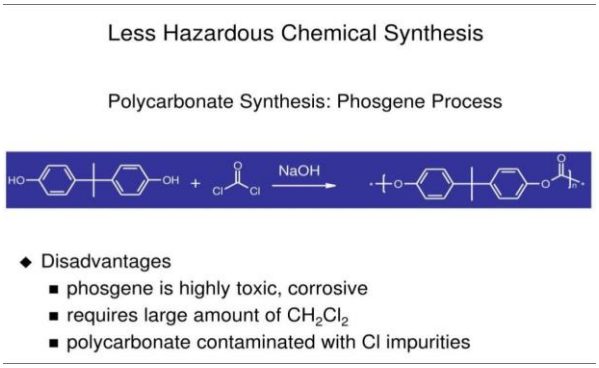


Figure-1.3.

Example: Polycarbonate manufacture Conventional (phosgene-based) route drawbacks Phosgene ($COCl_2$) is highly toxic and corrosive.[23]

Designing Safer Chemicals

When creating modern chemical items, they ought to be planned to perform their aiming part viably whereas posturing negligible hurt to human wellbeing or the environment. An advance illustration is the advancement of polyphenylene sulfone (PPSU), a high-performance polymer that is flame-resistant, strong, and naturally more secure. It is presently utilized in airship ad and tram trains, where both security and non-flammability are basic.[24] Goal: Accomplish effectiveness and usefulness without presenting unsafe properties.

Approach: Incorporate toxicology information early in the plan stage.[25]

Safer Solvents and Auxiliaries

In green chemistry, the use of solvents and auxiliary agents (such as separation aids) should be avoided whenever possible. If necessary, they must be non-toxic, safe, and recyclable. Conventional organic solvents are often hazardous, volatile, and energy-intensive to recycle, contributing to environmental pollution. Safer alternatives focus on stability, low volatility, worker safety, and sustainability while maintaining efficiency. Selection of a solvent should consider safety, recyclability, process performance, and sustainability.[26]

Design for Energy Efficiency

Chemical forms frequently utilize a part of vitality, which impacts both the environment and takes a toll. To diminish this, responses ought to in a perfect world run at room temperature and typical weight.

Vitality Efficiency: Maintenance & Recuperation: Great separator and appropriate gear upkeep avoid vitality misfortune. Squander warm or by-products can be reused for warming water, workplaces, or indeed shared with adjacent communities.

Practical Case: The CO_2 discharged is too bolstered to plants like tomatoes, boosting development whereas reusing squander.[27] Elective vitality sources such as light, microwaves, or ultrasound can moreover progress productivity.[28]

Use of Renewable Feedstocks

The utilization of renewable feedstocks is a central feature of green chemistry, emphasizing the substitution of nonrenewable fossil resources with materials decided from characteristic or prudent sources. Renewable feedstocks join

biomass such as plant oils, starches, lignocellulosic materials, sugars, and agrarian or food-industry misuse.

Illustration: Catalytic Alter of Fructose and Glucose A prominent case incorporates the utilization of fructose (from sources like sugar cane or corn syrup) or glucose (from cellulose or starch) as starting materials.[29]

Reduce Derivatives

Reducing derivatization bolsters feasible hones by disentangling the response pathway and constraining the utilization of unsafe materials. It adjusts with other green chemistry standards such as squander anticipation, vitality productivity, and more secure synthesis.

Examples 1. Coordinate Amidation of Carboxylic Acids: Traditional blend includes shaping corrosive chlorides utilizing reagents like thionyl chloride ($SOCl_2$). The green strategy permits coordinate amidation of acids with amines, creating as if they were water as a by-product (Shi et al., 2014).

Reaction: $R–COOH + R'–NH_2 \rightarrow R–CONHR' + H_2O2$.[30]

Catalysis

Definition: Catalysis is a chemical handle in which the rate of a response is upgraded by a substance called a catalyst, which remains chemically unaltered at the conclusion of the response.

Types

A] Homogeneous Catalysis B] Heterogeneous Catalysis C] Biocatalysis

Importance in Green Chemistry:

1) Reduced vitality utilization by bringing down actuation energy.
2) Minimizes squander arrangement compared to stoichiometric reagents.
3) Promotes the utilization of biodegradable and renewable catalysts.[31]

Example:

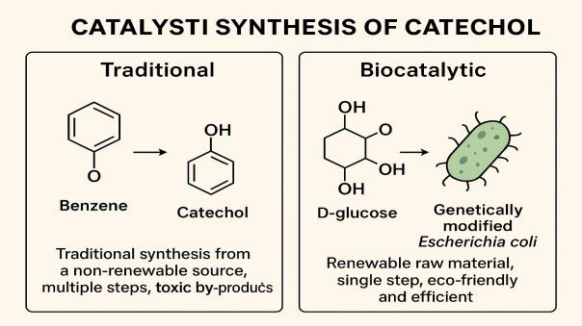


Figure-1.4.

Design for degradation

Design for Degradation" is one of the twelve benchmarks of green chemistry proposed by Paul T. Anastas and John C. Warner. It emphasizes the necessity to arrange chemical things and materials that break down into secure, non-toxic substances after utilization, instead of persevering in the environment and causing defilement or bioaccumulation.

Key Aspects:

1. Nuclear Plan.
2. Keeping up a vital separate from Persevering Compounds.
3. End-of-Life Thought.
4. Utilization of Renewable and Biodegradable Feedstocks.

Examples: Biodegradable Polymers: Polylactic corrosive (PLA) and polyhydroxyalkanoates (PHA) are cases of biodegradable plastics planned to really break down by microbial activity.[32]

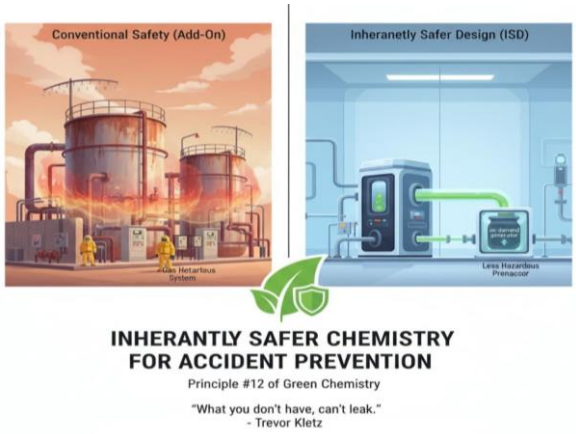
Real-Time Analysis for Pollution Prevention

Real-time examination to halt contamination is one of the 12 Green Chemistry Standards. It centers on observing and controlling chemical forms as they happen.

Importance

1. Anticipating contamination is way better than settling it later—because it's more viable and cheaper.
2. Real-time checking makes a difference alter things like temperature, weight, and pH for the best results.
3. Nonstop checking finds perilous gasses or spills rapidly, keeping laborers and the environment safe.
4. Techniques Utilized in Real-time Analysis Spectroscopic Strategies, Chromatographic Strategies, Mass Spectrometry, Sensor-Based Frameworks.[33]

Inherently Safer Chemistry for Accident Prevention



Intrinsically more secure chemistry is a critical portion of green chemistry that makes a difference in anticipating chemical mischances. Instead of attempting to settle issues after they happen, it centers on maintaining a strategic distance from or lessening hurtful dangers from the start. This strategy includes making chemicals more secure, making strides in chemical forms, and utilizing more reliable hardware to diminish the chances of mishaps amid generation, capacity, and use.

Key Concepts

1. Utilize more secure materials.
2. Utilize littler sums.
3. Make forms less difficult.
4. Control response conditions.[34]

Application

1. Pharmaceuticals: Green chemistry in pharmaceuticals supports safer and more sustainable drug production.
2. Agrochemicals: Green chemistry supports sustainable agriculture by reducing the use of harmful chemicals.
3. Materials Science: Applied to materials development with the aim of reducing pollution and energy consumption.
4. Energy Production: Carbon capture and utilization (CCU) converts CO2 into useful chemicals.[35]

Merits and Demerits of Green Chemistry Merits

1. Environmental Protection.
2. Resource Efficiency.
3. Energy Conservation.
4. Performance Limitations.

Demerits

1. High Initial Cost
2. Limited availability of green alternatives.
3. Technical Challenges.
4. Performance Limitations.[36]

The Future of Green Chemistry

The future of green chemistry is profoundly connected with the vision of a feasible & pollution-free planet. As the worldwide request for chemicals, materials, and vitality continues to rise, businesses are moving toward ecologically capable strategies of generation. Integration of Biotechnology and Manufactured Biology In the long time to come, biotechnology will end up being a foundation of green chemical fabrication. Renewable Feedstocks and Carbon Utilization One of the most promising bearings for green chemistry is the substitution of non-renewable petroleum-based feedstocks with renewable options such as biomass, rural squander, green growth, and indeed carbon dioxide (CO_2).Green Nanotechnology and Keen Materials Nanotechnology is anticipated to make green chemistry more proficient and exact. Counterfeit Insights and Digitalization The chemical industry is experiencing advanced change, and fake insights (AI) will be a crucial driver of green chemistry in the future. Circular Economy and Squander Valorization The rule of a circular economy adjusts impeccably with green chemistry. Instead of taking after a "take-make-dispose" show, future chemical generation will take after "reduce-reuse-recycle. Challenges and Openings Ahead Despite its guarantee, green chemistry still faces challenges such as high execution costs, the need for mindfulness, and innovative impediments.

CONCLUSION

Green chemistry speaks to a vital step toward a maintainable & dependable future in chemical science. By prioritizing squandering anticipation, utilizing renewable assets, and using more secure solvents and energy efficient forms it gives successful ways to decrease natural hurt while keeping up financial and mechanical development. As worldwide challenges such as climate alteration and asset exhaustion proceed to develop, the selection of green chemistry is no longer optional, it is fundamental. Proceeding with investigation, instruction, and arrangement back will guarantee that chemistry remains an arrangement to natural issues or maybe even a supporter to them.

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