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Eco-Friendly Chemical Processes: The Role of Green Chemistry in Modern Industries

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Abstract

Green chemistry focuses on the development of chemical products and processes that minimize or eliminate hazardous substances, promoting sustainability throughout the chemical life cycle. Unlike environmental chemistry, which studies pollutants, green chemistry proactively designs safer alternatives to prevent environmental damage. This field spans multiple disciplines, including organic, inorganic, analytical, and physical chemistry, with applications across pharmaceuticals, manufacturing, and materials science. The principles of green chemistry, first formulated by Paul Anastas and John Warner, outline twelve key guidelines that drive innovation toward sustainability. These principles emphasize waste prevention, atom economy, less hazardous chemical syntheses, designing safer chemicals, safer solvents and auxiliaries, energy efficiency, renewable feedstocks, reducing derivatives, catalysis, design for degradation, real-time analysis for pollution prevention, and inherently safer chemistry for accident prevention. By adhering to these principles, scientists and industries can develop processes that reduce toxicity, improve efficiency, and lower environmental impacts. One of the most significant areas of green chemistry is the use of renewable feedstocks. Traditional chemical manufacturing often relies on petrochemical resources, which are non-renewable and contribute to greenhouse gas emissions. Green chemistry seeks to replace these with bio-based alternatives, such as plant-derived chemicals, algae-based fuels, and biodegradable polymers. This shift not only reduces reliance on fossil fuels but also mitigates environmental pollution and enhances resource sustainability. Catalysis plays a crucial role in green chemistry by improving reaction efficiency and selectivity while reducing the need for hazardous reagents. Heterogeneous and homogeneous catalysts, including metal-organic frameworks, enzyme-based systems, and nanoparticle catalysts, enable more efficient chemical transformations with fewer byproducts. For example, green catalytic processes are now employed in pharmaceutical manufacturing to streamline drug synthesis, minimizing waste and harmful emissions.

Keywords: Green chemistry, sustainability, biodegradable polymers, catalysis, renewable energy

INTRODUCTION

Green chemistry represents an innovative and forward-looking approach to chemical research and industrial practice, emphasizing the design of products and processes that reduce or eliminate the use and generation of hazardous substances. Unlike environmental chemistry–which primarily focuses on the detection, fate, and effects of pollutants–green chemistry proactively seeks to prevent environmental harm by developing safer chemical alternatives from the outset. As a multidisciplinary field, it integrates concepts from organic, inorganic, analytical, and physical chemistry and finds wide application in pharmaceuticals, manufacturing, agriculture, energy production, and materials science.

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Key Principles of Green Chemistry

Green chemistry is guided by twelve fundamental principles, developed by Paul Anastas and John Warner:

1. *Prevention:* Avoid waste generation rather than treating it afterward.
2. *Atom Economy:* Maximize the incorporation of materials into the final product.
3. *Less Hazardous Syntheses:* Design chemical processes that minimize toxicity.
4. *Safer Chemicals:* Develop effective yet low-risk chemical products.
5. *Safer Solvents and Auxiliaries:* Reduce or eliminate solvent usage.
6. *Energy Efficiency:* Conduct reactions under mild conditions to conserve energy.
7. *Renewable Feedstocks:* Use renewable raw materials where feasible.
8. *Reduce Derivatives:* Avoid unnecessary modifications that produce waste.
9. Catalysis: Prefer catalysts over stoichiometric reagents.
10. *Design for Degradation:* Ensure products break down into non-toxic components.
11. *Real-Time Analysis:* Monitor processes to prevent hazardous byproducts.
12. *Inherently Safer Chemistry:* Select substances and processes that lower accident risks.

Implementing Green Chemistry in Industry

Businesses integrate green chemistry by focusing on research and development, process optimization, and resource management:

- *Sustainable R&D:* Investing in eco-friendly materials and low-impact chemical processes.
- *Process Efficiency:* Utilizing catalysts, energy-efficient reactions, and waste reduction strategies.
- *Renewable Resources:* Replacing fossil fuels with plant-based alternatives, as demonstrated by Genomatica's engineered microbial production.

Success Stories in Green Chemistry

Many companies have successfully implemented green chemistry principles:

- *Pfizer:* Optimized drug synthesis, reducing waste and eliminating toxic solvents.
- *IKEA:* Replaced formaldehyde-based resins with bio-based adhesives, cutting emissions.
- *Dow Chemical:* Developed bio-based plasticizers to replace toxic phthalates.
- *Novozymes:* Created enzyme-based detergents for energy-efficient cleaning.
- *Neste:* Transitioned from fossil fuels to renewable diesel production.

Pfizer's Achievements in Green Chemistry

Pfizer has significantly reduced its environmental footprint through its green chemistry initiatives:

- *Waste Reduction:* Cut methylene chloride by 60%, n-hexane by 90%, and chloroform by 98%, eliminating 1.8 million pounds of hazardous waste.
- *Efficiency Gains:* Increased product yield, decreased raw material consumption by 60%, and improved process productivity by 56%.
- *Sustainable Drug Manufacturing:* Developed greener production processes for Sertraline (Zoloft), Sildenafil (Viagra), Pregabalin (Lyrica), and Atorvastatin (Lipitor).
- *Energy Savings:* The Pregabalin synthesis alone reduced CO_2 emissions by an amount equivalent to three million tons.

Operational Impact of Pfizer's Green Chemistry Program

Pfizer's sustainability efforts have enhanced overall operational efficiency:

- *Waste Reduction:* 19% less waste across multiple production lines.
- *Improved Yields:* More efficient chemical reactions, doubling the yield in key drug syntheses.
- *Life Cycle Optimization:* Adoption of continuous manufacturing, biocatalysis, and solvent reduction techniques.
- *Notable Innovations:* Sertraline process eliminated titanium tetrachloride, significantly cutting industrial waste.

The Role of Training in Green Chemistry Adoption

Education and training have been integral to Pfizer's green chemistry success:

- *Employee Development:* Workshops, internal seminars, and training programs on sustainability.
- University Engagement: The "Workshop on Wheels" (WoW) initiative educates students on green chemistry principles.
- *Educational Tools:* Internal metrics for evaluating process sustainability and environmental impact.

Pfizer's Green Chemistry Tools and Technologies

To facilitate sustainable practices, Pfizer has implemented several key tools:

- *Life Cycle Analysis (LCA) & Process Mass Intensity (PMI):* Metrics to assess environmental impact.
- *Solvent Selection Guide:* A framework for choosing safer alternatives.
- *Tracking Systems:* Internal tools for measuring progress in green chemistry initiatives.

Key Green Chemistry Projects at Pfizer

Pfizer has pioneered multiple sustainable projects:

- *Sertraline (Zoloft):* Improved efficiency, reducing solvent waste and raw material usage.
- *Sildenafil (Viagra):* Optimized chemical synthesis, cutting solvent consumption by 95%.
- *Pregabalin (Lyrica):* Used biocatalysis to lower emissions and production costs.
- *Atorvastatin (Lipitor):* Integrated eco-friendly biocatalysis in manufacturing.

Green Chemistry Innovations in Pfizer's Zoloft Production for Sertraline (Zoloft)

Pfizer implemented several major green chemistry advances:

- *Process Simplification:* Condensed three manufacturing steps into one.
- *Catalytic Optimization:* Used selective palladium catalysts to minimize impurities.
- *Solvent Replacement:* Eliminated four hazardous solvents, substituting them with ethanol.
- *Waste Reduction:* Decreased hazardous byproducts, cutting 970,000 pounds of solid waste annually.

AIM

The goal of green chemistry is to create medication candidates using eco-friendly and sustainable methods. Among the main goals are:

- *Primary Goals:* Reduce the number of resources and waste produced throughout the drug-discovery and development process; utilize fewer toxic and hazardous chemicals; and increase the general effectiveness and safety of pharmaceutical synthesis.
- *Specific Strategies:* Create synthetic routes with the highest possible atom economy. Use beginning ingredients that are biodegradable and renewable; use more environmentally friendly solvents and reaction conditions; Create synthetic processes with little effect on the environment.
- *Advanced Techniques:* Employ high-throughput screening and computational techniques. Use continuous flow synthesis. Utilize generative artificial intelligence to enhance chemical processes. Examine cutting-edge catalytic techniques, such as biocatalysis [1–10].

In order to reduce the ecological imprint of the pharmaceutical business and support sustainable development goals, the ultimate goal is to develop medications that are both therapeutically effective and environmentally responsible.

OBJECTIVES

Green chemistry concepts are used in the synthesis of a therapeutic candidate with the goals of reducing environmental impact, increasing efficiency, and guaranteeing sustainability. The procedures and tactics listed here will help you match green chemistry with medication production.

- *Employing Safer Auxiliaries and Solvents Goal:* Use safer, more environmentally friendly solvents in place of dangerous ones. With instance, substitute water, ethanol, or supercritical CO_2 with solvents based on petroleum or chlorination.

Implementation - Stage 1

Create reactions without the need of solvents or in water. Make use of biodegradable solvents or ionic solutions.

- *Energy-Efficient Design Goal:* Reduce the amount of energy used during synthesis. For instance, carry out reactions at room temperature and pressure.

Execution

Utilize synthesis aided by ultrasonic or microwave technology to save energy. Optimize energy efficiency by putting flow chemistry into practice.

- *Utilizing Sustainable Feedstock Goal:* Obtain raw materials from sustainable sources. With instance, substitute bio-based precursors, such as fatty acids, glucose, or cellulose with petrochemical derivatives.

Implementation - Stage 2

Create artificial pathways by beginning with natural items. Create intermediates by biocatalyzing microorganisms.

1. *The Atom Economy and Catalysis Goal:* Use effective catalysts to improve atom economy and selectivity. Use metal complexes, organocatalysts, or enzymes, for instance. Implementation: Reduce byproducts by employing biocatalysts to carry out asymmetric synthesis. Reduce waste by using reusable catalysts.
2. *Cutting Down on Waste and Byproducts Goal:* Reduce side products by optimizing reactions. For instance, carry out cascade or one-pot reactions.

Implementation - Stage 3

To cut down on steps and intermediates, create convergent syntheses. Use in-line purification methods, such as filtering or crystallization.

1. *Reduction of Hazard and Toxicity Goal:* Steer clear of dangerous intermediates and reagents. Example: Use safer substitutes for hazardous chemicals like cyanides.
2. *Application:* Replace chromium-based oxidants with bio-derived oxidants, such as hydrogen peroxide. Use non-toxic, detachable protective groups in place of dangerous ones.
3. *Process control and real-time monitoring Goal:* Use monitoring to stop the production of dangerous byproducts. For instance, employ chromatography or in-situ spectroscopy. Implementation: To keep an eye on important metrics, incorporate Process Analytical Technology (PAT). Dynamically optimize the reaction conditions.
4. *Creating Biodegradable Final Goods Goal:* Make sure the medication and its byproducts break down in the environment in a safe manner. For instance, stay away from halogenated substances that are resistant to breakdown.

Implementation - Stage 4

Examine and alter chemical structures to make them more resilient to the environment. Create prodrugs using linkers that decompose naturally.

- *Example of Application:* Acetaminophen (paracetamol)Hazardous chemicals are used in the traditional production of paracetamol. Using water as the solvent or a biocatalyst to directly couple phenol with acetic anhydride is one green method. Cutting waste by allowing the product to crystallize in water. Following these guidelines makes the synthesis process more economical, ecologically friendly, and sustainable [11].

PLAN OF WORK

Here's a structured Plan of Work for synthesizing a drug candidate using green chemistry principles:

Literature Survey

Goal: Find a synthetic approach for the medication candidate that is environmentally friendly. Examine books, patents, and scientific journals to learn about green practices.

Pay attention: utilization of renewable raw materials. Water-based or solvent-free processes. Biocatalysts, organocatalysts, or low-toxicity metal catalysts are examples of catalysis. Atom economy and waste reduction. Energy-saving procedures (such as ultrasonic, microwave, etc.). Examine earlier synthesis routes for the drug candidate or related substances.

Deliverables: A thorough report outlining possible green chemistry pathways and providing support for the selected approach.

Procurement of Chemicals

Enumerate the reagents and compounds needed for the synthesis. Set priorities:

- Green solvents, such as ionic liquids, water, and ethanol.
- Less hazardous or biodegradable chemicals.
- Recyclable or reusable catalysts.
- Purchase chemicals from approved vendors who follow the guidelines of green chemistry.
- Deliverables include a list of every substance's MSDS (Material Safety Data Sheets) [12].

Perform the Synthesis

- *Goal:* Follow the chosen synthetic path. Observe the following green chemical guidelines:
  - Steer clear of dangerous chemicals, such as heavy metals.
  - Reduce the number of reaction stages to improve atom economy.
  - Make use of energy-efficient techniques (such as synthesis assisted by microwaves).
  - Keep track of every experimental parameter, including yields, temperature, pressure, and time.

Deliverables include a thorough experimental protocol accompanied by observations.

Characterization of Drug Intermediate

Utilize sophisticated analytical methods to verify the purity and structure:

- *Methods of Spectroscopy:*
  - NMR (1H and 13C).
  - FTIR.
  - Ultraviolet light.
- *Chromatographic Methods:* For purity analysis, use GC or HPLC.
- *Spectrometry by mass:* Verify the fragmentation pattern and molecular weight. Make that the intermediates fulfil the requirements for additional synthesis.
- *Deliverables:* Interpretation and analytical data (chromatograms, spectra, etc.).

RESULTS AND DISCUSSION

- *Examine and report the Findings:* Examine yields, purity, and reaction efficiency in comparison to traditional techniques. Talk about the ways that green chemistry concepts were used to lessen their negative effects on the environment. Describe the difficulties encountered during synthesis and how they were overcome. Assess the possible industrial uses and scalability. Deliverables: A thorough report that summarizes the findings, compares them to traditional methods, and offers suggestions for further research [13].

Synthesis of Drug Candidate Using Green Chemistry

Green chemistry represents a revolutionary approach to pharmaceutical synthesis that minimizes environmental impact while improving drug development processes. The fundamental goal is to design chemical products and processes that reduce or eliminate hazardous substances.

Key Principles of Green Chemistry in Drug Synthesis Core Strategies

- Utilize green solvents, preferably water.
- Minimize waste generation.
- Reduce energy consumption.
- Implement more efficient reaction techniques.
- Design molecules with reduced toxicity Innovative Approaches: Computational methods for compound screening.
- High-throughput screening techniques.
- Flow chemistry to reduce waste.
- Catalytic reactions instead of stoichiometric processes.

Benefits of Green Chemistry

Green chemistry strategies offer significant advantages in drug discovery by:

- Minimizing resource consumption
- Reducing hazardous chemical usage
- Improving overall process efficiency
- Enhancing environmental sustainability
- Developing safer and more effective drug candidates.

The approach fundamentally transforms drug synthesis from a potentially harmful process to an environmentally conscious and scientifically advanced methodology, ensuring both pharmaceutical innovation and ecological responsibility.

How does green chemistry improve the efficiency of drug synthesis? Green chemistry significantly improves drug synthesis efficiency through multiple strategic approaches:

Key Efficiency Improvements Process Optimization

- Reduces synthetic steps, enabling faster manufacturing.
- Increases plant production capacity.
- Saves energy and water consumption.

Minimizes Waste Generation Innovative Techniques

- Implements continuous flow synthesis.
- Utilizes computational methods and high-throughput screening.
- Applies catalytic reactions to minimize reagent usage.

Employs green solvents, like water instead of harmful organic solvents Performance Metrics Practical implementations, demonstrate remarkable improvements:

- 19% reduction in waste generation.
- 56% enhanced productivity compared to traditional methods.
- Higher chemical reaction yields.

Decreased use of feedstock materials Advanced Technologies Emerging Technologies

- Generative AI for optimizing chemical reactions.
- Machine learning to predict the best reaction conditions.
- AI-assisted design of pharmaceuticals with improved biodegradability.
- Electrocatalysis for efficient organic synthesis. Green chemistry transforms drug synthesis by simultaneously improving environmental sustainability and scientific efficiency, creating a more responsible pharmaceutical development ecosystem [14].

How does atom economy contribute to the sustainability of drug synthesis? Atom economy is a crucial principle in green chemistry that significantly enhances the sustainability of drug synthesis by minimizing waste and optimizing resource utilization.

Key Sustainability Contributions Waste
Reduction
- Maximizes incorporation of reactant atoms into the final product.
- Minimizes unwanted byproducts.
- Reduces hazardous material disposal costs.

Economic Benefits
- Lowers production costs.
- Decreases material requirements.

Improves Overall Process Efficiency Practical Implementation Optimization Strategies
- Carefully selecting starting materials.
- Utilizing catalytic reaction systems.
- Designing reactions that incorporate most reactant atoms.

Preferring addition and rearrangement reactions over elimination processes Quantitative Measurement Atom economy can be calculated using the formula: $$ \text{Atom Economy} = \frac{\text{Molecular weight of desired product}}{\text{Molecular weight of all reactants}} \times 100\% $$ Real-World Example: Merck developed a greener synthesis for molnupiravir (COVID-19 antiviral), reducing solvent waste and cutting the process from five to three steps, demonstrating atom economy's practical sustainability impact. By prioritizing atom economy, pharmaceutical companies can create more environmentally friendly and efficient drug synthesis processes.

How can atom economy be maximized in drug synthesis? Atom economy in drug synthesis can be maximized through several strategic approaches:

Key Optimization Strategies Reaction Design
- Carefully select starting materials.
- Utilize catalytic reaction systems.
- Prefer addition and rearrangement reactions over elimination processes.
- Design reactions that incorporate most reactant atoms.

Practical Techniques Optimization Methods
- Use of efficient catalysts to reduce waste.
- Implement enantioselective total synthesis techniques.
- Choose reactions with minimal byproduct formation.
- Explore alternative synthetic routes with higher atom efficiency.

Quantitative Improvement
The atom economy formula $$ \text{Atom Economy} = \frac{\text{Molecular weight of desired product}}{\text{Molecular weight of all reactants}} \times 100\% $$ helps chemists evaluate and improve reaction efficiency.

Key Benefits
- Reduced waste production.
- Lower production costs.
- Minimized environmental impact.
- Enhanced sustainable drug manufacturing.

By prioritizing atom economy, pharmaceutical researchers can develop more efficient and environmentally friendly drug synthesis processes that maximize material utilization and minimize unnecessary waste [15].

What are some practical examples of maximizing atom economy in drug synthesis? Green chemistry offers several practical approaches to maximize atom economy in drug synthesis:

Reaction Strategies Preferred Reaction Types
- Addition reactions (100% atom efficiency).
- Rearrangement reactions.
- Catalytic transformations.

Isomerization Processes Practical Examples Specific Synthesis Techniques
- Ruthenium-catalyzed isomerization of propargyl alcohols into α, β-unsaturated carbonyl compounds.
- Aqueous medium addition reactions for creating γ, δ-unsaturated ketones and aldehydes
- Catalytic hydrogenolysis of esters.
- Biocatalytic synthesis of 6-Amino-penicillanic Acid (6-APA) Optimization Methods.

Key Approaches
- Use heterogeneous catalysis.
- Implement homogeneous catalysis.
- Apply biocatalysts.
- Select reactions with minimal by product formation.
- Performance Improvement.
- Traditional nitrobenzene reduction:
  - 35% atom economy
- Greener catalytic route:
  - 72% atom economy by prioritizing these strategies, pharmaceutical researchers can significantly enhance the efficiency and sustainability of drug synthesis processes.

What are some innovative catalysts used to enhance atom economy in drug synthesis? Innovative Catalysts for Enhanced Atom Economy Emerging Catalyst Technologies:
- RhRu bimetallic oxide clusters (RhRuOx/C).
- Enzymatic catalysts.
- Single-atom catalysts.
- Metal-Organic Frameworks (MOFs).
- Nanocatalysts.

Key Catalyst Characteristics Advanced Catalyst Types
- Earth-abundant metals (nickel, copper, iron).
- Bio-based catalysts with high selectivity.
- Nanoparticle catalysts with high surface area.
- Photocatalysts like modified titanium dioxide.

Performance Advantages Innovative
- Catalysts offer significant improvements:
  - Reduced waste generation.
  - Higher reaction efficiency.
  - Lower energy consumption.
  - Minimized use of toxic metals.
  - Enhanced reaction selectivity.
- *Breakthrough Example:* Researchers developed one-nanometer-sized RhRu bimetallic oxide clusters that utilize molecular oxygen as a non-toxic oxidant, demonstrating exceptional catalytic activity while producing water as the only byproduct. These advanced catalysts represent a

transformative approach to making pharmaceutical synthesis more sustainable and environmentally friendly [16].

Procedure 1

Five milliliters of glacial acetic acid and 2.5 grams of salicylic acid were added to the process Flask. To the mixture, Figures 1 and 2, one or two drops of concentrated sulfuric acid were added. After that, it was microwaved on a gentle setting for 30 seconds. After cooling, 50 milliliters of water were added to the mixture. Filtered and recrystallized aspirin was separated from diluted alcohol (Table 1). After being weighed, the recrystallized aspirin was placed in a clearly marked, self-sealing bag. The melting point and yield were established [17].

Table 1. Materials used.

Raw Materials	Quantity	Role
Salicylic acid	2.5 ml	Starting material
Glacial acetic acid	5 ml	Green solvent
Water	50 ml	Solvent
Alcohol	20 ml	Solvent
Conc. sulphuric acid	2–3 drops	Catalyst

Figure 1. Synthesis of aspirin using green chemistry.

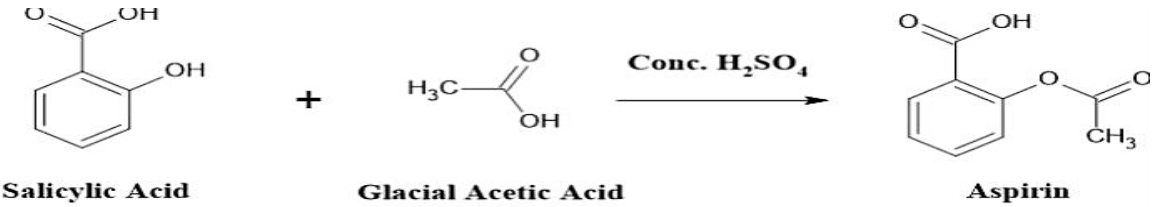


Figure 2. Process of making aspirin.

Result of Procedure 1

Glacial acetic acid was used to create aspirin, which has a melting point of 136°C. It has been reported that aspirin has antiviral, antibacterial, antifungal, and antitumor properties. The strategy promotes ecologically friendly behaviors and waste reduction (Figure 3), which are in line with the ideas of green chemistry [18].

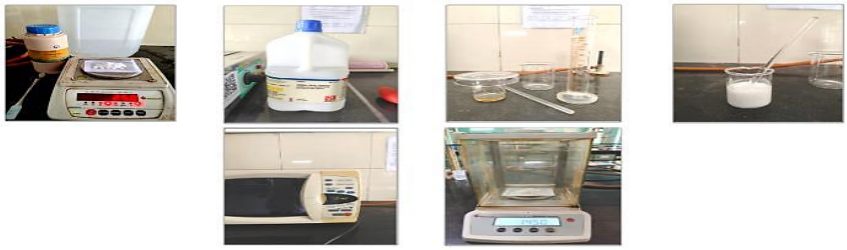


Figure 3. A quicker, safer, and greener approach is provided by using glacial acetic acid and microwave irradiation.

Procedure 2

In an iodine flask, 1 g of glycine was dissolved in 8 ml of a 10% LIOH solution. Benzoyl chloride (1.5 ml) was added. A cotton plug was used to seal the flask's mouth. The flask was agitated until the benzoyl chloride odor was eliminated. To make the liquid acidic (Figures 4–6), one or two drops of concentrated HCL were added. After filtering, water was used to wash the product. Hot water was used to recrystallize the dried product, and a little amount of Charcoal. After being gathered in a Buchner funnel, the product was oven-dried. They recorded the melting point and yield (Table 2) [19].

Table 2. Material used.

Raw Materials	Quantity	Role
Glycine	1 g	Starting material
Benzoyl chloride	1.5 ml	Starting material
10% Lithium hydroxide	8 ml	Green solvent
Conc. HCL	1–2 drops	Reagent
Water	10 ml	Solvent

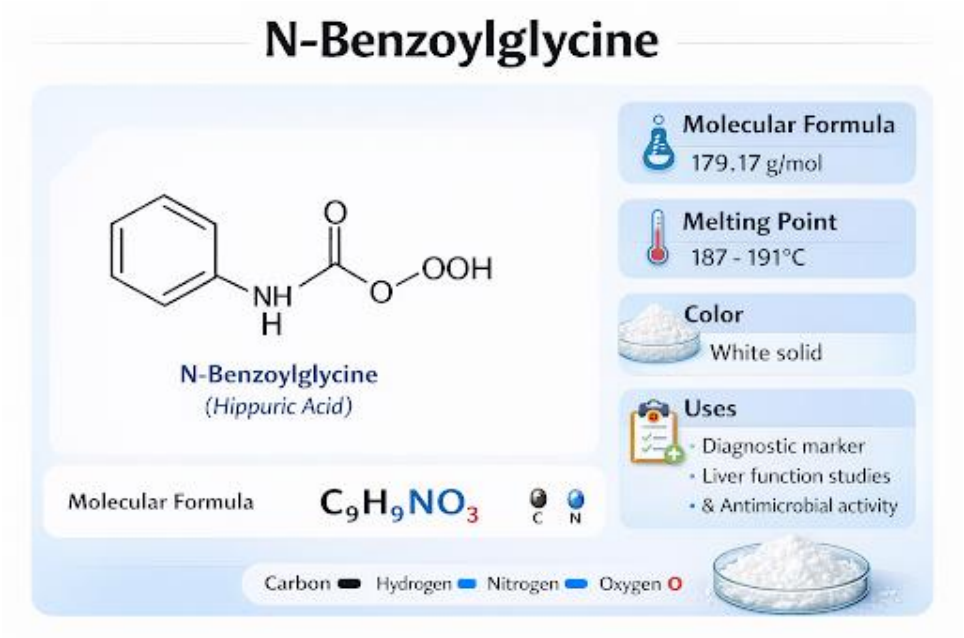


Figure 4. Eco-friendly chemical processes: The role of green chemistry in modern industries.

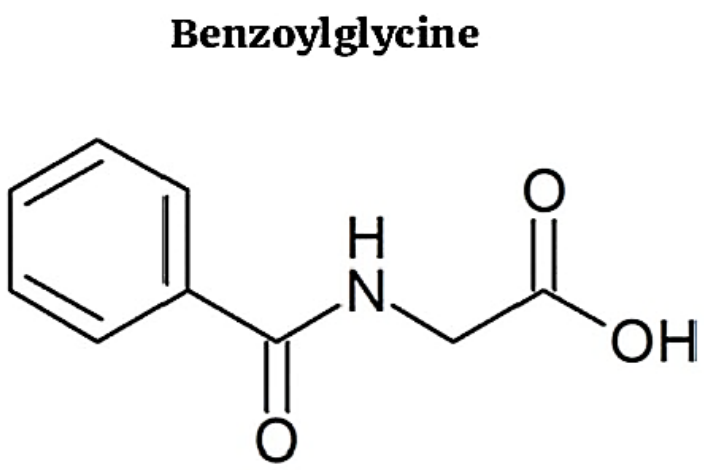


Figure 5. Structure of benzoglycine.

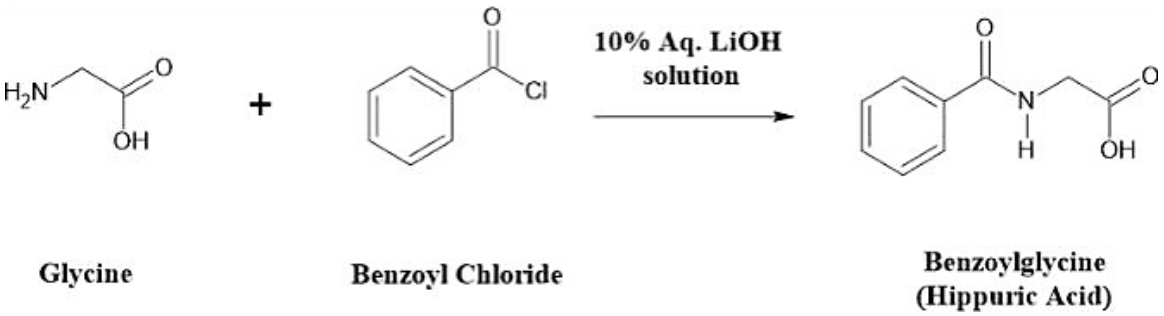


Figure 6. Process of making benzoylglycine.

Result of Procedure 2

Lithium hydroxide was used to create benzoylglycine, which has a melting point of 190°C. • It has been observed that derivatives of benzoylglycine possess antiviral, antibacterial, antifungal, and antitumor properties. The method reduces human danger and uses safer solvents, which is in line with green chemistry principles. A safer, quicker, and greener approach is provided by using lithium hydroxide rather than sodium hydroxide (Figure 7).

Figure 7. The yield from the LIOH approach was higher than the yield from the conventional method.

Procedure 3

Twenty milliliters of a 5% LiOH solution were used to dissolve 3.5 grams of α-naphthol in 250 milliliters of iodine. Flask After adding 0.5 g of charcoal, the liquid was heated and filtered. Benzoyl chloride (2.9 ml) was added (Figures 8 and 9). For ten minutes, or until there was no more odor, the flask was tightly sealed and shaken. After passing through a Buchner funnel, the resulting solid was rinsed with cold water. Thirty milliliters of ethanol were used to recrystallize the crude product. After filtering, the crystals were dried. After gathering crystals, the melting point was ascertained (Table 3).

Table 3. Material used.

Raw Materials	Quantity	Role
B-Naphthol benzoate	3.5 gm	Starting material
Benzoyl chloride	2.5 ml	Starting material
Lithium hydroxide	20 ml	Green solvent
Ethanol	20 ml	Recrystallization solvent
Water	10 ml	Solvent

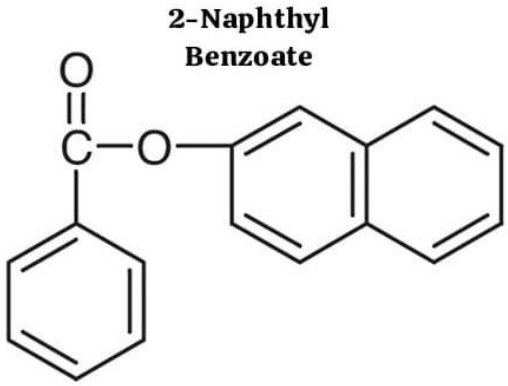
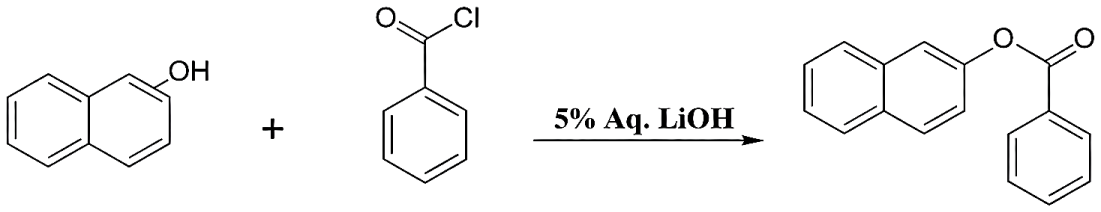


Figure 8. Synthesis of 2-naphthyl benzoate using lithium hydroxide.



β-naphthol benzoate **Benzoyl Chloride** **2-Naphthyl benzoate**

Figure 9. The process of making 2-naphthyl benzoate.

Result of Procedure 3

2-Lithium hydroxide was used to manufacture naphthyl benzoate, which has a melting point of 110°C. 2-derivatives of naphthyl benzoate are said to have antibacterial qualities and be used as a hardening agent for paraffin. Proteomics, the large-scale study of proteins, especially their structures and activities, uses them as a biochemical as well (Figure 10). The method uses the catalytic amount of base needed for synthesis and cleaner solvents, which are both in line with green chemistry principles [20–24].

Figure 10. A safer and greener approach is provided by using lithium hydroxide rather than sodium hydroxide.

Procedure 4.

An iodine flask was filled with 2.5 ml of aniline and 25 ml of a 10% Aq. LiOH solution. It was mixed with 3.5 milliliters of benzoyl chloride. After being stoppered, the flask was forcefully shaken for ten

minutes because heat developed during the reaction (Figures 11 and 12). The flask was maintained in an ice bath, the reaction mixture's alkalinity was guaranteed when the reaction was a Buchner funnel was used to filter the mixture after it had been diluted with 10 milliliters of water. Water was used to wash and drain the product. Hot alcohol was used to collect and recrystallize the solid product. After gathering crystals, the melting point was ascertained (Table 4).

Table 4. Material used.

Raw Materials	Quantity	Role
Aniline	2.5 ml	Starting material
Benzoyl chloride	3.5 ml	Starting material
Lithium hydroxide	25 ml	Green solvent
Methylated spirit	20 ml	Recrystallization solvent
Water	10 ml	Solvent

Figure 11. Synthesis of benzanilide using lithium hydroxide.

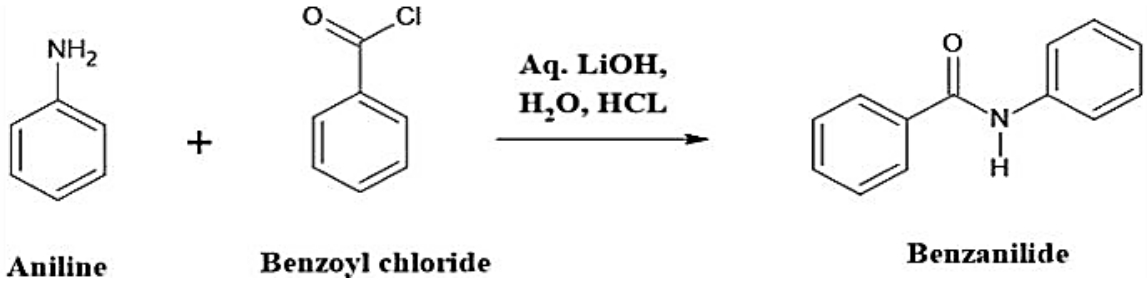


Figure 12. Process of making benzanilide.

Result of Procedure 4.

Lithium hydroxide was used to create benzoanilide, which has a melting point of 163 °C. It has been reported that novel benzanilide compounds can treat hyperlipidemia, cholesterol ester storage disease, and atherosclerosis. The method uses the catalytic amount of base needed for synthesis and cleaner solvents, which are both in line with green chemistry principles (Figure 13).

Figure 13. A safer and greener approach is provided by using lithium hydroxide rather than sodium hydroxide.

Procedure 5

Step 1: Synthesis of Benzoylglycine (Hippuric acid)

In a 250 ml conical Boek, 5 g of glycine was dissolved in 50 ml of a 10% LiOH solution. It was vigorously stirred while 9 milliliters of benzoyl chloride were added in increments. The addition of benzoyl chloride caused the flask's mouth to stop (Figures 14 and 15). Until the benzoyl chloride odor vanished, the reaction mixture was shaken. A small amount of crushed ice was added to the reaction mixture to chill it down. A 500 mL beaker was filled with the reaction mixture. Conc. HCI was added gradually while stirring to get the mixture acidic. Water was used to filter it, cleanse it, and then recrystallize it (Table 5).

Table 5. Material used.

Raw Materials	Quantity	Role
B-Naphthol benzoate	3.5 gm	Starting material
Benzoyl glycine	1.95 g	Starting material
Lithium hydroxide	5.5 g	Green reagent
Acetic acid	2.5 ml	Solvent
Ethanol	15 ml	Recrystallization solvent

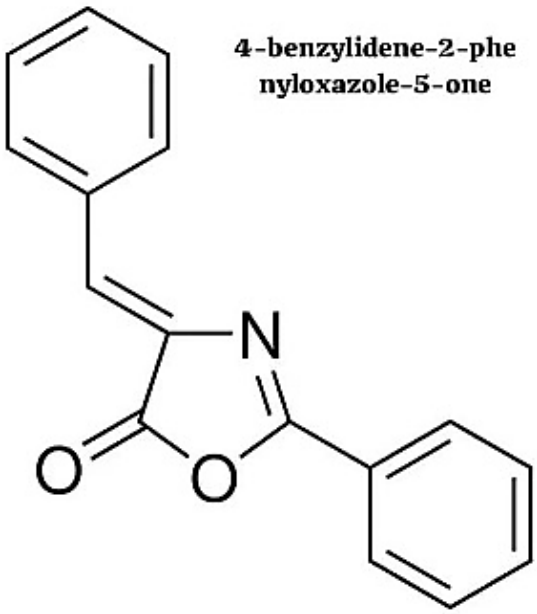


Figure 14. Synthesis of 4-benzylidene-2-phenyloxazole-5-one using lithium hydroxide.

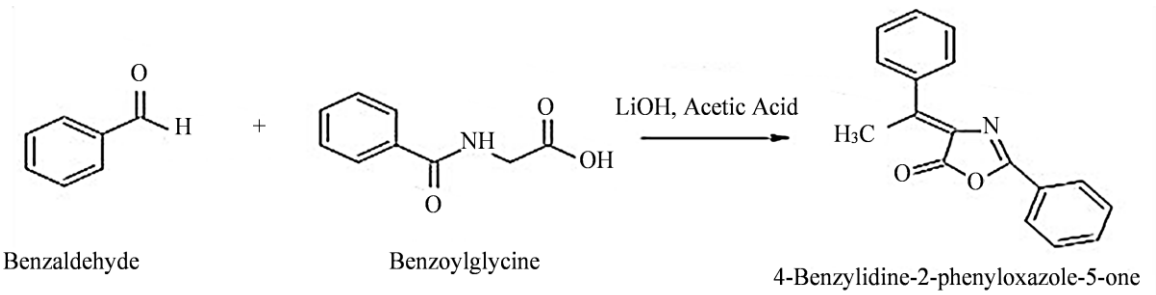


Figure 15. Process of making 4 benzylidene 2 phenyloxzole 5 one.

Step 2: Synthesis of 4-Benzylidine-2-Phenyloxazole-5-one

100 milliliters of RBF were mixed with 3.25 milliliters of benzaldehyde and 5.5 grams of benzoylglycine. It was mixed with 2.5 ml of acetic acid and 1.9 g of LiOH. To liquefy the mixture, it

was cooked on a hot plate while being stirred occasionally. A reflux condenser was used to further heat the mixture for two hours. After carefully adding 15 milliliters of ethanol, the reaction mixture was left overnight. The product underwent two rounds of ice-cold water washing and filtering. Following drying, the product's yield and melting point were recorded.

Result of Procedure 5

Lithium hydroxide was used to create 4-benzylidene-2-phenyloxazole-5-one, which has a melting point of 165–167°C. Derivatives of 4-benzylidene-2-phenyloxazole-5-one are said to possess anti-cancer qualities. This strategy is in line with green chemistry principles, which call for the use of cleaner solvents and the minimum amount of base needed for synthesis (Figure 16).

Figure 16. A safer and greener approach is provided by using lithium hydroxide rather than sodium hydroxide.

CONCLUSIONS

Green chemistry is revolutionizing the chemical industry by prioritizing sustainability and efficiency at every stage of production. From pharmaceuticals to materials science, its principles drive innovation that reduces environmental harm while enhancing performance. As advancements in renewable energy, computational modeling, and nanotechnology continue to emerge, green chemistry will play a crucial role in building a more sustainable future. By integrating eco-friendly practices, industries can not only meet regulatory standards but also contribute to a cleaner, healthier planet. The ongoing commitment to green chemistry ensures that scientific progress aligns with environmental responsibility, paving the way for long-term global sustainability.

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