

A REVIEW ON: GREEN CHEMISTRY INFLUENCES IN ORGANIC SYNTHESIS

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Abstract

Green chemistry has emerged as a transformative approach in modern chemical research, aiming to minimize environmental impact while enhancing the efficiency of chemical processes. In organic synthesis, the adoption of green chemistry principles has significantly influenced the development of safer, sustainable, and economically viable methodologies. This review highlights the integration of eco-friendly strategies such as the use of renewable feedstocks, benign solvents, and non-toxic catalysts in synthetic pathways. Special emphasis is placed on innovative techniques including microwave-assisted synthesis, solvent-free reactions, and biocatalysis, which reduce energy consumption and waste generation. Furthermore, the role of green reagents and alternative reaction media, such as ionic liquids and water, is discussed in improving reaction selectivity and yield.

Keywords: Non-toxic, Green chemistry, Recycling, Manufacturing, Energy consumption.

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INTRODUCTION

Green chemistry is an approach to the design, manufacture and use of chemical products to intentionally reduce or eliminate chemical hazards. It focuses on the reduction, recycling/ elimination of the use of toxic and hazardous chemicals in production processes by finding creative, alternative routes for making the desired products that minimize the impact on the environment. Sustainable economic growth requires safe, sustainable resources for industrial production [1]. This article describes an introductory account of the basic tenets on which the concept of the Green Chemistry is based Green chemistry which is the latest and one of the most researched topics now days has been in demand since 1990's. Majority of research in green chemistry aims to reduce the energy consumption required for the production of desired product whether it may be any drug, dyes and other chemical compounds. It aims to reduce or even eliminates the production of any harmful bi products and maximizing the desired product without compromising with the environment.

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the production of desired product whether it may be any drug, dyes and other chemical compounds. It aims to reduce or even eliminates the production of any harmful by-products' and maximizing the desired product without compromising with the environment. The goal of green chemistry (GC) is the design (or redesign) of products and manufacturing processes to reduce their impact on human health and the environment. Fundamental to the GC concept is the idea of sustainability-reducing environmental impacts and conserving natural resources for future Green generations.

HISTORY

Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. The goal is to make chemistry safer, cleaner, and more sustainable by preventing pollution at the source instead of cleaning it up later [2]. It focuses on waste prevention, safer chemicals, energy efficiency, renewable materials, and designing products that degrade safely. Basically: do the chemistry, but without the toxic mess.

- 1960s-1980s: Growing concern over pollution and toxic chemicals from industrial processes sparked early environmental awareness.

- 1990: U.S. Pollution Prevention Act shifted focus from cleanup to preventing pollution at the source
- 1991: Paul Anastas coined the term “green chemistry” while at the U.S. EPA.
- 1995: U.S. Presidential Green Chemistry Challenge Awards launched to promote innovation.
- 1998: Anastas and John Warner published *Green Chemistry: Theory and Practice*, defining the 12 principles. Still in use today, that relies on the minimization or non-use of toxic solvents in chemical processes and analyzes, as well as the non-generation of wastes from these processes.
- 2000s-Present: Adopted globally by academia and industry, driving safer solvents, catalysts, bio-based materials, and sustainable manufacturing.

THE PRINCIPLES OF GREEN CHEMISTRY

I. Prevention

It is better to prevent the formation of waste materials and/or by-products than to process or clean them. Organic syntheses in the absence of solvents. This principle has stimulated so-called “grinding chemistry”, in which the reagents are mixed without solvent, sometimes by simply grinding them in a Mortar [3]. Chen et al. described a good example of a three-component Friedel–Crafts reaction on indoles, leading to the functionalized indole. In a similar way, Venkateswarlu et al. developed a synthesis of 4-quinazolinone **8** using a rapid method without solvent. “Grinding chemistry” has recently been reviewed. An expanding area of chemistry without solvents involves the use of microwaves to irradiate mixtures of neat reagents. One ex-ample of this approach is the synthesis of 4,4'-diaminotriphenyl-methanes using microwave irradiation

2. Energy Efficiency

The energy requirements involved in the chemical processes should be accounted for, in view of their influence on the environment and the economic balance, and the energy requirements should be diminished. If possible, the chemical processes should be carried out at room temperature and atmospheric pressure. The reaction energy could be photochemical, microwave or ultrasonic irradiation. A boom is currently occurring in the use of these green energy sources and this is also associated with a marked decrease in the reaction time, to higher yields and, very often, to higher product purity. Mariappan et al. developed a synthetic green and broad substrate scope protocol for S–N bond formation via intramolecular cyclization to afford substituted 5-amino-based 1,2,4-thiadiazole derivatives in the presence of hypervalent iodine (III) as an inexpensive catalyst. The merit of this synthetic approach is that it is metal-free and has a short reaction time and good-to-excellent yield of products at ambient temperature.

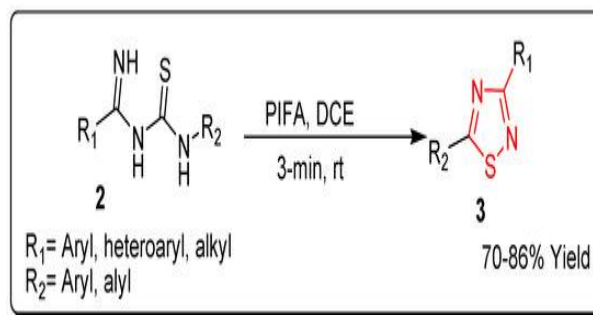
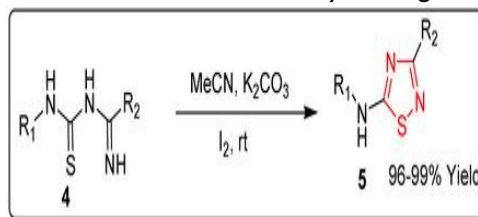


Fig 01: Synthesis of 1,2,4-thiadiazoles **3** via intramolecular cyclization.

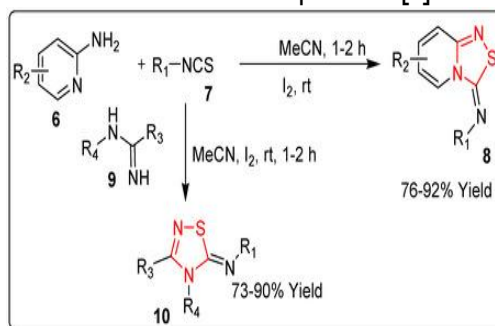
Wang et al. reported an efficient synthetic approach for the construction of 5-amino- and 3,5-diamino-substituted 1,2,4-thiadiazoles via oxidative N–S Bond formation in scalable fashion by utilizing molecular [4].



$\text{R}_1 = \text{R}_2 = \text{-ph, -methyl, -propyl, -dimethyl, -imidoyl, -guanyl, -nitro, -Cl, -Br, -CF}_3, \text{-NH}_2$

Fig 02: Synthesis of 1,2,4-thiadiazoles **5** via molecular **I₂** as sole oxidant.

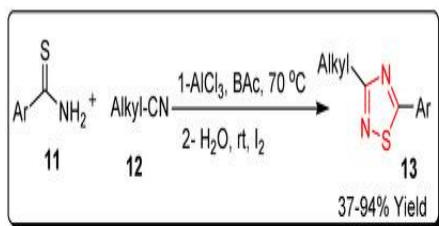
Mangarao et al. reported an expeditious approach to achieve the novel N-fused and 3,4-disubstituted 5-imino-1,2,4-thiadiazolehybrid structures by treating substituted isothiocyanate **7** with 2-aminopyridine/amidine, which underwent intramolecular cyclization to form N–S bonds in the presence of an inexpensive **I₂** catalyst and acetonitrile as a solvent at ambient temperature [5].



$\text{R}_1 = \text{R}_2 = \text{R}_3 = \text{-methoxy, -methyl, -dimethyl, -phenyl, cyclopropyl, -propyl, cyclohexyl, -Cl, -Br}$

Fig 03: Regio-specific synthesis of 3,4-disubstituted 5-imino-1,2,4-thiadiazole hybrids

Chai et al. afforded 3,5-disubstituted 1,2,4-thiadiazole in an efficient and simple one-pot green protocol through the sequential intermolecular combination of alkyl substituted nitriles with aryl substituted thioamide, through intramolecular oxidative coupling of N–H and S–H bonds in an aqueous medium and iodine as the sole oxidant catalyst.



Alkyl-CN= CH₃CN, CH₃CH₂CH₂CN, CH₃CH₂CH₂CH₂CN, cyclopropyl-CN, butene-CN, Chloropropyl-CN, phenylacetone nitrile, o-tolylacetone nitrile, p-tolylacetone nitrile, 3-fluorophenyl acetone nitrile, 4-chlorophenyl acetone nitrile, naphthylacetone nitrile, 4-hydroxyphenylacetone nitrile, 4-methoxyphenylacetone nitrile, 4-nitrophenylacetone nitrile
Aryl= -phenyl, 3-methylphenyl, 4-methylphenyl, 2-chlorophenyl, 4-chlorophenyl, 4-bromophenyl, 4-nitrophenyl, thiophene

Fig 04: One-pot green synthesis of 3,5-disubstituted 1,2,4-thiadiazoles

A number of azaheterocycles i.e. pyrrole, imidazole, indole and carbazole react remarkably quickly with alkyl halides to give exclusively N-alkyl derivatives under microwave conditions. A series of imines was synthesized by an ultrasound assisted reaction of aldehydes and primary amines using silica as the promoter.

3. Atom Economy: Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product. High atom economy ensures minimal generation of byproducts, leading to more efficient and sustainable chemical reactions. Atom economy is crucial in green chemistry as it helps reduce waste and increase efficiency. For instance, reactions like the Diels-Alder reaction have 100% atom economy, meaning all atoms from reactants are incorporated into the product [6,7]. Atom economy is a fundamental principle in green chemistry that aims to maximize the efficiency of chemical reactions. It's about designing reactions to incorporate as many atoms as possible from the reactants into the final product, minimizing waste and reducing the environmental impact.

Maximize atom utilization: Design reactions where most atoms from reactants become part of the product.

Minimize waste: Reduce by-products and waste generation.

Efficient use of resources: Optimize reactions to save energy and raw materials.

4. Use of Renewable Feedstock's

A raw material or feedstock should be renewable rather than depletable whenever technically and economically feasible. Utilizing biomass or agricultural waste over fossil fuels reduces dependency on non-renewable resources and promotes circular economy models. Renewable feedstocks in green chemistry mean using raw materials that are replenished naturally, like plants, biomass, or waste materials, instead of finite resources like petroleum. This helps reduce dependence on non-renewable resources and promotes sustainability [8].

5. Reuse Derivatives: Unnecessary derivatization-such as the use of blocking or protecting groups-should be minimized or avoided. These extra steps often require additional reagents and generate waste, lowering the overall efficiency of the reaction. "Reduce derivatives" in green chemistry means minimizing unnecessary steps like protection/deprotection or temporary modifications in syntheses. This reduces waste and makes processes more efficient. For instance, in pharmaceutical synthesis, avoiding unnecessary protection groups can reduce steps, waste, and energy use.

6. Less Hazardous Chemical Syntheses: Wherever possible, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment. Safer reagents and milder reaction conditions make processes more environmentally friendly and reduce risk to workers [9].

7. Safer Solvents And Auxiliaries: The use of auxiliary substances (e.g., solvents, separation agents) should be made unnecessary wherever possible and, when used, should be innocuous. Since solvents often account for a large portion of chemical waste, selecting safer or recyclable solvents greatly improves sustainability.

8. Inherently Safer Chemistry 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 explosions, fires, and toxic releases. This principle enhances safety by addressing hazards during the design phase.

CATALYSIS

Waste reduction: A 1 mol% Pd catalyst replaces 1 equiv of toxic Sn or Pb reagents in cross-couplings. Suzuki, Heck, Sonogashira reactions run catalytic vs old stoichiometric methods. **Energy savings:** Catalysts lower activation energy, so reactions run at room temp instead of reflux. Ex: Ru-catalysed metathesis vs harsh thermal routes.

Selectivity: Enzymes and chiral catalysts give one enantiomer, avoiding 50% waste from racemic mixtures. Lipases for kinetic resolution, proline for aldol.

Safer reagents: Catalytic hydrogenation with H₂ + Pd/C replaces dangerous NaBH₄ or LiAlH₄ for many reductions. New pathways: C-H activation catalysts let you functionalize unreactive bonds directly, skipping multiple protection/deprotection steps [10].

Recyclable systems: Heterogeneous catalysts, ionic-liquid supported catalysts, and magnetic nanoparticles can be filtered and reused.

REAL TIME ANALYSIS

Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances. "In-line monitoring: Use PAT tools like

FTIR, Raman, or UV-Vis probes inside the reactor to track reactant disappearance and product formation. Prevent runaway reactions: Real-time temperature and pressure sensors + feedback loops stop exothermic reactions before they become unsafe.

Reduce waste: Catch incomplete reactions or byproduct formation early, so you adjust conditions instead of discarding a whole batch. Optimize yield: Flow chemistry with HPLC or MS at the outlet lets you tune flow rates, catalyst loading, and temp on the fly. Safer workups: Detect toxic intermediates like isocyanates or azides instantly, so they're quenched before isolation.

Process intensification: Continuous monitoring enables safe use of hazardous reagents like phosgene or diazomethane in flow, because you never build up large volumes [11].

DESIGN FOR DIGRADATION

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."

Introduce cleavable bonds: Build esters, amides, acetals, or carbamates into structures so they hydrolyse in water, soil, or under enzymes. Ex: PLA plastic uses ester linkages that break down to lactic acid.

Avoid persistent motifs: Skip per fluorinated chains, polychlorinated aromatics, and highly branched alkyls that resist microbial attack. PFAS are the classic "non-degradable" problem. Use natural building blocks: Amino acids, sugars, fatty acids, and lignin fragments give microbes a pathway to metabolize the product. Triggerable degradation: Add linkages that break under UV, pH, or redox conditions. Ex: drug prodrugs that release active compound, then degrade [12].

Balance stability vs degradability: Product must be stable during use and storage, but break down after. Done via protecting groups, ring strain, or electronic tuning. Computational design: Use QSAR models to predict biodegradation pathways before synthesis, saving time and waste.

INHERENTLY SAFER CHEMISTRY

"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." Replace hazardous reagents: Use H_2O_2 instead of Cr (VI) for oxidation, NaOCl instead of Cl_2 for chlorination, dimethyl carbonate instead of phosgene. Avoid dangerous reaction conditions: Catalytic hydrogenation at 1 atm with flow reactors vs high-pressure bombs. Photo redox at room temp vs high-temp thermolysis.

Minimize inventory: Flow chemistry generates hazardous intermediates like diazomethane, azides, or nitration's in-situ and consumes them immediately. No stockpiling. Use safer solvents: Water, ethanol, ethyl acetate instead of ether, benzene, or CCl_4 which are flammable/toxic. Design for low energy release: Pick

reactions with small exotherms. Avoid nitro compounds, peroxides, or metal azides unless absolutely needed. Solid forms over gases/liquids: Use solid reagents like Tri phosgene instead of phosgene gas, or urea-hydrogen peroxide instead of 90% H_2O_2 [13,14].



Fig 05: Accidents prevention

CONCEPT AND IDEAS

Green chemistry is that the utilization of a group of principles which will help reduces the utilization and generation of hazardous substances during the manufacture and application of chemical products. Green chemistry aims to protect the environment not only by cleaning up, but also by inventing new chemical processes that do not pollute. It is a rapidly developing and a crucial area within the chemical sciences. The program of green chemistry helps and supports the inventions or new things of more eco-friendly chemical processes which decrease or maybe eliminate the generation of harmful or hazardous substances.

APPLICATION

Benefits of Solvent-free reactions: Mechanochemical grinding for aldol, Michael additions.

Water as solvent: Diels-Alder, Claisen rearrangements in aqueous media.

Supercritical CO_2 : Replacement for organic solvents in extractions and reactions.

Ionic liquids: Recyclable polar solvents for catalysis and separations [15].

Biocatalysis: Enzymes for chiral alcohols, amines, ester hydrolysis.

Whole-cell catalysis: Microbes to do redox or C-H functionalization

Microwave-assisted synthesis: Fast heterocycle and peptide bond formation

Ultrasound promotion: Cavitation to accelerate reactions, reduce reagents.

Photoredox catalysis: Visible light + Ru/Ir/organic dyes for C-C, C-N bonds.

Electrosynthesis: Electrons as traceless reagents for oxidation/reduction.

Catalytic hydrogenation: H_2 + Pd/C, Ni, or Fe replacing $NaBH_4$, $LiAlH_4$.

Organocatalysis: Proline, thiourea catalysts avoiding metals for asymmetric synthesis.

Flow chemistry: Continuous reactors for safer, efficient, scalable reactions.

One-pot multicomponent reactions: Ugi, Passerini reactions with high atom economy.

Click chemistry: CuAAC and thiol-ene reactions, 100% atom economy.

CO₂ as C1 feedstock: Synthesis of cyclic carbonates, carboxylic acids, methanol.

Biomass-derived feedstocks: Furfural, levulinic acid, glycerol → monomers.

Atom-economical additions: Hydroformylation, hydroamination with no byproducts.

Catalytic C-H activation: Direct functionalization without pre-activated substrates.

Benign oxidation: H₂O₂, O₂, or air with Fe/Mn catalysts replacing Cr(VI), MnO₂. All push toward less waste, safer reagents, and lower energy [16, 17].

GREEN CHEMISTRY

Environment: Many chemicals are released into the environment either on purpose (like insecticides) while being used, unintentionally (like emissions during manufacturing), or through disposal. Green chemicals are either recycled for additional use or breakdown into harmless compounds. When harmful substances are present in the environment, plants and animals are less harmed. Less chemistry to disturb ecosystems and use of landfills should be reduced, especially those for hazardous waste.

Human health: Elimination of persistent toxic chemicals that may enter the system of food chain; fewer toxic pesticides that are toxic only to specific pests and degrade rapidly after use. Clean water as less release of hazardous chemical wastes to water leading to cleaner drinking and recreational water [18].

Increased worker safety in the chemical sector; decreased use of dangerous substances; reduced need for personal protective equipment; and decreased risk of mishaps (such as fires or explosions). Safer consumer goods of all kinds will be produced; new, safer products will be sold; some products, like medications, will be produced with less waste; and some products, like insecticides and cleaning supplies, will take the place of less safe alternatives.

Economy: Permit the replacement of a waste product for a purchased feedstock. Greater chemical yields, which require less feedstock to produce the same amount of product. Waste reduction by doing away with expensive remediation, hazardous waste disposal, and end-of-pipe treatments. Fewer synthetic stages frequently enable quicker product manufacturing, higher plant capacity, and energy and water savings. Improved performance, using less product to fulfil the same function. Increased ability of chemical producers and their clients to compete. Reduced use of petroleum products, slowing their depletion and avoiding their hazards and price fluctuations [19].

Less waste: High atom economy and catalysis mean fewer by-products. Ex: new ibuprofen route cut waste by 99%.

Safer labs: Replaces toxic solvents/reagents like benzene, Cr(VI), phosgene with water, enzymes, H₂O₂. Lower exposure risk.

Lower cost: Fewer steps, less solvent, recyclable catalysts, and less waste disposal save money at scale.

Energy efficient: Catalysts, microwave, flow, and room-temp reactions cut heating/cooling needs

Better selectivity: Enzymes and chiral catalysts give single enantiomers, avoiding 50% waste from racemates

Scalability & safety: Real-time analysis + flow chemistry lets you run hazardous steps safely, avoiding runaway reactions.

Regulatory edge: Easier EPA/OSHA compliance and faster approval since processes avoid SVHCs and heavy metals.

Renewable feedstocks: Using biomass or CO₂ reduces dependence on petroleum and volatile oil prices.

Product lifecycle: Design for degradation prevents persistent pollutants like DDT or PFAS

Brand & market value: Greener processes appeal to consumers, investors, and meet ESG goals.

DISADVANTAGE:

Environmental pollution: Many organic synthesis processes use toxic chemicals and generate hazardous waste. This can lead to air, water, and soil pollution if not properly managed.

Use of harmful reagents: Some reactions require dangerous substances (e.g., strong acids, bases, or toxic solvents), which can pose risks to human health and safety.

High-cost Organic synthesis can be expensive due to:

1. Specialized equipment
2. Energy consumptions (heating, cooling, pressure condition)

Low efficiency and yield: Some reactions produce low yields or unwanted by-products, making the process inefficient and requiring extra purification steps.

Time-consuming processes: Multi-step syntheses can take a long time, especially when purification and isolation of products are involved.

Energy consumption: Many reactions need high temperatures, pressures, or long reaction times, leading to high energy usage.

Waste generation: Large amounts of chemical waste are often produced, which must be treated or disposed of safely.

Complexity of reactions: Designing and controlling organic reactions can be complicated, especially for large or complex molecules.

Safety risks: There is a risk of explosions, fires, or exposure to toxic substances during synthesis.

MEDICAL USES

Medical uses driven by green chemistry in organic synthesis: focus on making drugs cleaner, safer, and cheaper to produce. Pharma is where green chemistry has had the biggest real-world impact because of scale, regulation, and cost.

Medical applications

1. Biocatalysis for chiral drugs: Enzymes make single-enantiomer APIs with no heavy metals. Ex: Sitagliptin (Januvia) transaminase enzyme replaced high-pressure Rh catalyst. Cuts waste 19%, eliminates metal. Ex: Atorvastatin (Lipitor) 3 enzymes + 2-keto-reductase replaced cyanide and Pd steps.

2. Catalytic routes to cut waste: Metal catalysis replaces stoichiometric reagents. Ex: Ibuprofen new 3-step catalytic process vs old 6-step, 99% less waste. Same API, greener synthesis. Ex: Sildenafil (Viagra) switched to cyclization in ethanol/water, removed tin chloride and chlorinated solvents.

3. Safer reagents/solvents in API synthesis: Avoids genotoxic impurities. Ex: Sertraline (Zoloft) imine formation in ethanol, eliminated $TiCl_4$ and hexane. Ex: Pregabalin (Lyrica) enzyme resolves racemate, avoids large-volume raney nickel.

4. Flow chemistry for hazardous steps: Makes dangerous intermediates safe to use. Ex: Diazomethane, azides, nitration's for tetrazole drugs like losartan made in-situ in flow, no explosion risk.

5. Atom economy in peptide drugs: Ex: Solid-phase peptide synthesis with greener coupling reagents, water-based SPPS being developed for drugs like semaglutide.

6. Renewable feedstocks for drug building blocks: Ex: Paclitaxel side chain from fermentation instead of yew bark extraction. Ex: Shikimic acid for Tamiflu from engineered E. coli instead of star anise [20].

7. Real-time analysis for quality: PAT with IR/Raman in continuous API manufacturing. FDA's push for continuous manufacturing of drugs like Prezista relies on this.

8. Design for degradation: Prodrugs that metabolize to harmless fragments. Ex: Statin lactones, arsenic acid antimalarials designed to break down post action.

Pharma cares: E-factor for drug synthesis used to be 25-100 kg waste per kg API. Green chemistry drops that to <10 kg. Pfizer, Merck, GSK all have internal green chemistry programs because waste disposal and solvent cost are huge.

Efficacy of green chemistry in organic synthesis: Measured by how well it delivers the same or better molecules with less waste, lower hazard, and better economics. Pharma and fine chemicals track it using matrices.

MEDICAL SIDE EFFECT: Reducing toxic byproducts, lowering occupational hazards for chemists, and creating safer, more sustainable pharmaceuticals.

- **Reduced Toxicity and Exposure:** Green chemistry focuses on designing chemicals with

little or no toxicity to human health. By utilizing safer solvents (e.g., toluene instead of benzene) and reducing hazardous chemical synthesis, it minimizes worker exposure to carcinogens and toxic compounds.

- **Safer Pharmaceutical Production:** The pharmaceutical industry is shifting to green chemistry, which promotes the synthesis of bioactive molecules with lower environmental impact, improved efficiency, and less waste.
- **Lowered Environmental Contamination:** Traditional organic synthesis often releases persistent, bioaccumulative toxins (PBTs) that contaminate the food chain and cause health issues like cancer or endocrine disruption. Green alternatives help prevent this, resulting in cleaner air and water.
- **Improved Product Safety:** Green chemistry principles applied to the production of drugs, pesticides, and cleaning products lead to safer end-products, decreasing the overall hazard risk to consumers.

Specific "Side Effects" (Influences) on Organic Synthesis Techniques:

- **Improved Safety:** Replacement of hazardous reagents like phosgene with safer alternatives.
- **Higher Efficiency (Atom Economy):** The shift to using renewable feedstocks and designing high-energy-efficiency processes means fewer by-products, which reduces the need for managing harmful waste.
- **Process Innovation:** Increased adoption of catalysis, solvent-free reactions, and safer, renewable solvents (e.g., heptane over hexane) to reduce environmental footprint.

USES IN ORGANIC SYNTHESIS:

developing new drugs, synthesizing natural products, producing polymers, creating specialty dyes, and engineering materials for electronics.

Pharmaceuticals and Drug Discovery: Synthesis enables the creation of life-saving medicines, such as Ibuprofen, and provides techniques like combinatorial chemistry for rapid drug screening.

Natural Product Synthesis: Scientists reproduce complex natural molecules (e.g., in medicinal plants) in the laboratory, allowing for large-scale production without relying on scarce natural sources [21].

Agriculture and Agrochemicals: Synthesis produces pesticides, herbicides, and fertilizers that enhance food security and support sustainable agriculture.

Materials Science and Technology: It is used to develop advanced polymers, conductive materials, liquid crystals for displays, and materials for electronics, such as mobile phones and spacecraft.

Specialty Chemicals and Cosmetics: Synthesis produces specialized compounds like dyes, flavours, fragrances, and ingredients for cosmetics.

Diagnostics and Imaging: Organicsynthesis creates markers, probes, and radiopharmaceutical ligands used in diagnostic imaging to detect diseased tissues.

INFLUENCE OF GREEN CHEMISTRY ON ORGANIC SYNTHESIS

Green chemistry has fundamentally shifted organic synthesis from a mindset of “yield at any cost” to “efficiency with responsibility.” Its influence shows up in 3 major ways

Good Synthesis:

The old metrics were yield, purity, and cost. Green chemistry added atom economy, E-factor, energy use, toxicity, and degradability. A 95% yield route that uses tons of toxic solvent and heavy metals is no longer considered “good” chemistry. The best route now balances performance with environmental footprint.

DRIVING INNOVATION IN METHODS AND TOOLS

To meet the 12 Principles, organic chemists developed:

Catalysis Over Stoichiometry: Asymmetric organocatalysis, biocatalysis, and recyclable metal catalysts replaced wasteful reagents

Safer Solvents & Solvent-Free Reactions: Water, ethanol, scCO₂, ionic liquids, and mechanochemistry cut VOC use

Renewable Feedstocks: Shikimic acid from fermentation, furans from biomass, and CO₂ as a C1 source are replacing petrochemicals

Energy Efficiency: Microwave, flow chemistry, and photo redox enable faster reactions with less heating [22].

CONCLUSION

Green chemistry has revolutionized organic synthesis by prioritizing waste reduction, atom economy, and the use of benign solvents, fundamentally shifting the focus from simply achieving high yields to designing sustainable, safe, and efficient processes. It promotes the adoption of green catalysts, renewable feedstocks, and energy-efficient methods (e.g., microwave/flow chemistry) to mitigate environmental risks. The integration of green chemistry principles into organic synthesis represents a significant advancement toward sustainable and environmentally responsible chemical practices. By emphasizing waste prevention, energy efficiency, and the use of safer reagents, green chemistry has reshaped traditional synthetic approaches. The adoption of alternative solvents, renewable resources, and innovative catalytic systems has not only reduced the ecological footprint of chemical processes but also improved reaction efficiency and selectivity.

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No

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REFERENCE:

1. Singhal M, Singh A, Khan SP. Green chemistry potential for past, present and future perspectives. *Int Res J Pharm.* 2012;3(4).
2. Trost BM. Atom economy-A challenge for organic synthesis: Homogeneous catalysis leads the way. *Angew Chem Int Ed Engl.* 1995;34:259.
3. de Marco BA, Rechelo BS, Tótolí EG, Kogawa AC, Salgado HRN. Evolution of green chemistry and its multi-dimensional impacts: A review. *Saudi Pharm J.* 2019;27(1):1–8. doi:10.1016/j.jsps.2018.07.011.
4. Singh SK, Rao DN, Agrawal M, Pandey J, Narayan D. Air pollution tolerance index of plants. *J Environ Manage.* 1991;32(1):45–55. doi:10.1016/S0301-4797(05)80080-5.
5. Wahyuningsih TD, Kurniawan YS. Green synthesis of some novel dioxolane compounds from Indonesian essential oils as potential biogreases. *AIP Conf Proc.* 2017;1823. doi:10.1063/1.4978154.
6. Kurniawan YS, Ramanda Y, Thomas K, Hendra, Wahyuningsih TD. Synthesis of 1,4-dioxaspiro[4.4] and 1,4-dioxaspiro[4.5] novel compounds from oleic acid as potential biolubricant. *Indones J Chem.* 2017;17(2):301–308. doi:10.22146/ijc.24891.
7. Wahyuningsih TD, Kurniawan YS. Synthesis of dioxo-dioxane and dioxo-dioxepane ethyl oleate derivatives as biolubricant base stocks. *Indones J Chem.* 2020;20(3):504–509. doi:10.22146/ijc.42317.
8. Wahyuningsih TD, Kurniawan YS, Amalia S, Wardhani TAK, Muriningsih CES. Diethanolamide derivatives as a potential enhanced oil recovery agent from Indonesian castor oil and used frying oil: Isolation, synthesis, and evaluation as nonionic biosurfactants. *Rasayan J Chem.* 2019;12(2):741–748. doi:10.31788/RJC.2019.1225140.
9. Poliakoff M, Fitzpatrick JM, Farren TR, Anastas PT. Green chemistry: Science and politics of change. *Science.* 2002;297(5582):807–810. doi:10.1126/science.297.5582.807.
10. Mulvihill MJ, Beach ES, Zimmerman JB, Anastas PT. Green chemistry and green engineering: A framework for sustainable technology development. *Annu Rev Environ Resour.* 2011;36:271–293. doi:10.1146/annurev-environ-032009-095500.
11. Linthorst JA. An overview: Origins and development of green chemistry. *Found Chem.* 2010;12(1):55–68. doi:10.1007/s10698-009-9079-4.
12. Anastas P, Eghbali N. Green chemistry: Principles and practice. *Chem Soc Rev.* 2010;39:301–312. doi:10.1039/B918763B.

13. Giusti L. A review of waste management practices and their impact on human health. *Waste Manag.* 2009;29(8):2227–2239. doi:10.1016/j.wasman.2009.03.028.
 14. Kurniawan YS, Sathuluri RR, Ohto K. Droplet microfluidic device for rapid and efficient metal separation using host-guest chemistry. In: *Advances in Microfluidic Technologies for Energy and Environmental Applications*. London: IntechOpen; 2020. doi:10.5772/intechopen.89846.
 15. Yoshida JI, Kim H, Nagaki A. Green and sustainable chemical synthesis using flow microreactors. *ChemSusChem.* 2011;4(3):331–340. doi:10.1002/cssc.201000271.
 16. Yoshida JI, Kim H, Nagaki A. “Impossible” chemistries based on flow and micro. *J Flow Chem.* 2017;7(3):60–64. doi:10.1556/1846.2017.00017.
 17. Kim H, Nagaki A, Yoshida JI. A flow-microreactor approach to protecting-group-free synthesis using organolithium compounds. *Nat Commun.* 2011;2(1). doi:10.1038/ncomms1264.
 18. Mohamed TA, Osman A, Khattab A, Zaki M. *J Tribol.* 2015;137(1):1–5.
 19. Léonard A, Hantson P, Gerber GB. *Mutat Res Rev Genet Toxicol.* 1995;339(3):131–137.
 20. Aral H, Vecchio-Sadus A. *Ecotoxicol Environ Saf.* 2008;70:349–356.
 21. Kang DHP, Chen M, Ogunseitan OA. *Environ Sci Technol.* 2013;47(10):5495–5503.
 22. El-Fadel M, Khoury R. *Resour Conserv Recycl.* 2001;33(2):75–91.
 23. Talkit KM, Mahajan DT, Massand VH. *J Chem Bio Phys Sci.* 2012;3(1):490–497.
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