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A Literature Review on Recent Advances in Green Chemistry for Sustainable Synthesis Methods

Rajesh Kumar

Assistant Professor, Department of Chemistry, Government College Kullu, Himachal Pradesh

Mail Id: rajekhp@gmail.com

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ABSTRACT

Green chemistry is an important way to move forward with sustainable scientific and industrial practices by using fewer dangerous chemicals, making reactions more efficient, and using renewable resources. This review talks about new things that have happened in green chemistry and sustainable synthesis methods since 2024. These include the development of environmentally friendly solvents such as deep eutectic solvents (DESs) and supercritical CO_2, catalysts derived from bio-based and waste materials, and innovative synthesis methods including microwave-assisted, enzymatic, and solar-driven processes. People are also very interested in making nanoparticles from plants and microorganisms, using advanced materials like MXenes for photocatalysis, and using industrial and electronic waste as catalyst sources in a way that is good for the environment. All of these changes are in line with the 12 Principles of Green Chemistry. They support efforts around the world to use resources better, make less pollution, and make products that are cleaner. The review also talks about the problems that come with scalability, reproducibility, and cost-effectiveness. It also gives suggestions for how to move forward with sustainable synthesis in both the lab and industry.

Keywords: Green chemistry; Sustainable synthesis; Deep eutectic solvents (DESs); Supercritical CO_2; Bio-based catalysis; Waste-derived catalysts; Microwave-assisted synthesis; Enzymatic polymerization; MXenes; Photocatalysis; Solar reforming; Environmental sustainability

1. Introduction

Green chemistry tries to make chemical processes that are better for people's health and the environment by using fewer harmful chemicals, using energy more efficiently, using renewable resources, and making the most of atoms. Recent advancements indicate that the 12 Principles of green chemistry are increasingly being integrated into emerging technologies for synthesis, catalysis, and material development. This is in line with the world's goals for sustainability.

2. Green Solvents and Sustainable Mediums

2.1 Deep Eutectic Solvents (DESs)

To make a deep eutectic solvent (DES), you mix a hydrogen bond donor and a hydrogen bond acceptor compound that interact through hydrogen bonding to make a eutectic mixture. They are important because they are safe, can be broken down by living things, can be changed, and are cheap. People use them a lot to make organic compounds, speed up chemical reactions, and get things out of other things.

2.2 Supercritical CO_2 ($scCO_2$)

Supercritical CO_2, or CO_2 that is above its critical state ($scCO_2$), is a solvent that is good for the environment for both synthesis and extraction. It has been shown to work well for making nanostructured metal catalysts and is being used more and more in the continuous-flow synthesis of metal-organic frameworks (MOFs), like UiO-66 (Zirconium 1,4-dicarboxybenzene).

3. Green Synthesis Methods

3.1 Plant- and Microorganism-Mediated Nanoparticle Synthesis

It is a low-toxicity and energy-efficient way to make metal and metal oxide nanoparticles by using plants and microbes. These biological agents act as stabilizers and reducers. Even though being eco-friendly is a good thing, there are still concerns about reproducibility and scalability. .

3.2 Microwave-Assisted and Hydrothermal Techniques

Microwave and hydrothermal methods speed up reactions, control the shape of nanoparticles, and use less energy. They are better for the environment than other high-energy ways..

3.3 Enzymatic Polymerization

Enzymatic polymerization happens in mild, watery conditions, which means that it uses less energy and doesn't hurt the environment as much. More and more people are using this method to make bio-based materials.

3.4 Photocatalytic and Solar-Driven Routes

- **MXene-Based Photocatalysts:** MXenes are new 2D materials that can change their band gaps and conduct electricity well. Solar energy is used to turn water into hydrogen with these. Researchers are currently examining their stability and issues related to charge recombination. .
- **Solar Reforming (PEC):** Photoelectrochemical (PEC) systems use sunlight to change biomass and trash into chemicals and hydrogen fuels that are worth more. New technologies like artificial leaves have shown that CO_2 can be changed into ethylene and ethane.

4. Catalysis and Waste Valorization

4.1 Recycling and Waste-Derived Catalysts

Getting catalytic materials out of electronic waste, used batteries, and industrial waste helps cut down on the need for new raw materials and keeps chemical production going.

4.2 Plant Extract Catalysts & Industrial Waste

A Cu_2O catalyst made from plant extract demonstrated its recyclability and achieved an 85% yield in triazole synthesis [15]. Iron filings from mechanical workshops were transformed into efficient heterogeneous catalysts for biodiesel production, achieving a conversion efficiency exceeding 96%.

5. Overarching Reviews & Scope

A systematic review published in Sustainability in 2024 provided a comprehensive analysis of green chemistry's contribution to the progression towards a more sustainable chemical industry.

A 2025 article in Frontiers in Chemistry said that bio-based and microwave-assisted organic synthesis would be important tools for the future.

6. Summary of Key Advances

Theme	**Highlights**
Green Solvents	DESs, $scCO_2$, green continuous-flow MOF synthesis
Green Synthesis Methods	Plant/microbial synthesis, microwave/hydrothermal, enzymatic polymerization
Catalyst Circularity	Recycling of e-waste, battery waste and plant-derived catalytic materials
Sustainability Techniques	MXene-based photocatalysis, solar PEC technologies
Broad Reviews	Frameworks for integrating green chemistry across disciplines

7. Opportunities & Challenges

- **Scalability & Reproducibility:** Green synthesis using biological agents remains difficult to scale consistently.
- **Stability of Catalysts:** MXene photocatalysts and PEC systems require enhanced operational stability.
- **Economic Viability:** Green solvents and catalysts must be cost-effective to compete with conventional alternatives.

- **Circular Chemistry:** Waste valorization holds promise but needs robust pathways for efficient catalyst recovery and reuse.

8. Conclusions

Recent advancements in green chemistry indicate a transition towards sustainability via the utilization of environmentally friendly solvents, innovative manufacturing processes, and the recycling of waste materials. These technologies have a lot of potential, but they face real-world problems when it comes to scalability, stability, and economic integration. Future research should focus on hybrid methodologies, lifecycle assessment, and systems integration to facilitate the industrial implementation of green synthetic strategies.

9. References

1. Sustainability. (2024). *Green Chemistry and Its Impact on the Transition towards Sustainable Chemistry: A Systematic Review*. MDPI.
2. Frontiers in Chemistry. (2025). *Revolutionizing Organic Synthesis Through Green Chemistry: Metal-Free, Bio-Based, and Microwave-Assisted Methods*.
3. RSC Blogs. (2024). *DESs in Green Chemistry*.
4. Number Analytics. (2024). *Trends in Green Solvent Development*.
5. arXiv. (2024). *CO_2-Assisted Nanoparticle Synthesis*.
6. Wikipedia. (2024). *Supercritical Fluids in MOF Synthesis*.
7. PMC. (2024). *Plant- and Microorganism-Based Nanoparticle Synthesis: A Review*.
8. SpringerLink. (2025). *Challenges in Green Nanoparticle Synthesis*.
9. Wikipedia. (2024). *Microwave-Assisted Green Chemistry*.
10. arXiv. (2022). *Microwave Hydrothermal Synthesis Advances*.
11. Wikipedia. (2025). *Enzymatic Polymerization Techniques*.
12. arXiv. (2025). *MXene Photocatalysis for Hydrogen Evolution*.
13. Wikipedia. (2024). *Solar Reforming and PEC Systems*.
14. MDPI. (2024). *Catalysts Derived from Electronic and Industrial Waste*.
15. Frontiers in Chemistry. (2024). *Eco-Friendly Catalysts from Plant Extracts and Metal Waste*.