STM JOURNALS

International Journal of
Photochemistry and
Photochemical Research

Volume 1, Issue 2, 2023
July–December
DOI Journal: 10.37591/IJPPR

https://journals.stmjournals.com/ijppr

Review IJPPR

Emerging Photochemical Techniques in Green Chemistry

Neha Sahu*[1], Rizwan Arif[2,]

Abstract

Creating environmentally friendly and sustainable chemical processes is one of the main objectives of green chemistry. A viable strategy for accomplishing this goal is the use of light to trigger chemical reactions in emerging photochemical techniques. An overview of current developments in photochemical techniques that support green chemistry is given in this abstract. Key innovations include the use of visible light photocatalysis, which offers a sustainable alternative to traditional high-energy UV light processes. Transition metal complexes, organic dyes, and semiconductor materials are highlighted as effective photocatalysts that can operate under mild conditions and with high selectivity. Furthermore, the integration of photochemical techniques with flow chemistry and continuous processing enhances reaction efficiency and scalability, reducing waste and energy consumption. Advances in photoredox catalysis have enabled the development of novel synthetic pathways, facilitating the construction of complex molecules with minimal environmental impact. The application of these techniques in natural product synthesis, pharmaceutical manufacturing, and polymer chemistry illustrates their versatility and potential for widespread industrial adoption. In conclusion, emerging photochemical techniques provide a robust platform for advancing green chemistry principles. By leveraging the energy of light, these methods offer environmentally benign alternatives to conventional chemical processes, aligning with the global imperative for sustainable development. This paper explores the recent advancements and applications of photochemical techniques in green chemistry, highlighting their potential to revolutionize synthesis processes while reducing energy consumption, waste generation, and reliance on hazardous reagents. Key areas of focus include: ***Solar-driven reactions:*** *Harnessing sunlight as a clean and abundant energy source for driving chemical transformations, including photoredox catalysis and photocatalytic reactions.* ***Solvent-free and mild conditions:*** *Utilizing photochemistry to conduct reactions under solvent-free or mild conditions, reducing the use of volatile organic solvents and minimizing environmental footprint.* ***Selective activation:*** *Leveraging the selectivity of light to activate specific functional groups or bond cleavage, enabling precise control over reaction pathways and reducing the need for protecting groups.* ***Flow chemistry:*** *Integrating photochemical reactions into continuous flow systems to enhance efficiency, scalability, and safety while reducing resource consumption.* ***Sustainable material synthesis:*** *Applying photochemical methods for the synthesis of green materials such as polymers, nanoparticles, and pharmaceuticals, with improved efficiency and reduced environmental impact.* ***Photobiocatalysis:*** *Combining photochemistry with enzymatic catalysis for sustainable synthesis of fine chemicals and pharmaceuticals, offering mild reaction conditions and high selectivity.* ***Waste minimization and atom economy:*** *Achieving high atom economy and minimizing waste generation through the use of*

***Author for Correspondence**
Neha Sahu
E-mail: nehasahu082018@gmail.com

[1]Research Scholar, Department of Chemistry School of Basic and Applied Sciences, Lingaya's Vidyapeeth bFaridabad, Haryana, India
[2]Assistant Professor, Department of Chemistry School of Basic Applied Sciences, Lingaya's Vidyapeeth, Faridabad, Haryana, India

Received Date: May 28, 2024
Accepted Date: May 29, 2024
Published Date: June 10, 2024

Citation: Neha Sahu, Rizwan Arif. Emerging Photochemical Techniques in Green Chemistry. International Journal of Photochemistry and Photochemical Research. 2023; 1(2): 39–45p.

photochemical reactions, contributing to the principles of green chemistry. This review provides insights into the potential of emerging photochemical techniques to address the challenges faced by traditional synthetic methods, paving the way for a more sustainable and environmentally friendly chemical industry. Through interdisciplinary collaborations and continued research efforts, photochemistry holds promise as a key enabler of green and sustainable chemistry practices.

Keywords: photochemistry, green chemistry, photocatalysis, visible light, photoredox catalysis, sustainable synthesis, flow chemistry.

INTRODUCTION

Photochemistry, the study of chemical reactions triggered by light, has emerged as a powerful tool in the realm of green chemistry, aiming to minimize the environmental impact of chemical processes. This burgeoning field capitalizes on the unique properties of light to drive chemical transformations with high selectivity and efficiency, often under mild conditions, thus reducing the reliance on traditional energy-intensive and polluting methods [1].

In recent years, the application of photochemical techniques in green chemistry has expanded rapidly, offering innovative solutions to pressing environmental challenges. By harnessing renewable light energy sources such as sunlight and using them to activate specific chemical reactions, photochemistry holds promise for sustainable synthesis routes and environmentally benign processes. This introduction will explore key emerging photochemical techniques in green chemistry, highlighting their principles, advantages, and applications. From photocatalysis and photoredox catalysis to photodegradation and photopolymerization, these techniques offer versatile approaches to address various aspects of sustainability in chemical synthesis and industrial processes [2].

Moreover, this introduction will delve into the underlying mechanisms and principles that govern photochemical reactions, elucidating how light interacts with matter to initiate and drive chemical transformations. Understanding these fundamental aspects is essential for harnessing the full potential of photochemistry in green chemistry and advancing towards a more sustainable future. **Figure 1 shown:** Introduction to Green Chemistry. Through a comprehensive overview of emerging photochemical techniques, this introduction aims to inspire further research and innovation in the field of green chemistry, fostering the development of eco-friendly processes and materials with reduced environmental footprint. By embracing the power of light-driven chemistry, we can pave the way towards greener and more sustainable chemical practices, contributing to a healthier planet for generations to come [2].

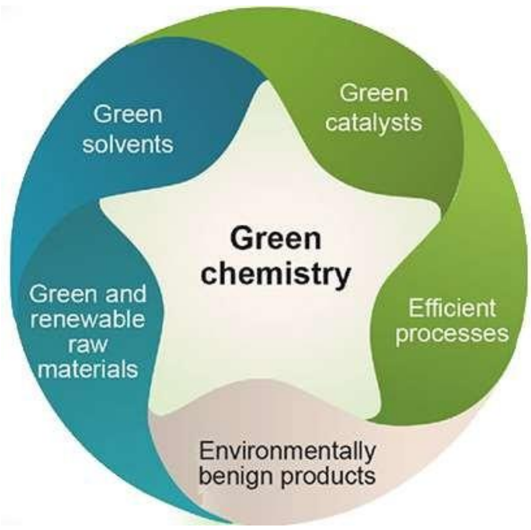

Figure 1. Introduction to green chemistry.

LITERATURE

Emerging photochemical techniques in green chemistry are becoming increasingly prominent in the literature due to their potential to enable sustainable synthesis processes. Here are some notable techniques and trends:

1. *Photoredox catalysis:* This technique employs visible light to activate catalysts, facilitating organic transformations with high efficiency and selectivity. By utilizing readily available light sources and avoiding the use of toxic metals, photoredox catalysis offers a green alternative to traditional synthetic methods [3].
2. *Flow photochemistry:* Flow photochemistry involves performing photochemical reactions in continuous flow systems. This approach offers several advantages over batch reactions, including improved safety, scalability, and efficiency. Flow photochemistry minimizes the use of solvents and reagents, making it an attractive option for green synthesis [3].
3. *Visible light photocatalysis:* Visible light photocatalysis utilizes visible light-absorbing catalysts to drive chemical reactions. These catalysts can activate substrates under mild conditions, avoiding the need for high-energy UV light sources. By harnessing solar energy and reducing energy consumption, visible light photocatalysis holds promise for sustainable synthesis pathways [4].
4. *Photochemical water splitting:* Photochemical water splitting is a green approach to hydrogen production, utilizing sunlight to drive the decomposition of water into hydrogen and oxygen. This process can be coupled with renewable energy sources, such as solar panels, to produce clean hydrogen fuel without the generation of greenhouse gases [4].
5. *Photoreactive materials:* The development of photoreactive materials, such as photoresponsive polymers and nanoparticles, is gaining traction in green chemistry research. These materials can undergo controlled structural changes or initiate chemical reactions upon exposure to light, enabling applications in drug delivery, sensing, and environmental remediation [5].
6. *Photobiocatalysis:* Photobiocatalysis combines the principles of photochemistry and biocatalysis to perform enzymatic reactions under light irradiation. By harnessing the catalytic power of enzymes and the selectivity of light-driven processes, photobiocatalysis offers a sustainable approach to synthesis with high stereo- and regioselectivity [6].
7. *Photochemical upcycling:* Photochemical upcycling involves the conversion of waste materials or pollutants into valuable products using light-driven processes. By leveraging the reactivity of photoactivated species, such as radicals and excited states, photochemical upcycling can transform harmful compounds into useful chemicals or fuels, contributing to waste reduction and resource recovery [7].

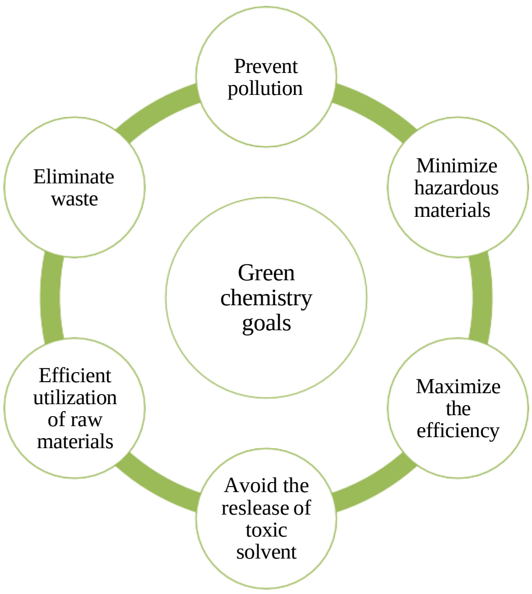

Figure 2. Green chemistry goals.

These emerging photochemical techniques highlight the innovative strategies being developed to address sustainability challenges in chemical synthesis and promote the principles of green chemistry. **Figure 2 shown:** Green Chemistry goals. As research in this field continues to advance, it is expected to drive the development of cleaner and more efficient synthetic methodologies [8].

METHODOLOGY

Photochemical techniques in green chemistry leverage light energy to initiate chemical reactions, reducing or eliminating the need for traditional, often environmentally harmful, reaction conditions. Here's a general methodology for employing emerging photochemical techniques:

1. *Selection of photochemical reaction:* Identify a chemical transformation suitable for photochemical activation. This could involve bond formation, bond cleavage, or other types of reactions where light energy can drive the process efficiently [9].
2. *Substrate selection:* Choose substrates that are compatible with photochemical conditions and are environmentally benign. This might involve considering factors like toxicity, biodegradability, and availability [10].
3. *Selection of photoredox catalyst:* Photoredox catalysts are often crucial in photochemical reactions as they absorb light and undergo redox reactions, generating reactive intermediates. Choose catalysts that are non-toxic, inexpensive, and readily available [10].
4. *Solvent selection:* Opt for green solvents that are non-toxic, biodegradable, and have low environmental impact. Water, supercritical CO2, and some bio-based solvents are popular choices [11].
5. *Optimization of reaction conditions:* Determine the optimal parameters for the photochemical reaction, including light intensity, wavelength, temperature, and reaction time. This optimization process aims to maximize reaction efficiency while minimizing energy consumption and waste generation [11].
6. *Scale-up and process integration:* Once optimized, scale up the photochemical reaction to larger volumes while maintaining green principles. Consider integrating the photochemical step into existing synthetic routes or designing new processes that minimize waste and energy usage [12].
7. *Product isolation and purification:* Develop efficient methods for isolating and purifying the desired product from the reaction mixture. Minimize the use of hazardous reagents and wasteful separation techniques wherever possible [12].
8. *Characterization and analysis:* Thoroughly characterize the synthesized products using analytical techniques such as spectroscopy, chromatography, and mass spectrometry. Ensure that the product meets desired specifications and is suitable for its intended application [12].
9. *Safety and regulatory compliance:* Adhere to safety protocols throughout the photochemical process to minimize risks to personnel and the environment. Ensure compliance with relevant regulations and guidelines governing the use of chemicals and processes [13].
10. *Evaluation of environmental impact:* Conduct a life cycle assessment to evaluate the overall environmental impact of the photochemical process, including energy consumption, waste generation, and resource usage. Compare the green photochemical approach with traditional methods to demonstrate its environmental benefits. By following this methodology, researchers can harness the power of photochemistry to drive sustainable chemical transformations and contribute to the advancement of green chemistry principles [14].

APPLICATION

Photochemistry, particularly in the context of green chemistry, has gained significant attention due to its potential for sustainable synthesis processes. Here are some emerging photochemical techniques and their applications in green chemistry:

1. *Photocatalysis:* Photocatalysis involves the use of a catalyst to initiate chemical reactions under light irradiation. In green chemistry, photocatalysis can replace traditional, energy-intensive processes by utilizing sunlight as a clean and abundant energy source. Applications include organic synthesis, water purification, and pollutant degradation [15].

2. *Photooxidation:* Photooxidation involves the use of oxygen and light to initiate oxidation reactions. This technique is utilized in the oxidation of organic pollutants in water and air, as well as in the synthesis of valuable compounds like pharmaceuticals and fine chemicals. By using oxygen as an oxidant and light as an energy source, photooxidation can minimize the use of hazardous chemicals and reduce waste generation [16].
3. *Photoredox catalysis:* Photoredox catalysis employs light-induced electron transfer reactions to facilitate chemical transformations. This technique enables the use of mild reaction conditions and selective bond formation, reducing the need for harsh reagents and improving atom economy. Applications include cross-coupling reactions, C-H functionalization, and polymer synthesis [17].
4. *Photopolymerization:* Photopolymerization involves the use of light to initiate polymerization reactions, leading to the formation of polymers and coatings. This technique offers several advantages over traditional thermal polymerization processes, such as rapid curing, solvent-free conditions, and spatial control over polymerization. Applications range from adhesives and coatings to 3D printing and microfabrication [18].
5. *Photochemical upconversion:* Photochemical upconversion utilizes light-absorbing molecules to convert low-energy photons into higher-energy ones, enabling the utilization of a broader spectrum of sunlight for chemical reactions. This technique can enhance the efficiency of solar energy conversion and enable the activation of normally inert molecules under mild conditions [19].
6. *Photobiocatalysis:* Photobiocatalysis combines the principles of photocatalysis and enzymatic catalysis to perform selective chemical transformations using light and enzymes. By harnessing the specificity of enzymes and the energy of light, photobiocatalysis offers a sustainable approach to synthesis with high selectivity and minimal byproduct formation. These emerging photochemical techniques in green chemistry have diverse applications across various sectors, including pharmaceuticals, materials science, environmental remediation, and renewable energy. By harnessing the power of light and sustainable catalytic processes, these techniques contribute to the development of cleaner and more efficient chemical synthesis methods [20].

CONCLUSION

In conclusion, the emergence of photochemical techniques in green chemistry represents a significant stride towards sustainable and environmentally friendly chemical processes. These innovative methods harness the power of light to drive chemical reactions, offering several advantages over traditional approaches. Firstly, photochemical reactions often operate under mild conditions, requiring lower temperatures and pressures compared to conventional thermal methods. This characteristic not only reduces energy consumption but also minimizes the formation of unwanted by-products, leading to higher selectivity and atom efficiency.

Secondly, many photochemical transformations utilize renewable energy sources such as sunlight, making them inherently greener and more sustainable. By tapping into solar energy, these techniques offer a pathway to reduce reliance on fossil fuels and mitigate the environmental impact associated with conventional energy-intensive processes. Furthermore, photochemical reactions often proceed with high efficiency and specificity, enabling the synthesis of complex molecules with precise control over stereochemistry and functional group compatibility. This level of control is particularly valuable in pharmaceutical, agrochemical, and materials science applications, where the synthesis of structurally diverse compounds is crucial. Additionally, photochemical methods enable the activation of typically inert chemical bonds, expanding the synthetic toolbox and facilitating the development of novel transformations. By accessing previously inaccessible reactivity pathways, these techniques unlock new possibilities for green and sustainable synthesis. However, despite these advancements, challenges remain in the widespread adoption of photochemical techniques in green chemistry. Issues such as scalability, reactor design, and the development of efficient photocatalysts need to be addressed to realize the full potential of these methods on an industrial scale.

In conclusion, the integration of photochemical techniques into green chemistry practices offers a promising avenue for achieving more sustainable and environmentally benign chemical processes. Continued research and innovation in this field hold the key to unlocking further benefits and overcoming existing limitations, ultimately contributing to a greener and more sustainable future.

REFERENCES

1. Atomic-level coordination structures meet graphitic carbon nitride (g-C<inf>3</inf>N<inf>4</inf>) for photocatalysis: Energy conversion and environmental remediation 2024, Applied Catalysis B: Environmental
2. Demonstrating photocatalytic esterification as a potential strategy to improve the properties of feedstock oil derived from dairy waste scum for biodiesel production 2024, Energy Conversion and Management
3. Development of an electrophotochemical flow microreactor for efficient electrophotocatalytic C-H hydroxylation of benzene to phenol 2024, Chemical Engineering Science
4. Bismuth sulfide-impregnated cobalt oxide nanocrystals: An enhanced photocatalyst for improved hydrogen production beneath visible light 2024, Inorganic Chemistry Communications
5. Photocatalytic reforming of biomass for hydrogen production: A comprehensive overview 2024, Fuel Processing Technology
6. Electrochemical and Photocatalytic Synthesis of Organic Compounds Utilizing a Greener Approach. A review 2024, Molecular Catalysis
7. C. Zhu, H. Yue, J. Jia, M. Rueping Recent advances in nickel-catalyzed C-heteroatom cross-coupling reactions under mild conditions via facilitated reductive elimination Angew. Chem. Int. Ed. (2020), 10.1002/anie.202013852
8. M. Schmalzbauer, M. Marcon, B. König Excited state anions in organic transformations Angew. Chem. Int. Ed. (2021), 10.1002/anie.202009288
9. L. Schmermund, S. Reischauer, S. Bierbaumer, C.K. Winkler, A. Diaz Rodriguez, L.J. Edwards, S. Kara, T. Mielke, J. Cartwright, G. Grogan, *et al.* Chromoselective photocatalysis enables stereocomplementary biocatalytic pathways Angew. Chem. Int. Ed. (2021), 10.1002/anie.202100164
10. P. Li, J.A. Terrett, J.R. Zbieg Visible-light photocatalysis as an enabling technology for drug discovery: a paradig shift for chemical reactivity ACS Med. Chem. Lett., 11 (2020), pp. 2120-2130
11. I.A. MacKenzie, L. Wang, N.P.R. Onuska, O.F. Williams, K. Begam, A.M. Moran, B.D. Dunietz, D.A. Nicewicz Discovery and characterization of an acridine radical photoreductant Nature, 580 (2020), pp. 76-80
12. M. Neumeier, U. Chakraborty, D. Schaarschmidt, V. de la Pena O'Shea, R. Perez-Ruiz, A. Jacobi von Wangelin Combined photoredox and iron catalysis for the cyclotrimerization of alkynes Angew. Chem. Int. Ed., 59 (2020), pp. 13473-13478
13. B.D. Ravetz, N.E.S. Tay, C.L. Joe, M. Sezen Edmonds, M.A. Schmidt, Y. Tan, J.M. Janey, M.D. Eastgate, T. Rovis Development of a platform for near-infrare photoredox catalysis ACS Cent. Sci., 6 (2020), pp. 2053-2059
14. S. Reischauer, V. Strauss, B. Pieber A modular, self assembling metallaphotocatalyst for cross couplings using the full visible-light spectrum ACS. Catal., 10 (2020), pp. 13269-13274
15. C. Rosso, S. Gisbertz, J.D. Williams, H.P.L. Gemoets, W. Debrouwer, B. Pieber, C.O. Kappe An oscillatory plug flow photoreactor facilitates semi-heterogeneous dual nickel/carbon nitride photocatalytic C–N couplings React. Chem. Eng., 5 (2020), pp. 597-604
16. M. Schmalzbauer, M. Marcon, B. König Excited state anions in organic transformations Angew. Chem. Int. Ed. (2021), 10.1002/anie.202009288
17. G. Laudadio, Y. Deng, K. van der Wal, D. Ravelli, M. Nuño, M. Fagnoni, D. Guthrie, Y. Sun, T. Noë C(sp3)–H functionalizations of light hydrocarbons using decatungstate photocatalysis in flow Science, 369 (2020), pp. 92-96

18. Xiao, S.; Li, Z.; Fu, Q.; Li, Y.; Li, J.; Zhang, L.; Liao, Q.; Zhu, X. Hybrid Microbial Photoelectrochemical System Reduces CO_2 to CH_4 with 1.28% Solar Energy Conversion Efficiency. *Chem. Eng. J.* 2020, *390*, 124530, DOI: 10.1016/j.cej.2020.124530
19. Kumaravel, V.; Bartlett, J.; Pillai, S. C. Photoelectrochemical Conversion of Carbon Dioxide (CO_2) into Fuels and Value-Added Products. *ACS Energy Lett.* 2020, *5*, 486– 519, DOI: 10.1021/acsenergylett.9b02585
20. Giesbrecht, P. K.; Freund, M. S. Recent Advances in Bipolar Membrane Design and Applications. *Chem. Mater.* 2020, *32*, 8060– 8090, DOI: 10.1021/acs.chemmater.0c02829

