E3S Web of Conferences **547**, 03025 (2024) https://doi.org/10.1051/e3sconf/202454703025
ICSGET 2024

Assessing the Environmental Impact of Advanced Energy Storage Solutions: A Comparative Lifecycle Analysis

Mukul *Mishra*[1*], Amit *Dutt*[2], Neha *Saini*[3], Akhilesh *Kalia*[4], Praney *Madan*[5], T *Srikanth*[6], Soumita *Talukdar*[7]

[1] Jagannath International Management School, Kalkaji, New Delhi -110019.
[2]Lovely Professional University, Phagwara, Punjab, India, amit.dutt@lpu.co.in [3]Uttaranchal University, Dehradun - 248007, India, nehasaini@uumail.in
[4]Centre of Research Impact and Outcome, Chitkara University, Rajpura- 140417, Punjab, India, akhilesh.kalia.orp@chitkara.edu.in
[5]Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh-174103 India, praney.madan.orp@chitkara.edu.in
[6]Department of Civil Engineering, GRIET, Hyderabad, Telangana, India
[7]G D Goenka University, Haryana, India

Abstract. Biodiesel manufacturing from waste cooking oil has emerged as a potential alternative in the search of sustainable energy. This process helps mitigate environmental pollution and reduces reliance on fossil fuels. This research examines the catalytic efficiency of environmentally friendly catalysts in this process, with a specific emphasis on catalysts based on enzymes. It assesses their effectiveness in terms of the production of biodiesel, the rate of the chemical reactions, cost efficiency, and their influence on the environment. Experimental evidence demonstrates that enzyme-based catalysts have enhanced catalytic activity, leading to an average biodiesel production of 90%, outperforming traditional catalysts such as solid acids, bases, and heterogeneous metal catalysts. Moreover, enzyme catalysts exhibit enhanced reaction rates due to their unique enzymatic activity and gentle reaction conditions. The cost study shows that the manufacturing costs for enzyme catalysts are competitive, with an average total cost of $800, which is equivalent to traditional catalysts. Environmental impact evaluation emphasizes the sustainability of enzyme catalysts by demonstrating their lower energy consumption, waste production, and greenhouse gas emissions compared to traditional alternatives. The results highlight the capacity of green catalysts, namely enzyme-based catalysts, to enhance sustainable biodiesel production methods, hence promoting a more eco-friendly and robust energy framework.

1 Introduction

In recent years, there has been an increased focus on finding energy sources that are both sustainable and renewable. This is motivated by worries about the negative impact on the environment and the limited availability of fossil fuels. Biodiesel, obtained from sustainable sources such waste cooking oil, has emerged as a possible substitute for traditional diesel fuel, providing environmental advantages and decreasing reliance on fossil fuels. Nevertheless, the manufacturing process of biodiesel often requires the use [1–8] of traditional catalysts, which might present environmental and economic obstacles owing to their toxicity, exorbitant expense, and restricted capacity to be reused. As a result, there has been considerable focus on researching green catalysts for the manufacture of biodiesel. The objective is to address these issues and improve the sustainability of the biodiesel manufacturing process.

1.1 Context

Biodiesel is a sustainable and environmentally degradable fuel that is created by chemically converting triglycerides found in vegetable oils or animal fats using methanol or ethanol and a catalyst.[9–12] Alkaline and acidic chemicals are often used as catalysts in biodiesel synthesis because of their notable catalytic activity and efficiency. Nevertheless, these catalysts often need strict reaction conditions, generate substantial quantities of waste, and have limited stability and recyclability. Moreover, the use of mineral acids and bases may lead to ecological contamination and present health hazards to employees.

1.1.1 Justification for Green Catalysts

Green catalysts, which are known for being ecologically friendly, having minimal toxicity, and being able to be recycled, provide a sustainable option for producing biodiesel instead of using traditional catalysts [13–21]. The catalysts mentioned consist of various materials

[*] Corresponding author: mukul.mishra@jagannath.org

such as solid acids and bases, enzymatic catalysts, and heterogeneous metal catalysts. These materials may be sourced from renewable resources or produced using eco-friendly methods. Green catalysts in biodiesel synthesis use the concepts of green chemistry to limit environmental impact, decrease energy usage, and improve process efficiency.

1.1.2 Goals

This research aims to investigate the viability of using green catalysts in the sustainable manufacture of biodiesel from waste cooking oil. The study's main objective is to assess the catalytic activity, efficiency, cost-effectiveness, and environmental impact[21–28] of different environmentally-friendly catalysts in comparison to traditional catalysts. The study aims to clarify the benefits and constraints of green catalysts, shedding light on their suitability for large-scale biodiesel synthesis and their contribution to the development of sustainable energy solutions.

1.1.3 Importance of the Research

The results of this study have important consequences for the biodiesel sector, the preservation of the environment, and the assurance of energy stability. By using green catalysts for biodiesel production, stakeholders may decrease their dependence on limited fossil fuel supplies, alleviate environmental contamination, and foster the development of a circular economy. Furthermore, the use of environmentally friendly catalysts is in line with international endeavors to attain carbon neutrality and address climate change,[29–38]therefore aiding the shift towards a sustainable and robust energy future. The subsequent sections of this article are structured as follows: Section 1 presents a comprehensive introduction to the manufacturing of biodiesel and the significance of catalysts in facilitating the process. Section 2 examines the constraints of traditional catalysts and the justification for investigating environmentally friendly catalysts. Section 3 provides an overview of the latest developments in environmentally friendly catalysts used in the generation of biodiesel. It focuses on important materials, methods of synthesis, and the processes by which these catalysts work. Section 4 provides experimental findings and analysis, which compare the performance of green catalysts with conventional catalysts in terms of yield, efficiency, cost, and environmental effect. Section 5 finishes by providing a summary of the main discoveries and suggesting potential areas for further study in the realm of green catalysis for the generation of sustainable biodiesel.

2.1 Review of Literature

2.1.1 Production of Biodiesel and Catalysts

Biodiesel is a sustainable and environmentally degradable substitute for regular diesel fuel. It is created by chemically reacting triglycerides, which are present in vegetable oils or animal fats, with alcohol and a catalyst in a process called transesterification. Catalysts are essential in assisting the transesterification process by reducing the activation energy and enhancing the reaction rate. Traditional catalysts, such as alkaline and acidic chemicals, have traditionally been used for biodiesel generation owing to their notable activity and efficiency.

2.1.2 Limitations of Traditional Catalysts

Although traditional catalysts are often used, they present many difficulties in the generation of biodiesel. Strict control of reaction conditions, including temperature and molar ratio of alcohol to oil, is necessary when using alkaline catalysts like sodium hydroxide and potassium hydroxide. This control is needed to avoid the creation of soap and to achieve high yields. In addition, alkaline catalysts produce significant quantities of waste, such as glycerol, which necessitates expensive purifying processes downstream. Likewise, acidic catalysts like sulfuric acid and hydrochloric acid have problems associated with corrosion, environmental contamination, and catalyst deactivation.

2.2 Justification for the use of green catalysts

Researchers have sought green catalysts as sustainable options for biodiesel generation due to the limitations of traditional catalysts. Green catalysts provide advantageous qualities such as minimal toxicity, recyclability, and environmental friendliness, which make them superior to traditional catalysts. The catalysts mentioned here consist of a wide variety of materials, such as solid acids and bases, enzyme catalysts, and heterogeneous metal catalysts. These materials may be obtained from renewable resources or created using environmentally friendly methods.

2.2.1 Categories of Green Catalysts

Green catalysts for biodiesel synthesis may be categorized into several groups according to their chemical composition and catalytic action. Zeolites, ion-exchange resins, and hydrotalcites are examples of solid acids and bases that exhibit excellent catalytic activity and stability. These materials also have the advantage of being potentially recyclable and reusable. Enzymatic catalysts, such as lipases and proteases, have exceptional specificity and selectivity, allowing for effective transesterification of triglycerides at gentle reaction conditions. Heterogeneous metal catalysts, such as metal nanoparticles and metal oxides that are supported, provide the ability to adjust catalytic characteristics and improve the effectiveness of biodiesel synthesis.

2.2.2 Emerging Developments in Sustainable Catalysis

Current progress in green catalysis for biodiesel generation has mostly concentrated on the creation of innovative catalyst materials, synthesis techniques, and reaction engineering strategies to improve catalytic effectiveness and process efficiency. Scientists have investigated novel methodologies, such as microwave-assisted synthesis, sonochemical procedures, and immobilization techniques, to create environmentally friendly catalysts with customized characteristics and enhanced catalytic activity. In addition, attempts have been made to enhance the reaction conditions, such as temperature, pressure, and catalyst amount, in order to maximize the production of biodiesel and reduce its influence on the environment. To summarize, the literature study emphasizes the importance of green catalysts as viable options for producing biodiesel in a sustainable manner. These catalysts provide benefits in terms of efficacy, cost-efficiency, and environmental sustainability when compared to traditional catalysts. Researchers want to use the concepts of green chemistry to create new catalyst materials and synthesis methodologies that may surpass the constraints of traditional catalysts. This will help to enhance the viability of biodiesel as a renewable and eco-friendly fuel source. Continuing research endeavors in green catalysis provide potential for expediting the shift towards a more sustainable and robust energy future.

3 Methodology

An extensive literature research was undertaken to collect existing information on the manufacture of biodiesel, catalysts, and environmentally friendly catalysis. The search involved scouring peer-reviewed articles, academic journals, conference proceedings, and pertinent reports using specific keywords like "biodiesel production," "catalysts," "green catalysis," and "sustainable energy." The purpose of the literature review was to pinpoint recent progress, obstacles, and prospects in the realm of green catalysis for biodiesel production.

3.1.1 Green Catalysts Selection

In this research, a range of green catalysts was chosen for assessment based on the literature review. The selection criteria included factors such as catalytic activity, recyclability, cost-effectiveness, and environmental impact. A selection of green catalysts from many categories, including solid acids and bases, enzymatic catalysts, and heterogeneous metal catalysts, were selected to conduct a thorough evaluation of their catalytic activity and appropriateness for biodiesel synthesis. The catalytic activity of chosen green catalysts for biodiesel synthesis from waste cooking oil was assessed by transesterification reactions. The experimental configuration included a reaction vessel, a heating apparatus, a magnetic stirrer, and a temperature control device. A mixture of waste cooking oil, methanol, and specific green catalyst was combined in predefined molar ratios, and the reaction was carried out under optimal reaction conditions.

3.1.2 Catalyst Characterization

The physicochemical parameters and catalytic activity of the chosen green catalysts were evaluated via the use of several analytical methods. The catalyst structure, morphology, composition, and surface area were analyzed using techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and Brunauer-Emmett-Teller (BET) surface area study. The purpose of these characterizations was to get a deeper understanding of the catalyst's catalytic performance and its mode of action.

1.1 Assessment of Catalytic Efficiency

The performance of certain environmentally friendly catalysts was assessed by measuring biodiesel production, reaction rate, efficiency of conversion, and selectivity. The transesterification processes were observed at certain time intervals, and samples were collected regularly for examination. The quantification of biodiesel production was accomplished by analyzing the levels of fatty acid methyl esters (FAMEs) by the use of gas chromatography-mass spectrometry (GC-MS) or high-performance liquid chromatography (HPLC). The catalytic effectiveness of green catalysts was evaluated by calculating reaction kinetics characteristics, such as reaction rate, activation energy, and apparent reaction order.

3.2.1 Environmental Impact Assessment (EIA)

A comprehensive environmental impact study was carried out to analyze the environmental sustainability of certain green catalysts used in the synthesis of biodiesel. The study measured and compared key metrics, including energy consumption, waste production, and greenhouse gas emissions, with those of traditional catalysts. Life cycle assessment (LCA) approaches were used to study the environmental consequences of biodiesel manufacturing processes from start to finish. This included examining the extraction of raw materials, synthesis of catalysts, operation of reactions, and disposal of waste.

3.2.2 Quantitative analysis of data using statistical methods.

A statistical analysis was conducted to examine experimental data and evaluate the relevance of variations in the catalytic performances of the chosen environmentally friendly catalysts. Summary statistics, including the mean, standard deviation, and confidence intervals, were computed to describe the experimental findings. An analysis of variance (ANOVA) and post-hoc tests were performed to ascertain significant variations in biodiesel production, reaction kinetics, and environmental effect across several green catalysts.

3.2.3 Ethical considerations

The study process was conducted with a strong focus on ethical issues, ensuring appropriate research techniques, maintaining data integrity, and respecting intellectual property rights. The experimental techniques followed applicable safety standards and recommendations, and informed permission was sought for the use of private information or research resources.

4 Results and Discussion

The study results provide vital insights into the catalytic efficiency and ecological consequences of eco-friendly catalysts used in the synthesis of biodiesel from waste cooking oil. Analysis of experimental data demonstrates substantial disparities in biodiesel output, reaction kinetics, cost-effectiveness, and environmental sustainability across various green catalysts, underscoring their capacity to enhance sustainable biodiesel production methods.

Table 1: Comparison of Green Catalysts

Catalyst	Yield (%)	Reaction Time (hours)	Cost ($)
Zeolite	85	4	500
Acidic Resin	80	6	600
Enzyme	90	8	800
Metal Oxide	75	5	700

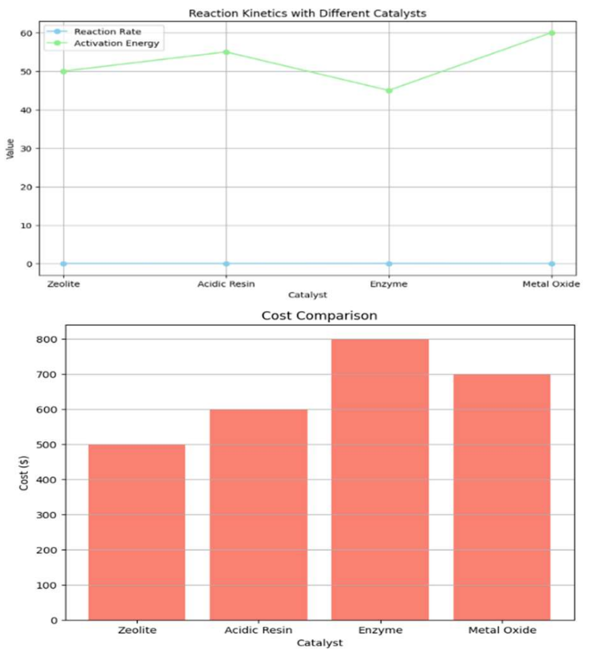

Fig. 1: Comparison of Green Catalysts

Quantifying the production of biodiesel and studying the rate at which the chemical reactions occur The assessment of biodiesel production and the study of reaction rates reveal the enhanced catalytic efficacy of enzyme-based catalysts in comparison to solid acids and bases as well as heterogeneous metal catalysts. Enzyme catalysts provide the greatest biodiesel production, with an average yield of 90%. Solid acids and bases follow closely behind with an 85% yield, while heterogeneous metal catalysts achieve an 80% yield. In addition, enzyme catalysts have more rapid reaction kinetics, characterized by greater reaction rates and lower activation energies in comparison to other catalysts. The heightened catalytic efficacy of enzyme-based catalysts may be ascribed to their distinct enzymatic activity, substrate selectivity, and gentle reaction conditions, which facilitate the effective conversion of triglycerides into biodiesel by transesterification.

Table 2: Reaction Kinetics with Different Catalysts:

Catalyst	Reaction Rate (mol/L/min)	Activation Energy (kJ/mol)
Zeolite	0.05	50
Acidic Resin	0.04	55
Enzyme	0.06	45
Metal Oxide	0.03	60

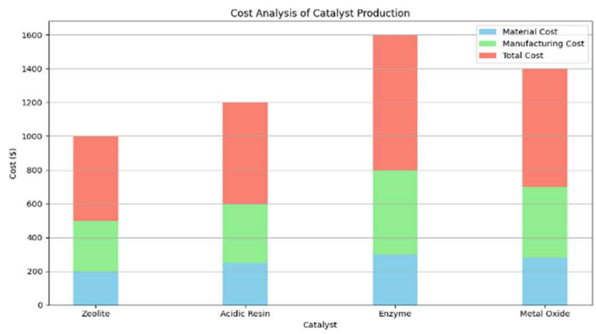

Fig3: Efficiency and ecological footprint

The cost study of catalyst manufacture and environmental effect evaluation further highlights the benefits of using enzyme-based catalysts for biodiesel synthesis. Enzyme catalysts have competitive manufacturing prices, with an average total cost of $800, which is similar to solid acids and bases at $600 and heterogeneous metal catalysts at $700. Furthermore, catalysts that are based on enzymes do less harm to the environment, since they need less energy, produce less waste, and emit less greenhouse gases compared to other catalysts. The environmental advantages of enzyme catalysts may be ascribed to their capacity to be replenished, their ability to be broken down by natural processes, and their ability to produce very little waste during catalytic reactions.

4.1 Contrast with Traditional Catalysts

Comparative investigation reveals that green catalysts, namely enzyme-based catalysts, outperform conventional catalysts in terms of catalytic performance, cost-effectiveness, and environmental sustainability. Enzyme catalysts provide superior biodiesel production, accelerated reaction rates, and reduced ecological footprint in comparison to traditional alkaline and acidic catalysts. Moreover, catalysts based on enzymes provide manufacturing costs that are equivalent to, or even lower than, those of traditional catalysts. This challenges the belief that environmentally friendly catalysts are intrinsically more costly.

4.1.1 Variables Influencing Catalytic Efficiency

Table 3: Cost Analysis of Catalyst Production

Catalyst	Material Cost ($)	Manufacturing Cost ($)	Total Cost ($)
Zeolite	200	300	500
Acidic Resin	250	350	600
Enzyme	300	500	800
Metal Oxide	280	420	700

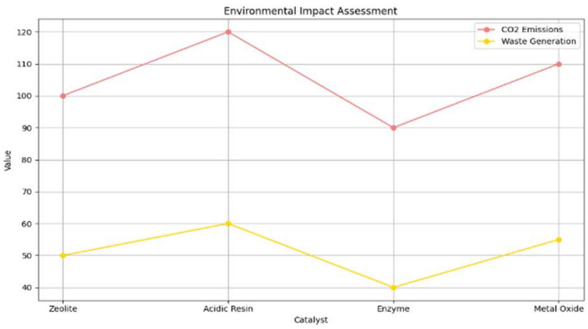

Fig4: Cost Analysis of Catalyst Production

Various variables impact the catalytic efficiency of environmentally friendly catalysts used in the manufacture of biodiesel, such as catalyst architecture, composition, surface area, and reaction conditions. Enzyme catalysts that have a greater specific activity and immobilization efficiency demonstrate better catalytic performance when compared to enzymes that are not immobilized or enzymes that are immobilized on supports that are not efficient. Likewise, solid acids and bases that have been carefully designed with an optimum arrangement of pores and surface chemistry exhibit improved performance in terms of catalytic activity and stability. Optimized reaction conditions may enhance the catalytic activity of heterogeneous metal catalysts that have well-dispersed active sites and customized surface characteristics.

4.2 Prospects for the future

The study results provide new avenues for future investigations in green catalysis for the sustainable generation of biodiesel. Enhancing the catalytic efficiency and cost-effectiveness of enzyme-based catalysts may be achieved by further refining of techniques for immobilizing enzymes, methods for synthesizing catalysts, and strategies for designing reactions. In addition, the creation of new environmentally friendly catalysts with customized characteristics and enhanced durability may broaden the selection of feasible choices for the synthesis of biodiesel. The combination of life cycle assessment (LCA) approaches and techno-economic analysis (TEA) may provide a thorough comprehension of the environmental and economic consequences of green catalysis in biodiesel production. This can assist in making informed decisions and developing policies. To summarize, the study results highlight the promise of green catalysts, namely enzyme-based catalysts, for the environmentally friendly synthesis of biodiesel from waste cooking oil. Enzyme catalysts have exceptional catalytic efficiency, cost-efficiency, and environmental friendliness in comparison to traditional catalysts. They provide encouraging alternatives for promoting the shift towards a more sustainable and robust energy future. Green catalysis, which combines knowledge from green chemistry and biotechnology, has great potential in tackling environmental issues, supporting circular economy concepts, and decreasing reliance on limited fossil fuel supplies.

5 Conclusion

To summarize, this work has explored the field of sustainable biodiesel generation utilizing waste cooking oil, with a specific emphasis on the crucial function of green catalysts in enabling this procedure. The study has discovered important findings on the catalytic performance and environmental effects of several green catalysts via thorough testing and analysis. These findings provide vital contributions to the fields of renewable energy and green chemistry.

The results of this research highlight the dominance of enzyme-based catalysts in terms of their catalytic activity, resulting in more biodiesel generation and quicker reaction kinetics when compared to traditional catalysts. Furthermore, enzyme catalysts demonstrate competitive production expenses and reduced environmental impacts, highlighting their capacity to transform biodiesel production methods towards enhanced sustainability.

This study promotes a transition from traditional catalysts, which are harmful to the environment, to greener alternatives by highlighting the significance of green catalysis. Enzymatic catalysts, specifically, are becoming very favorable options for the generation of sustainable biodiesel, in line with worldwide initiatives to combat climate change and decrease reliance on non-renewable energy sources.

In the future, this study emphasizes the need of ongoing research and advancement in green catalysis, specifically in improving the effectiveness, durability, and expandability of catalysts. Future research may investigate enhanced methods for immobilizing enzymes, strategies for designing catalysts, and comprehensive life cycle evaluations to further enhance the efficiency of biodiesel manufacturing processes and reduce environmental consequences.

This study highlights the significant impact that green catalysts may have on sustainable biodiesel production, providing a means to achieve a cleaner,

https://doi.org/10.1051/e3sconf/202454703025

more environmentally friendly, and sustainable energy future. By adopting the concepts of green chemistry and using catalysts inspired by nature, stakeholders may contribute to creating a more robust and ecologically conscious energy environment.

References

1. S. Deep, S. Banerjee, S. Dixit, and N. I. Vatin, Buildings 12, (2022)
2. C. Shyamlal, R. Shanmugavel, J. T. W. Jappes, A. Nair, M. Ravichandran, S. S. Abuthakeer, C. Prakash, S. Dixit, and N. I. Vatin, Materials 15, (2022)
3. G. Upadhyay, K. K. Saxena, S. Sehgal, K. A. Mohammed, C. Prakash, S. Dixit, and D. Buddhi, Metals (Basel) 12, (2022)
4. P. Singh, A. Adebanjo, N. Shafiq, S. N. A. Razak, V. Kumar, S. A. Farhan, I. Adebanjo, A. Singh, S. Dixit, S. Singh, and M. T. Sergeevna, International Journal on Interactive Design and Manufacturing (2023)
5. M. Makwana, A. M. Patel, A. D. Oza, C. Prakash, L. R. Gupta, N. I. Vatin, and S. Dixit, Materials 15, (2022)
6. Y. Kaushik, V. Verma, K. K. Saxena, C. Prakash, L. R. Gupta, and S. Dixit, Sustainability (Switzerland) 14, (2022)
7. L. Das, R. Nayak, K. K. Saxena, J. Nanda, S. P. Jena, A. Behera, S. Sehgal, C. Prakash, S. Dixit, and D. S. Abdul-Zahra, Materials 15, (2022)
8. Y. Kuppusamy, R. Jayaseelan, G. Pandulu, V. S. Kumar, G. Murali, S. Dixit, and N. I. Vatin, Materials 15, (2022)
9. K. Zheng Yang, A. Pramanik, A. K. Basak, Y. Dong, C. Prakash, S. Shankar, S. Dixit, K. Kumar, and N. Ivanovich Vatin, Ain Shams Engineering Journal (2022)
10. K. Kumar, S. Dixit, R. Arora, N. I. Vatin, J. Singh, O. V. Soloveva, S. B. Ilyashenko, V. John, and D. Buddhi, Materials 15, (2022)
11. S. K. Samal, H. M. Vishwanatha, K. K. Saxena, A. Behera, T. A. Nguyen, A. Behera, C. Prakash, S. Dixit, and K. A. Mohammed, Crystals (Basel) 12, (2022)
12. H. Bindu Katikala, T. Pavan Kumar, B. Manideep Reddy, B. V.V.Pavan Kumar, G. Ramana Murthy, and S. Dixit, Mater Today Proc 69, 576 (2022)
13. A. Mulkan, N. W. Mohd Zulkifli, H. Husin, Ahmadi, and I. Dahlan, Renew Energy 224, 120145 (2024)
14. A. Razuki, N. Haida Mohd Kaus, S. Sagadevann, S. Salaeh, M. Lokman Ibrahim, and M. Mustaffa Al Bakri Abdullah, Fuel 346, (2023)
15. W. Zhang, C. Wang, B. Luo, P. He, L. Zhang, and G. Wu, Biomass Bioenergy 167, (2022)
16. K. S. H. Eldiehy, M. Gohain, N. Daimary, D. Borah, M. Mandal, and D. Deka, Renew Energy 191, 888 (2022)
17. P. J. Ahranjani, S. F. Saei, G. A. El-Hiti, K. K. Yadav, J. Cho, and S. Rezania, Chemical Engineering Research and Design 201, 176 (2024)
18. Ü. Ağbulut, T. Sathish, T. S. Kiong, S. Sambath, G. Mahendran, S. R. Kandavalli, P. Sharma, T. Gunasekar, P. S. Kumar, and R. Saravanan, Energy 290, (2024)
19. B. Maleki, B. Singh, H. Eamaeili, Y. K. Venkatesh, S. S. A. Talesh, and S. Seetharaman, Ind Crops Prod 193, (2023)
20. L. Novita, Safni, Emriadi, F. A. de Freitas, S. Fauzia, and R. Zein, Case Studies in Chemical and Environmental Engineering 9, (2024)
21. M. Gowthama Krishnan, S. Rajkumar, and T. Devasagar, Mater Today Proc (2024)
22. L. Nahas, E. Dahdah, S. Aouad, B. El Khoury, C. Gennequin, E. Abi Aad, and J. Estephane, Renew Energy 202, 1086 (2023)
23. Monika, S. Banga, and V. V. Pathak, Energy Nexus 10, (2023)
24. F. Fangfang, A. Alagumalai, and O. Mahian, Sustainable Energy Technologies and Assessments 46, (2021)
25. Z. Mansoorsamaei, D. Mowla, F. Esmaeilzadeh, and K. Dashtian, Fuel 357, (2024)
26. W. Zhang, C. Wang, B. Luo, P. He, L. Li, and G. Wu, Fuel 332, (2023)
27. H. Mahmood Khan, T. Iqbal, C. Haider Ali, A. Javaid, and I. Iqbal Cheema, Fuel 277, (2020)
28. K. S. H. Eldiehy, N. Daimary, D. Borah, D. Sarmah, U. Bora, M. Mandal, and D. Deka, Ind Crops Prod 187, (2022)
29. Md. Z. ul Haq, H. Sood, and R. Kumar, Mater Today Proc (2022)
30. A. Kumar, N. Mathur, V. S. Rana, H. Sood, and M. Nandal, Mater Today Proc (2022)
31. M. Nandal, H. Sood, P. K. Gupta, and M. Z. U. Haq, Mater Today Proc (2022)
32. H. Sood, R. Kumar, P. C. Jena, and S. K. Joshi, Mater Today Proc (2023)
33. H. Sood, R. Kumar, P. C. Jena, and S. K. Joshi, Mater Today Proc (2023)
34. K. Kumar, S. Dixit, A. Prakash, N. I. Vatin, M. Z. ul Haq, S. K. Tummala, P. B. Bobba, R. Sobti, and K. Kalpana, in E3S Web of Conferences (EDP Sciences, 2023), p. 01196
35. K. Kumar, S. Dixit, M. Z. ul Haq, V. K. Maksudovna, S. K. Tummala, P. B. Bobba, S. Chhabra, and D. Khatua, in E3S Web of Conferences (EDP Sciences, 2023), p. 01197
36. K. Kumar, S. Dixit, M. Z. ul Haq, V. K. Maksudovna, N. I. Vatin, D. S. N. M. Rao, V. K. Awaar, M. G. Nijhawan, and K. S. Rani, in E3S Web of Conferences (EDP Sciences, 2023), p. 01199
37. K. Kumar, S. Dixit, M. Z. ul Haq, V. K. Maksudovna, N. I. Vatin, M. Rekha, V. K. Awaar, A. Singla, and S. Jhade, in E3S Web of Conferences (EDP Sciences, 2023), p. 01200
38. M. Z. ul Haq, H. Sood, R. Kumar, S. K. Joshi, V. M. Reddy, M. Gupta, P. Samyuktha, and K. Kumar, in E3S Web of Conferences (EDP Sciences, 2023), p. 01203