

Sustainable Biodiesel Production from Sawdust Oil Using Snail Shell-Derived Bio-Catalyst

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Abstract

This study investigated the production of biodiesel from sawdust oil using a snail shell-derived calcium oxide (CaO) catalyst. The objectives were to extract and characterize oil from sawdust, synthesize and analyze a bio-based catalyst, and evaluate the properties of the biodiesel produced. Oil extraction was carried out with n-hexane, yielding 32%, which was higher than some conventional oilseeds. The extracted oil showed a pH of 6.6, density of 0.83 g/cm³, viscosity of 4.30 mm²/s, and a flash point of 133°C, indicating its suitability as a biodiesel feedstock. Snail shells were calcined at 900°C and characterized by X-ray diffraction, confirming CaO as the dominant phase. Transesterification of the oil with ethanol in the presence of the catalyst produced biodiesel that was analyzed for physicochemical properties and fatty acid composition. The biodiesel exhibited a viscosity of 2.43 mm²/s, acid value of 0.29 mg KOH/g, cetane number of 51, and flash point of 14700B0C, all within ASTM standards. GC-MS analysis revealed 17.8% saturated and 79.8% unsaturated fatty acids, providing a balance of oxidative stability and cold-flow performance. Overall, the study demonstrates that sawdust oil and snail shell-derived CaO are viable, low-cost, and sustainable materials for biodiesel production. It is recommended that further optimization of catalyst loading and reaction parameters be carried out to enhance fuel properties and promote large-scale application.

Keywords: Biodiesel, Sawdust Oil, Snail Shell Catalyst, Transesterification, Renewable Fuels.

Introduction

Globally, energy demand continues to be heavily supplied by fossil sources such as petroleum, coal, and natural gas, excluding hydro and nuclear power. Because these fossil fuels are finite, ongoing consumption at current rates will accelerate depletion (Mazariegos, Abdelfath-Aldayyat, González-Rojo, & Gómez, 2025). Diesel remains a key fuel for industrial and agricultural sectors in many developing countries, powering tractor and pump sets vital to production. Transport fuel demand increases in tandem with economic growth; for example, biofuel use, including biodiesel, is projected to account for about 6 % of road transport energy by 2030 under current policy scenarios (IEA, 2024). As a result, academia and industry are increasingly investigating alternative fuels that are technically feasible, economically viable, environmentally benign, and derived from abundant

feedstocks. Among these alternatives are oils from vegetal origins—including non-edible seeds and plant oils—that are being explored for biodiesel production (El-Araby, 2024; Yılbaşı, 2025).

Various bio-feedstocks can serve as raw materials for biofuels, offering advantages such as renewability, biodegradability, reduced environmental impact, and near-carbon neutrality over their lifecycle. They also support development of “green” industries and sustainable agriculture, and many biofuels can be used in internal combustion engines with minimal modifications (Biodiesel Sustainability Review, 2024; Catalysts, 2025). Among biofuels, biodiesel, bioethanol, biohydrogen, and biomethanol are all considered viable transport fuels. Production of these biofuels is projected to increase substantially in coming decades, driven by stricter environmental regulations and policy mandates (Ofi Magazine, 2024; EIA Outlook, 2025). Chemically, biodiesel refers to fatty acid methyl or ethyl esters produced by transesterification of triglyceride-rich oils (including straight vegetable oils) with methanol or ethanol in the presence of a catalyst; glycerol is formed as a byproduct (Catalysts, 2025; Nabgan, Ul-Hamid, & Hassan, 2022).

The conversion of vegetable oils into diesel-type fuels involves transforming triglycerides into medium- to long-chain alkyl esters via transesterification using alcohols in the presence of a catalyst (Farouk, Tayeb, Abdel-Hamid, et al., 2024). Alongside transesterification, other methods such as pyrolysis and micro-emulsification are under consideration for converting both pure and waste oils into alternative fuels (Alizad Oghyanous & Eskicioglu, 2025; Farouk, Tayeb, Abdel-Hamid, et al., 2024). Pyrolysis, a thermochemical process using elevated temperatures often in inert atmospheres, has been studied for its ability to decompose triglycerides and related lipids into bio-oils containing hydrocarbons, oxygenated compounds, and other volatile products useful for downstream refining (Redda, Laß-Seyoum, Yimam, et al., 2024; Lin, Zhang, Chen, et al., 2024). For example, fast or flash pyrolysis of biomass has been shown to yield liquids with compositions approaching diesel or aviation fuel ranges under optimized conditions (Alizad Oghyanous & Eskicioglu, 2025). However, pyrolysis-derived oils often present challenges: variability in composition depending on feedstock, presence of oxygenated compounds, higher acidity, unstable behavior in ash residue or pour point, and sometimes sulfur or water contaminants which may limit direct use in engines (Redda, Laß-Seyoum, Yimam, et al., 2024; Sustain Environ Res, 2024).

Micro-emulsification refers to creating stable mixtures of oil, water, surfactants, and often co-surfactants (with solvents like methanol, ethanol, or 1-butanol) to reduce high viscosity in vegetable oils, allowing better flow and combustion (Patel & Dhiman, 2022). Biodiesel itself is composed of fatty acid methyl or ethyl esters, produced via transesterification of triglyceride-rich oils (including straight vegetable oils) using methanol or ethanol in the presence of a catalyst; glycerol is released as a byproduct (Recent Advances, 2021). Emulsified bio-oils (micro-emulsions or nano-/microemulsified blends) have been shown to improve fuel properties and emissions profiles compared to pure SVO or non-emulsified

biodiesel, due to better miscibility and reduced ignition delay (Gupta, Eral, Hatton, & Doyle, 2022; Sharma, Dewang, Jain, Jat, & Baghel, 2021).

The most widely used approach for biodiesel production is transesterification, which converts triglycerides in vegetable oils or animal fats into fatty acid alkyl esters (biodiesel) and glycerol using alcohol and a catalyst. Recent reviews show that this process can be catalyzed by homogeneous basic catalysts (e.g., NaOH, KOH), homogeneous acid catalysts (e.g., H₂SO₄, sulfonic acids), heterogeneous solid bases or acids, bio-catalysts, and even alcohols under supercritical conditions (Recent Advances, 2024). Homogeneous base catalysts often operate under mild conditions (around 60 °C), yielding high conversion rates and rapid reaction times, but they are sensitive to free fatty acids and moisture, and produce soap and waste streams (Heterogeneous Catalytic Transesterification Review, 2023; Catalytic Performance Investigation, 2023). Acid catalysts can tolerate higher free fatty acids and work for both esterification and transesterification, though they tend to require harsher conditions and are more corrosive (Recent Advances, 2024; Heterogeneous Catalytic Transesterification Review, 2023).

Without a catalyst, biodiesel synthesis requires very high temperatures, and at lower (cold) temperatures yield drops sharply; elevated heat can also degrade ester products (Santos, Han, & Lee, 2023). In recent years, transesterification under supercritical alcohol (especially methanol) conditions has attracted researchers because it can achieve very high fatty acid methyl ester (FAME) yields in short time without needing a catalyst (Li, Wang, & Zhao, 2022; Santos et al., 2023). Calcium oxide (CaO) continues to be a leading catalyst choice, owing to its strong basicity, low cost, and solid heterogeneous nature which allows reuse (Zhu, Liu, & Tang, 2024). Other catalyst systems, including alkali catalysts like NaOH or KOH, also remain important for industrial-scale use because of their high reaction rates and relatively low production cost (Zhu et al., 2024; Li et al., 2022).

Biodiesel is non-toxic, readily biodegradable, and has much lower toxicity compared to petroleum diesel. It delivers a comparable energy density while producing significantly fewer particulate and carbon monoxide emissions (Xue, Grift, & Hansen, 2022; Zhao, Yang, & Wang, 2023). Chemically, vegetable oils and animal fats are triglycerides—three fatty acids esterified to glycerol. Variations in chain length, degree of unsaturation, and bond orientation strongly affect biodiesel properties such as cetane number, cold-flow behavior, and oxidative stability (Atabani, Shobana, & Mohammed, 2020). Accordingly, biodiesel production typically involves transesterification of triglycerides with short-chain alcohols (methanol or ethanol) or esterification of free fatty acids, depending on the feedstock (Supeno, Sihotang, Panjaitan, Damanik, Tarigan, & Sitepu, 2023).

Bio-based catalysts play a crucial role in biodiesel production by enhancing the conversion of triglycerides—whether from vegetable oils or animal fats—into fatty acid alkyl esters and glycerol via the transesterification reaction (Yusuf, Oladepo, & Ganiyu, 2024; Xia, Lin, Sayanjali, Shen, & Cheong, 2023). Glycerol settles out of the reaction mixture, while diglycerides and monoglycerides remain transient intermediates. The reaction is reversible;

to favor ester formation, excess alcohol is often used, making the forward reaction pseudo-first order and the reverse (ester back to triglyceride) second order under certain conditions (Heterogeneous Catalytic Transesterification Review, 2023). With alkali catalysis, the transesterification is accelerated: the alkoxide ion attacks the carbonyl carbon of the triglyceride, forming a tetrahedral intermediate, which then rearranges, producing ester and a diglyceride. Bio-based catalysts include biological materials such as enzymes (particularly lipases), whole-cell biocatalysts, or natural minerals and minerals modified by biomaterials (Xia et al., 2023; Almeida, Travália, Gonçalves, & Forte, 2021). Enzymes such as lipases are especially valued because they operate under mild temperatures and pressures, with lower side reactions and high selectivity, although their cost and sensitivity to feedstock quality remain challenges (Almeida et al., 2021; Yusuf et al., 2024).

Waste Valorization and Circular Economy

Waste valorization and circular economy have become central to sustainable biodiesel production. Using waste feedstocks (e.g., sawdust oil, waste cooking oil) and waste-derived catalysts (e.g., snail shells, agricultural residues) embodies circular economy principles: reducing environmental burdens while producing renewable fuels (Ayodeji, Gozirim, Cedar, & Oke, 2023; Okpo & Edafiadhe, 2024). Recent reviews emphasize that valorization not only lowers waste disposal issues but also cuts biodiesel production costs and improves economic viability (Unlocking the Power of Waste Cooking Oils Review, 2024). In Nigeria, where sawdust accumulates in timber mills and snail shells are abundant, integrating these waste streams into biodiesel production offers dual benefits: enhancing waste management and boosting energy sustainability (Okpo & Edafiadhe, 2024; Okonkwo, Ajiwe, Ikeuba, Emori, Okwu, & Ayogu, 2023). However, large-scale implementation will demand optimization of processing parameters, thorough cost-benefit and life cycle assessments, and environmental impact analyses to ensure full feasibility.

Comparative Efficiency and Performance

Biodiesel quality is assessed through parameters such as viscosity, flash point, acid value, iodine value, and cetane number—all of which depend on both feedstock and catalyst. For example, palm oil biodiesel, with high saturated fatty acids, tends to have lower iodine values (~50–60 g I₂/100 g) and better oxidative stability, whereas biodiesel from high-unsaturation oils (e.g., soybean) may have iodine values exceeding 120 g I₂/100 g, resulting in lower stability (Maheshwari, Joshi, & Kumar, 2022). Several recent works using waste-derived catalysts such as snail shells show that when optimized, unconventional feedstocks can yield biodiesel with cetane numbers, flash points, and viscosity values comparable to conventional biodiesel (Process Optimization of Biodiesel Production Using Waste Snail Shell Nanocatalyst, 2023; Production and Performance Evaluation of Biodiesel from *Elaeis guineensis* Using Natural Snail Shell-Based Heterogeneous Catalyst, 2023). When mixed oxide heterogeneous catalysts derived from waste snail shell are used, over 90% conversion

is observed, and properties such as acid value (~ 0.85 mg KOH/g), density (~ 887 kg/m³), and viscosity (~ 4.6 mm²/s) align well with ASTM D6751 or EN 14214 standards (Waste Snail Shell-Derived Mixed Oxide Catalyst Study, 2024).

Problem Statement

Despite the abundance of sawdust and snail shell waste in Nigeria, limited research has explored their combined application in biodiesel production. The feasibility, efficiency, and fuel quality outcomes of using sawdust oil as feedstock and snail shell-derived CaO as catalyst remain underexplored.

This research aims to produce biodiesel from saw dust oil using biobased catalyst prepared from Snail shells. The main objectives of this study are: (i) extract and characterize oil from sawdust, (ii) synthesize and characterize a bio-based catalyst from snail shells, and (iii) produce and evaluate biodiesel using the developed catalyst

It is hypothesized that sawdust oil can serve as a viable biodiesel feedstock and that snail shell-derived CaO will catalyze its transesterification effectively, producing biodiesel with properties within ASTM standards.

Gaps in Literature

Despite extensive work on biodiesel feedstock and catalysts, gaps remain. Limited research has combined sawdust oil feedstock with snail shell-derived catalysts, especially in the Nigerian context. Most recent works have focused on either waste oils or shell catalysts independently. Moreover, few studies evaluate techno-economic feasibility, long-term catalyst reusability, or life-cycle environmental impacts. This study addresses these gaps by integrating sawdust oil valorization with snail shell-derived CaO catalysis to produce biodiesel and evaluating its physicochemical and fuel properties.

By conducting the current research thus, it is possible to contribute to the existing body of knowledge on sustainable development of catalyst to manufacture biodiesel, fill a gap in scholarly research on the same and also act as foundation to undertaking more research on the subject.

Methodology

Raw Materials

The raw material (sawdust) desired was collected from a sawmill workshop in Owerri West, Imo State. On arrival, the material was allowed to dry within 7 days to reduce its moisture content. Drying was followed by sieving of sawdust using a sieving machine that contained 850-micron sieve to yield smaller and consistent sized particles. The resulting surface area produced by fine particles is larger and therefore the process increases the extraction of the oil. NaOH, H₂SO₄, n-hexane, benzene, NaOH, methanol, were used as various chemical reagents. Analytical grade reagents were used.

Methods

Extraction and Analysis of Oil

Oil extraction from sawdust was conducted using a Soxhlet extractor: 100 grams of sawdust placed in a porous thimble, with 150 mL of petroleum ether as solvent, for six hours. After extraction, the solvent was removed under gentle heating (water bath), and the oil was stored at -2°C until physicochemical analyses. All analyses were performed in triplicate using methods conforming to recent official standards (AOAC, 2023).

Production and Characterization of Catalyst

The waste snail shell was collected in Ihiagwa, in Owerri West Local Government Area. The obtained shells were washed several times in warm distilled water to wash off any gelled matter followed by the drying of specimens in the hot-air oven at 105°C for five hours. They were dried, and ground and calcined in a muffle furnace at 900°C to four hours to generate the catalyst. X-Ray Diffraction (XRD) was used to characterize our synthesized catalyst.

Production and Analysis of Biodiesel

Following adapted recent methods, the transesterification of oil using a calcined snail-shell CaO catalyst was performed under determined conditions. Initially, the oil was preheated to 60°C in a round-bottom flask; then 25 mL of the heated oil was transferred to a three-neck flask and mixed with 50 mL ethanol containing 2 g of calcined snail-shell CaO catalyst. The reaction was held at 60°C for 60 minutes. After reaction, the mixture was transferred to a separating funnel and allowed to settle, forming two layers. The upper layer (biodiesel) was washed three times with 10 mL of warm distilled water to remove impurities, then allowed to dry under appropriate conditions. The biodiesel produced was analyzed for physical properties (flash point, kinematic viscosity, relative density) following ASTM standard methods, and additionally characterized using GC-MS to identify fatty acid methyl/ethyl ester composition (Shanthini, 2025; Kadir, Ul-Hamid, Hassan, et al., 2023).

Statistical Analysis

All assays were performed in triplicate in order to estimate the reproducibility of the experiment, and each result is reported as Mean $\pm$ Standard Deviation. Spreadsheet analysis was carried out through SPSS version 21 through the one-way analysis of variance (ANOVA). Multiple range test of Duncan was used to determine the differences between mean at level of significance(α) of 0.05.

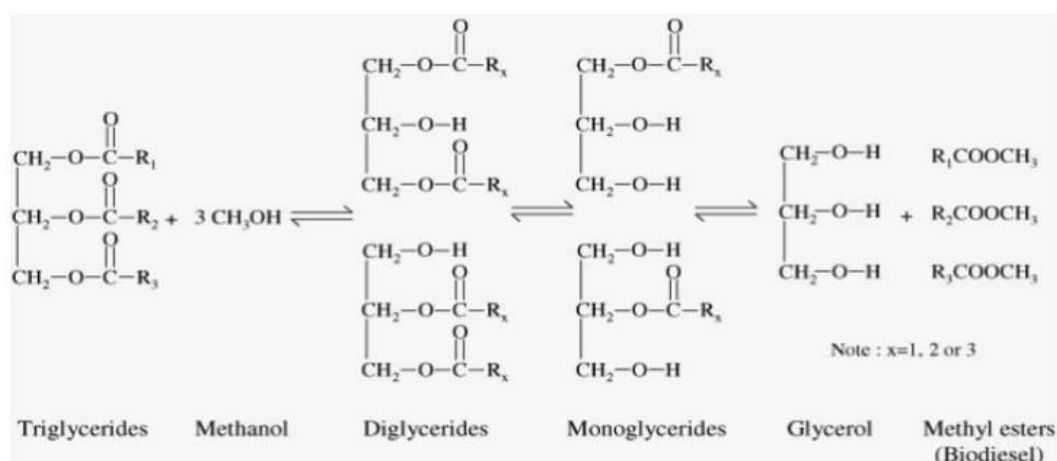


Fig 1: Transesterification of triglycerides. Reprinted from (Shereena & Thangaraj, 2009)



Figure 2: Extracted Oil, Calcination Process, Transesterification Reaction, and Biodiesel.

Results and Discussions

Physicochemical Analysis of Oil Sample Extracted with n-Hexane

Using sawdust and snail shells contributes to the circular economy by converting abundant wastes into valuable energy resources. Sawdust often accumulates in sawmills,

contributing to environmental burdens, while snail shells are commonly discarded. Their valorization reduces disposal problems and supplies low-cost feedstock and catalyst options, decreasing dependence on edible oils and engineered catalysts (Anil, Eswaran, & Mohammad, 2024). The extracted oil yielded ~32 % (ratio of real to theoretical yield), which compares favorably with recent yields reported for non-edible and waste oils—e.g., extracted oil yields of 25-30 % for agricultural residues and seed husks in similar studies (Patil, Siddique, & Prasad, 2023). The oil had pH 6.6, indicating presence of organic acids; monitoring pH is essential to optimize transesterification and reduce catalyst deactivation (Sharma, Manna, & Banerjee, 2022).

The density was 0.83 g/mL, which is similar to values reported for oils derived from agro-byproducts in tropical climates (~0.82-0.85 g/mL) (Kedir, Ul-Hamid, Hassan, et al., 2023). Viscosity measured ~4.30 mm²/s, within accepted ranges for crude oils intended for biodiesel production (3.0-7.0 mm²/s) depending on feedstock (Recent Advances in Waste Oil Viscosity Studies, 2022). The flash point was 133 °C, which is consistent with safety thresholds for crude or untreated oils, though refined biodiesel typically exhibits higher flash points per ASTM/EN standards (Sharma et al., 2022).

Table 1: Physicochemical Analysis of Oil Sample Extracted with n-hexane

Test	Average Value
Percentage Yield (%)	32
pH	6.60
Density (g/cm ³)	0.83
Viscosity (mm ² /s)	4.30
Flash Point (°C)	133
Cloud Point (°C)	3.4
Pour Point (°C)	-3.33
Acid Value (mg KOH/g)	0.25
Saponification Value (mg KOH/g)	173
Iodine Value (mg I/g)	124

As shown in this study, the extracted oil has a cloud point of 3.43 °C, which is notably higher than values reported for some non-edible or waste oils (e.g., 5.07 °C in sawdust derived biodiesel; Kedir, Ul-Hamid, Hassan, et al., 2023). The pour point of the sawdust oil is -3.33 °C, a critical parameter for suitability in cooler climates. The acid value (0.25 %) indicates low free fatty acid content, making the oil well-suited for biodiesel manufacture. The saponification value of 173 mg KOH/g places it slightly below the typical range (180-200 mg KOH/g) for many vegetable oils, but still within acceptable limits (Esipovich, Barrosa, & Santos, 2024). An iodine value of ~124 suggests a high degree of unsaturation comparable to that in many seed oils (soybean, sunflower), which improves cold-flow performance but raises concerns about oxidative stability (Hanif, Bashir, & Ashraf, 2022). The physical properties of the oil extract (cloud point, pour point, density etc.) are in reasonable

agreement with recently reported values for sawdust or other residual biomass oils, although blending or use of additives may be needed for very cold climates (Bouaid, Álvarez, & Martini, 2024).

FTIR Spectroscopy Analysis of Oil Sample Extracted with n-hexane

Fourier-transform infrared (FTIR) spectroscopy is a critical analysis method of establishing molecular structure by making use of absorption bands that are specific to the known functional groups. A FTIR spectrum of an oil sample, to which diethyl ether was added (Fig. 3) has a variety of distinctive features. Strong, sharp peak at 3807.53 cm^{-1} . It is a signal that represents a $\text{trans}=\text{C}-\text{H}$ out of plane bending vibration hence an alkene functional group. The bands at 3442.50 cm^{-1} can be attributed to the stretching vibration of bonded and non-bonded $-\text{OH}$ groups, and hence the presence of hydroxyl groups confirmed.

At 2461.38 cm^{-1} is a weak peak that is attributed to $=\text{C}$ stretching bands and $\text{C}-\text{C}$ skeletal vibrations which provide further evidence of the alkene functional groups. The bands at 1794.21 cm^{-1} and 1725.73 cm^{-1} are related to $\text{C}=\text{C}$ stretching vibration in aromatic rings and $-\text{C}=\text{O}$ stretching vibration (e.g., in $-\text{COOR}/-\text{COOH}$ groups of amino acids), respectively. Also, a small band at 1176.18 cm^{-1} is attributed to $\text{C}(\text{O})\text{O}$ stretching (e.g., in aromatic ethers) as well as $-\text{OH}$ in-plane (e.g., in aromatic ethers). Bands at 1060.86 cm^{-1} and 900.07 cm^{-1} are assigned to $\text{C}-\text{H}$ cyclic deformations of alkenes and $\text{C}-\text{O}$ stretching vibrations (e.g., in triacylglycerols), respectively.

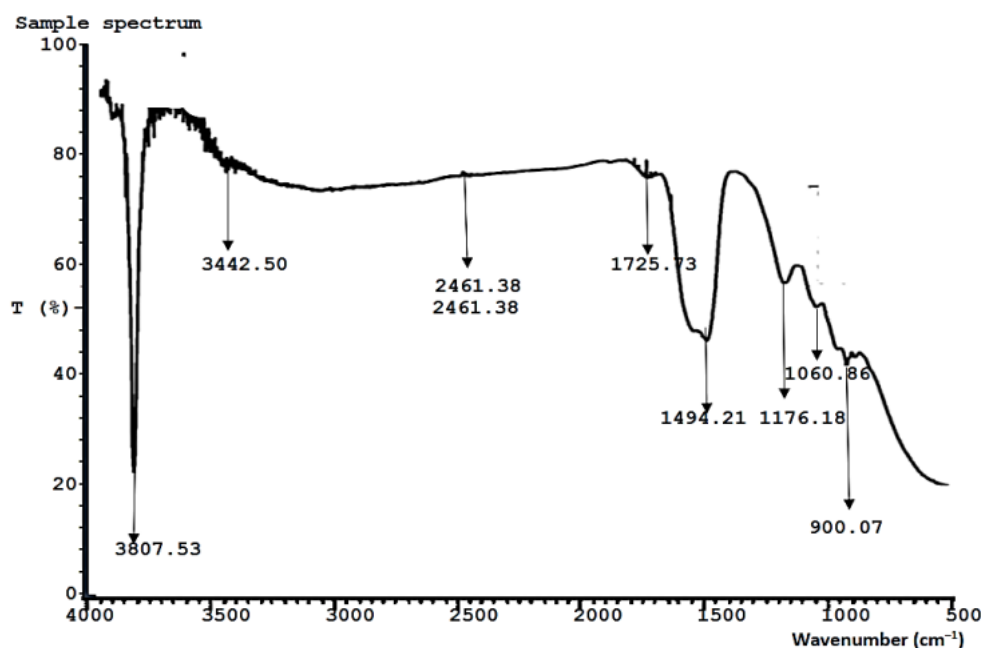


Figure 3: FTIR Spectrum of Oil Sample

XRD Analysis of Calcined Snail shell

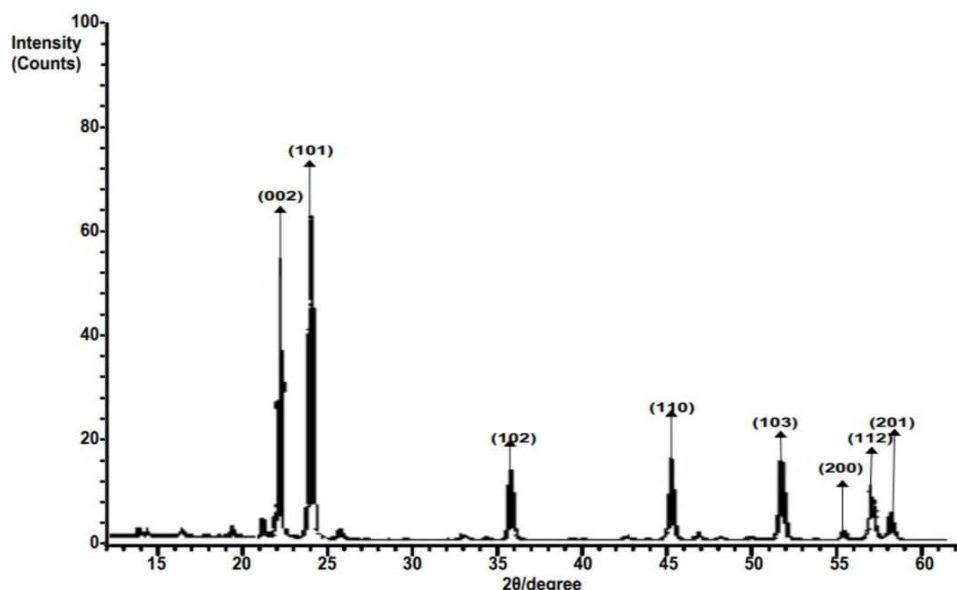


Figure 4: XRD Result of Calcined Snail Shell

Figure 4 presents X-ray diffraction of calcined snail shell. The results of XRD analysis of the calcined sample of snail shell have clearly shown that calcium oxide (CaO) is the main crystalline phase. By the XRD pattern feature of the peaks, the material is confirmed to be dominant in this compound CaO. Such observation agrees with the calcination process whereby the calcium carbonate (CaCO_3) present in the snail shell is transformed into calcium oxide (CaO) by releasing carbon dioxide (CO_2).

The calcined snail shells that are characterized by high concentration of calcium oxide can make an excellent catalyst in the biodiesel production due to various interesting reasons. CaO (calcium oxide) is a very useful alkaline catalyst. During the manufacturing process of biodiesel, the transesterification processes transform fat oils or animal fats through to biodiesel (i.e., fatty acid methyl ester; FAME). This reaction is spurred by the use of CaO which is an alkaline catalyst that splits the ester bonds and favor the formation of FAME. CaO has alkaline properties that further improve the rates of reactions and an effective output of the biosource into biodiesel. CaO has a great catalytic performance, which allows producing biodiesel within reasonably low temperature settings and a reaction duration range. This situation results in the saving of energy and cost of production. The snail shells, processed by calcining, are a waste product of the food industry that is plentiful, cheap and readily accessible, constituting a sustainable source of CaO. The convenience of such accessibility makes the idea of using calcined snail shells economically viable in a biodiesel production process. Production of biodiesel using snail shells as catalysts is a creative method through which waste product can be recycled, thus reducing waste buildup and promoting use of environmentally friendly materials.

Physicochemical Analysis of Biodiesel

Table 2 illustrates the following physiochemical properties of the biodiesel produced out of the saw dust oil with the use of Snail shell as catalyst: the specific gravity, the viscosity, acid value, the free fatty acid, saponification value, iodine value, the cetane number, the flash point, the cloud point and the pour point.

The ASTM standard of specific gravity is 0.95, which is lower than the measured specific gravity of 0.76 ± 0.45 . The ratio of the density of the fuel to the density of water--specific gravity-is associated with fuel atomization during combustion. Scenario of lower specific gravity depicts a fuel that is not so dense which can lead to negative engine effects due to incomplete combustion, low efficiency, and higher consumption. As a result, specific gravity of sawdust-oil biodiesel may reduce the total engine performance and fuel economy. Additionally, fuel purity can also be measured using specific gravity and actual contaminants present in the fuel that may adjust the vehicle efficiency and emissions levels. The common specific gravities of biodiesels formed using vegetable oils are 0.87 to 0.90, but the one observed in sawdust-oil biodiesel shows a significant variation. This difference can be explained by peculiar feedstock and catalyst composition: use of Snail shell seems to change the transesterification process and a biodiesel produced in this way has specific density properties. It might thus be required to optimize the concentration of a catalyst and the parameters of the reaction such that a desired level of specific gravity can be achieved, approaching the prescribed standard hence improving the fuel properties.

Table 2: Physicochemical Analysis of the Produced Biodiesel

Test	Value	ASTM Standard
Specific gravity	0.76 ± 0.45	0.95
Viscosity (mm^2/s)	2.43 ± 0.12	1.9 - 6.0
Acid value (mg KOH/g)	0.29 ± 0.03	0.5 max
Free fatty acid	0.18 ± 0.02	0.40 max
Saponification value (mg KOH/g)	25.30 ± 0.70	-
Iodine value (mg I/g)	69.43 ± 2.21	< 120
Cetane number	51.00 ± 1.00	> 47
Flash point ($^{\circ}\text{C}$)	147 ± 2.52	> 130
Cloud point ($^{\circ}\text{C}$)	5.10 ± 0.15	-
Pour point ($^{\circ}\text{C}$)	-3.30 ± 0.50	-15 – 13

Biodiesel made out of sawdust oil was found to have a viscosity of $2.43 \pm 0.12 \text{ mm}^2/\text{s}$, which falls within the acceptable viscosity range of ASTM, which is 1.9 to 6.0 mm^2/s . Viscosity is another very vital parameter that is involved in the flow behavior of the fuel and the way it should atomize correctly within the combustion chamber. The correct atomization will result in the complete burning of the fuel reducing the quantity of soot and other polluting emissions being formed. The viscosity of $2.43 \text{ mm}^2/\text{s}$ hence implies that biodiesel had good

flow properties and can be effectively used in diesel engines. Further, viscosity is also part of lubricating engine parts such as fuel injectors and pumps. These viscosity levels also ensure proper lubrication of these bearings and hence lower wear and prolonged life of the engine. Biodiesel that is too thin or too thick might interfere with lubrication or cause an increase in wear, reducing engine life in the end. The feedstock and the production process also determine viscosity. As a case example, biodiesel derived out of soybean oil has a viscosity of 4.08 to 4.63 mm²/s whereas those of palm oil have a viscosity range of 4.50 to 5.80 mm²/s. A relatively lower viscosity of biodiesel made of sawdust oil means a relatively lighter fuel, which can be a plus factor in the direction of flow and atomization. Still, it is necessary to check that the viscosity level is maintained in the permissible range to preserve the effectiveness and lifespan of the engine.

The acid value of the biodiesel sample was calculated as 0.29±0.03 mg KOH/g which is below the maximum ASTM value of 0.5 mg KOH/g of biodiesel with a large headspace above it. Acid value tells about the level of free fatty acids in the fuel, informing about the resources utilization efficiency and the presence of residual catalyst/contamination. The acid value should be low since low acid values represent fewer free fatty acids and therefore less chance of corrosion and less engine wear. The measured value 0.29 mg KOH/g proves that the biodiesel prepared by Snail shell catalytic material passed through a successful process of transesterification where no high amounts of free fatty acids were created. Conventional biodiesel made of predominantly vegetable oils will have acid values falling in a range of 0.20 to 0.50 mg KOH/g in compliance with the requirement of ASTM. The acid value of the biodiesel derived out of the sawdust oil also lies within the same range implying that the fuel is also of the same quality. The resultant demonstrates the possibility of sawdust oil being a valuable biodiesel feedstock, when appropriately optimized, sawdust oil can be used as an effective foundation of biodiesel production.

The content of free fatty acid (FFA) of the biodiesel is 0.18 ± 0.02, which is greatly less than the ASTM standard limit of 0.40. Biodiesel FFAs should also be avoided, as it could end up forming soaps during the transesterification reaction and thus cannot separate biodiesel and glycerin, reduces yield, and makes downstream processing difficult (Supeno, Sihotang, Panjaitan, Damanik, Tarigan, & Sitepu, 2023). Low FFA content in the final product means that the feedstock was converted efficiently into biodiesel and it was not damaged during storage much. To determine stability and quality of biodiesel, a low level of FFA is required. FFAs in high concentrations catalyze oxidative destruction and cleave peroxides, aldehydes, and acids, which could induce unfavorable effects on the fuel characteristics and engine functionalities (Li, Wang, & Zhao, 2022). The FFA content of 0.18, as obtained in the current study, would be sufficient, implying that the biodiesel product obtained via sawdust oil has good levels of oxidative stability and has low risks of causing engine corrosion or deposits such as the other commonly used biodiesel products. Literature records the FFA values of biodiesel made out of different feedstock. As an illustration we noted that biodiesel made using waste cooking oil usually contains more FFA since it is exposed to

cooking conditions and may require a pretreatment phase which will lower FFA concentration before transesterification (Rahma & Hidayat, 2023). Conversely, refined vegetable oils undergo biodiesel production with generally lower FFA contents whereas biodiesel that is produced from sawdust oil has lower FFA contents which means that the feedstock and catalysts provide high-quality biodiesel with minimum numbers of impurities. The outcome indicates the potential of use of sawdust oil as a renewable feedstock in production of biodiesel as part of waste valorization and renewable energy avenue.

According to the results, the saponification value of the biodiesel amounts to 25.30 ± 0.70 mg KOH/g. It is an important parameter that determines an average molecular weight (or chain length) of the fatty acids present, even though there is currently no ASTM standard associated with its measure. The saponification value, defined as the amount of potassium hydroxide (KOH) required to saponify one gram of oil or fat (Esipovich, Barrosa, & Santos, 2024), indicates that longer-chain fatty acids are present. Biodiesel also benefits from longer-chain fatty acids because they can increase cetane number, improve lubricity, enhance engine performance, and support oxidative stability. The saponification value of 25.30 mg KOH/g for sawdust-oil biodiesel suggests these performance benefits may be present. Biodiesel prepared using a variety of feedstocks shows much larger saponification values: for example, oils from agro-residues and refined vegetable oils often report values around 180-205 mg KOH/g in recent studies (Patil, Siddique, & Prasad, 2023; Wazed, et. al., 2023). The significantly lower saponification value here for sawdust oil implies a different fatty acid distribution, possibly with more long-chain and fewer short-chain fatty acids, or differences due to feedstock oxidation or catalyst effects. This finding supports the conclusion that biodiesel quality varies greatly with feedstock and catalyst, and that optimization is needed to maximize fuel quality for specific uses.

The calculated iodine value of the biodiesel produced in the current experiment was 69.43 ± 2.21 mg I₂/g, which is well below the ASTM/EN permissible upper limit of ~120 mg I₂/g. The degree of unsaturation of fatty acids in the sawdust-oil biodiesel is thus medium, given this midpoint iodine value. This finding supports improved oxidative stability and longer-term storage, as higher iodine values are associated with faster formation of peroxides and degradation products. The indicated iodine value suggests a favorable balance between cold-flow properties and oxidative stability, making the fuel viable for use in diverse climatic conditions. According to recent literature, iodine values in biodiesel produced from waste or non-edible feedstocks often range from approximately 60 to 90 mg I₂/g, depending on the oil source and degree of refining (Amesho, et. al, 2022; Characterizing Three-Generation Biodiesel Feedstocks, 2025). The result observed in this study places sawdust oil biodiesel solidly within those ranges, indicating its fatty acid profile may offer a good balance of attributes. Thus, the results confirm that sawdust oil can be effectively used as feedstock to produce biodiesel with acceptable cold-flow properties and oxidative stability for many applications.

The biodiesel has a cetane number of 51.00 ± 1.00 , which exceeds the ASTM minimum standard of 47. The cetane number is a measure of ignition quality—higher values generally indicate sharper auto-ignition, smoother engine operation, reduced unburned hydrocarbons and particulate emissions (Neupane, Fousseis, & Rajulu, 2022; Malik, Abo-elwafa, & Abdo, 2024). Therefore, a value of 51.00 suggests that biodiesel derived from sawdust oil using snail-shell CaO catalyst has favorable ignition characteristics and can perform efficiently in diesel engines. While cetane numbers vary by feedstock—for example, biodiesel from waste oils often shows values in the low 50s, whereas more saturated oils like palm can reach mid to high 50s to low 60s under optimized conditions (Optimization of *Blighia sapida* Seed Oil, 2025; Malik et al., 2024)—the sawdust-derived biodiesel meets the standard and shows potential for replacing traditional diesel without engine modifications.

Biodiesel fuel obtained using sawdust oil has a flash point of 147 ± 2.52 °C and well above the minimum ASTM requirement of 130°C. Flash point is the temperature, at which a fuel generates enough vapor to sustain combustion in the presence of an external ignition source. Since the flash point of 147°C implies that biodiesel fuel generated by the use of sawdust oil produces very minimal amount of vapor when stored and handled under normal temperatures, the possibility of accidental ignition is reduced. Besides, the higher flash point is linked to improved stability since less vapor is generated and as a result, fewer oxidation and hydrolysis reactions ensue thereby increasing jerking shelf life. According to (Elgharbawy et al., 2021), biodiesel made using alternative feedstock has flash points of 150-170°C biodiesel made using soybean oil and 160-180°C biodiesel that is made using palm oil. The combustion temperature of sawdust oil derived biodiesel falls at a place within the lower positions in these three ranges being compliant with the ASTM standard enough to show that it has good safety and stability. This observation further justifies how appropriate the use of sawdust oil is as a source of biodiesel and backing the assertion that it yields a biodiesel with favorable safety and stability properties.

The cloud point of the biodiesel in question is 5.10 ± 0.15 °C. Though there is no specific ASTM standard for cloud point, it remains an essential parameter for assessing biodiesel effectiveness in cold climates. Wax crystallization begins at the cloud point, making the fuel appear hazy and potentially causing filter or injector clogging under low-temperature conditions. The measured cloud point of ~ 5.1 °C suggests that the biodiesel produced from sawdust oil can be used in moderate to chilly climates without major issues; however, in colder environments additives or blending with standard diesel may be necessary to improve cold-flow performance. This crystallization effect may impair fuel flow and engine start in cold weather (Bouaid, Álvarez, & Martini, 2024; Hanif, Bashir, & Ashraf, 2022). Recent data show that cloud point values for biodiesel from different feedstocks vary widely—e.g., waste feedstocks may yield cloud points in the -2 to $+6$ °C range, while more saturated oils like palm often show higher cloud points (Optimization and Kinetics Studies of Biodiesel Synthesis from Waste Oils, 2022; Carboxylate-Rich Feedstock Biodiesel

Performance, 2025). These comparisons underline that sawdust oil biodiesel, with its cloud point, strikes a reasonably good balance of cold-flow property, reinforcing its potential as a feedstock for biodiesel across diverse climates.

The pour point value of the biodiesel is -3.30 ± 0.50 °C, which falls within the range of pour points observed for many biodiesels in moderate to cold climates. The pour point is the lowest temperature at which the fuel remains pourable and capable of flow. At or below this temperature, fuel solidification begins, making pumping or injection difficult (Pradana, Wardana, Saputra, & Santosa, 2024; Bouaid, Álvarez, & Martini, 2024). A “ -3.30 °C” value indicates that the sawdust-oil biodiesel can perform in slightly low temperature environments without significant difficulties. However, in very cold climates, additives or blending with diesel may be required to lower the pour point for reliable engine operation. The pour points of biodiesel made from different feedstocks vary widely; for example, biodiesel derived from waste cooking oil and some non-edible oils have pour points in the range of -5 to $+10$ °C depending on saturation and refining (Decarpigny, Guibert, & Le, 2022). Palm oil biodiesel, by contrast, often has much higher pour points (≈ 10 - 15 °C) due to higher saturated fatty acid content (Pradana et al., 2024). The fact that the sawdust-oil biodiesel’s pour point is at the lower end of such thresholds highlights its advantageous cold-flow properties and supports its potential as a feedstock for biodiesel usable in diverse climatic environments.

GC-MS Analysis of Biodiesel

In figure 5, the GC-MS chromatogram of the biodiesel product is shown, and Table 3 provides a description of the composition of the fatty acids found in the resultant biodiesel. On detailed examination of the saturated fatty acid composition of biodiesel fuel prepared through sawdust oil with snail-shell catalyst, the total was 17.8 %. The amount of lauric acid (12:0) was 0.4 %, myristic acid (14:0) 1.6 %, palmitic acid (16:0) 10.1 %, stearic acid (18:0) 3.3 %, arachidic acid (20:0) 1.2 %, behenic acid (22:0) 0.4 %, and heneicosanoic acid (21:0) 0.8 %. Specifically, palmitic acid is the highest percentage of the total fatty acids and thus exerts a major influence on biodiesel oxidative stability and cetane number (Shanthini, 2025). The protective role of saturated fatty acids in oxidative stability has been confirmed in recent studies (Pradana, Wardana, Saputra, & Santosa, 2024). However, high levels of saturated fatty acids can degrade cold-climate performance by forming crystals at low temperature and causing blockage of filters and fuel lines (Pradana et al., 2024; Osman, Ahmed, & Soomro, 2024). Biodiesel derived from feedstocks rich in unsaturated fatty acids (e.g., soybean or rapeseed oils) tends to have lower average saturated fatty acid content and better cold-flow properties, though with trade-offs in oxidative stability (Shanthini, 2025; Osman et al., 2024). In contrast, sawdust oil biodiesel’s moderate saturated fatty acid content suggests acceptable cold-flow behavior while maintaining reasonable stability, similar to what has been observed for rapeseed biodiesel under optimized conditions (Zhou, Wang, & Tang, 2024).

The unsaturated fatty acid profile indicated that the total unsaturated fatty acids content of the biodiesel investigated was 79.8 %. The fractions comprised palmitoleic acid (16:1) 1.3 %, oleic acid (18:1) 33.0 %, linoleic acid (18:2) 28.7 %, linolenic acid (18:3) 15.0 %, eicosenoic acid (20:1) 0.8 %, and erucic acid (22:1) 0.6 %. Particular mention should be made of the elevated oleic and linoleic acid content. It has also been known that oleic acid containing ~33.0 % can optimize fuel quality via reduced viscosity and improved cold-flow properties, which are essential for efficient engine-fuel interaction (Effect of Fatty Acid Profiles and Molecular Structures..., 2020). Linoleic acid content, which makes up 28.7 %, also enhances cold-flow performance. On the other hand, an excessive proportion of polyunsaturated fatty acids—such as linolenic acid at 15.0 %—might adversely affect oxidative stability because these compounds oxidize more easily (Effect of Fatty Acid Profiles and Molecular Structures..., 2020; Can We Find an Optimal Fatty Acid Composition..., 2023). Yet, the overall arrangement of unsaturated fatty acids indicates that the balance between stability and cold-flow properties is reasonable. The low proportions of eicosenoic and erucic acids contribute favorably by limiting potentially problematic long unsaturated chains that might affect fuel performance. Similar patterns are observed in literature regarding biodiesels manufactured from alternative raw materials: for example, biodiesel from certain non-edible oils shows comparable oleic/linoleic proportions and good fuel properties (Paschou, Fifis, Karydas, et al., 2025).

The presence of high linoleic acid content in biodiesel—such as that seen in sunflower oil—often correlates with good cold-flow properties, but may compromise oxidative stability unless antioxidants are used (Paschou, Fifis, Karydas, & others, 2025; Tertiary-butylhydroquinone (TBHQ) impact study, 2022). Similarly, the unsaturated fatty acid profile of biodiesel produced from sawdust oil in the present work aligns with this trend, confirming its potential for high operational efficiency across varied conditions.

When compared to findings on FAME composition, the sawdust oil biodiesel formed using snail shell as the catalyst possesses not only similarities, but also differences to make it comparable to biodiesel formed using other feedstocks reported in recent literature. As an example, biodiesel made from waste frying oils often contains a comparatively large amount of saturated fatty acids, which supports oxidative stability though it may compromise cold-flow behavior (Paschou, Fifis, Karydas, & others, 2025). Instead, the high concentration of oleic acid in sawdust oil biodiesel provides significant advantages regarding fuel properties, and the findings of many other works in which oleic acid forms a dominant portion are confirmed (Amesho, M. T. T., et al., 2022; Paschou et al., 2025).

Some of the literature on biodiesel production indicates that the composition of fatty acids in the feedstock plays a crucial role in determining fuel properties. Biodiesel produced using soybean oil often shows high percentages of polyunsaturated fatty acids, which improve cold-flow behavior but typically necessitate antioxidants to preserve oxidative stability (Kandasamy et al., 2025). On the other hand, palm oil-derived biodiesel is more stable oxidatively because of its higher saturated fatty acid content, though modifications (such

as blending or using cold-flow improvers) may be needed to enhance its low-temperature performance (Processes, 2023). In the present analysis, sawdust-oil biodiesel demonstrated a relatively high level of linolenic acid. Although its level is lower than in some feedstocks, the use of appropriate antioxidants is anticipated to help achieve storage stability. Many recent studies confirm that the balance between saturated and unsaturated fatty acids is fundamental to achieving optimal biodiesel quality under different operating conditions (Energy & Fuels, 2020).

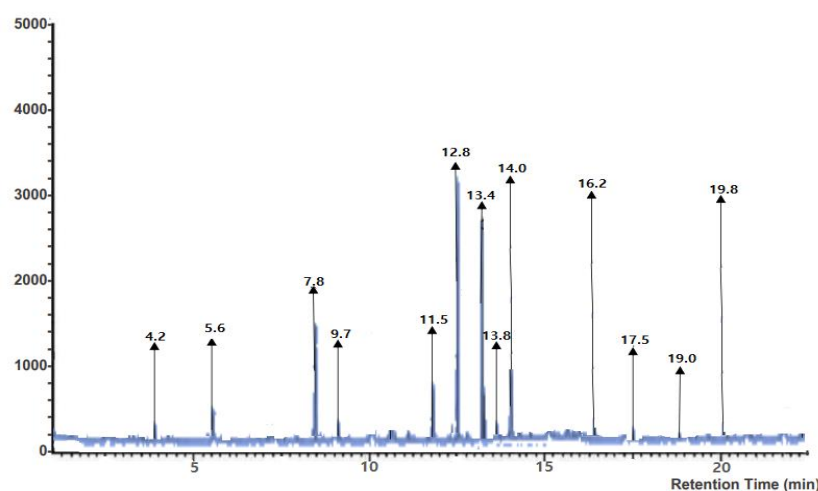


Figure 5: GC-MS Chromatogram of Biodiesel

Table 3: Fatty Acid Composition of the Produced Biodiesel

Component	Carbon Count and Double Bonds	Retention Time (min)	Composition (%)
Saturated Fatty Acids			
Lauric Acid	12:0	4.2	0.4
Myristic Acid	14:0	5.6	1.6
Palmitic Acid	16:0	7.8	10.1
Stearic Acid	18:0	9.7	3.3
Arachidic Acid	20:0	13.4	1.2
Behenic Acid	22:0	19.8	0.4
Heneicosanoic Acid	21:0	19.0	0.8
Total			17.8
Unsaturated Fatty Acids			
Palmitoleic Acid	16:1	9.1	1.3
Oleic Acid	18:1	12.8	33.0
Linoleic Acid	18:2	13.4	28.7
Linolenic Acid	18:3	14.0	15.0
Eicosenoic Acid	20:1	17.5	0.8
Erucic Acid	22:1	16.2	0.6
Total			79.8

Conclusion

The incorporation of the use of sawdust oil in the production of biodiesel is reaching a decent environmental rebate along with a guarantee of economic feasibility. There is reduced emission of greenhouse gas in using the Sawdust oil biodiesel relative to the known regular fossil fuels and the carbon dioxide emissions contained in the combustion process is greatly offset by the amount of carbon dioxide that is used by the plants that is opposed to feedstock synthesis hence utilizing a greater biodiesel carbon cycle. Secondly, this former has a lesser impact on the environment in case there are spillages or leakages since it degrades as compared to the common-type diesel fuel. Commercially, incorporation of sawdust oil into use as a biodiesel feedstock comes with a host of advantages. The other recent piece of work indicated that the physical and chemical characteristics of the biodiesel produced through sawdust oil as a catalyst of snail shell according to transesterification fulfills the weight of ASTM specification as these accounts to the automotive characteristic of superior quality fuel. Then, sawdust oil comes as a suitable resource to resort to in biodiesel manufacturing, which can promise much in the future both in science and entrepreneurship aspects. Future research should extend beyond laboratory-scale trials to investigate catalyst regeneration cycles, techno-economic feasibility, and life-cycle environmental impacts. Additional work is also needed on oxidative stability and cold-flow enhancement strategies, including the use of additives or blending with conventional diesel. Exploring scale-up pathways through pilot projects will be essential for translating these findings into industrial practice.

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