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Review

Study on the potential of used cooking oil and microalgae as biodiesel raw materials in Indonesia

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Abstract

The increase in cooking oil consumption in Indonesia has an impact on the high volume of used cooking oil waste which has the potential to pollute the environment as well as become an alternative source of energy. On the other hand, the development of microalgae as raw materials for third-generation biodiesel offers high lipid productivity without disrupting food sovereignty. This review article aims to map the potential of used cooking oil and microalgae as raw materials for biodiesel through a critical evaluation of the stages of conversion technology and its management strategy in Indonesia. The method used was a systematic review of several international literature in the last 5 years. The results of the analysis show that the key to the success of used cooking oil conversion lies in the efficiency of the pre-treatment stage and acid esterification to suppress the level of free fatty acids (FFA) to below 2% to avoid saponification. Meanwhile, the utilization of microalgae requires the integration of more modern lipid extraction technology to achieve optimal yields. The use of the latest innovations such as ultrasonic cavitation and magnetic nano catalysts has been proven to be able to increase biodiesel yield by up to 95% with a shorter reaction time compared to conventional methods. The conclusion of this study emphasizes that synergy between mapping the potential of local raw materials, the application of efficient assistance technology, and strengthening the capacity of human resources (HR) are the main prerequisites in realizing a sustainable national energy transition

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1. Introduction

The high consumption of cooking oil in Indonesian society is directly proportional to the increase in the volume of used cooking oil waste produced every year. The careless dumping of used cooking oil waste into waterways not only damages aquatic ecosystems, but is also a huge waste of energy resources (1). On the other hand, Indonesia is working hard to increase its renewable energy mix to reduce its dependence on fossil fuel imports whose prices continue to fluctuate (2). The use of used cooking oil and agro-industrial waste as alternative energy raw materials is a strategic solution to overcome environmental problems while strengthening energy security at the regional level (3).

The use of used cooking oil waste and leftover agricultural products has been implemented by the Government of Indonesia through mandatory biodiesel policies, such as the B35 program which continues to be improved towards B40 (4). However, the dependence of the national biodiesel industry on crude palm oil (CPO) often triggers conflicts of interest between food and energy needs in the domestic market. Competition for the use of CPO requires the diversification of raw materials through the use of second-generation biodiesel from used cooking oil and the exploration of the third generation of

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microalgae (3). Microalgae have great potential for Indonesia as a tropical country because of its very fast growth rate and does not require productive agricultural land. The technological transition from waste treatment to the utilization of microalgae biomass is a transformative step that needs to be studied immediately (5).

The transition of raw material technology has different technical challenges in the biodiesel production process in the field. Used cooking oil often has high levels of free fatty acids (FFA) so it requires a more intensive pre-treatment process than pure raw materials (1). Meanwhile, the production of biodiesel from microalgae requires mastery of more modern lipid extraction technology and significant infrastructure investment costs (6). Understanding the differences in technical characteristics of various lipid sources is essential for policymakers and biofuel industry players in Indonesia so that factory operations can run sustainably (7).

Biodiesel is a renewable liquid fuel composed of fatty acid alkyl esters, especially methyl esters, which are produced through transesterification of triglycerides with alcohol. Chemically, this reaction breaks the thick triglyceride structure into shorter chain esters so that it is more suitable for combustion in diesel engines. The advantages of biodiesel lie in its renewable properties, better biodegradability, and very low sulfur content, while its limitations arise in oxidative stability, cold flow properties, and quality dependence on feedstock quality. In practice, biodiesel is most effectively used as a diesel blend because it maintains engine compatibility while suppressing the weaknesses of its physical properties (8).

Recent studies have shown that the integration of Artificial Intelligence-based control systems is able to predict biodiesel quality in real-time based on fluctuations in the characteristics of waste raw materials. In addition, the use of magnetic-based heterogeneous nano catalysts has been shown to simplify the process of separating the catalyst from the final product, significantly reducing operational costs (9). The application of modern assistive technologies, such as ultrasonic cavitation and microwave radiation, is also noticeably able to accelerate the rate of transesterification reactions with much lower energy consumption than conventional heating methods (10). Recent research trends have even begun to explore the use of environmentally friendly solvents, green solvents, and dry washing methods to minimize liquid waste in the biodiesel purification process. However, scientific reviews on how the potential of used cooking oil and microalgae can be synergized in a single industrial management framework in Indonesia are still very limited. The review now offers novelty through an analysis of the availability of local raw materials linked to the readiness of process technology as well as the capacity of Human Resources (HR). Therefore, this review article was conducted with the aim of mapping the potential of used cooking oil and microalgae as biodiesel raw materials through a critical evaluation of the efficiency of conversion technology and its management strategies to meet international quality standards.

2. Materials and Methods

The method employed in this study is a systematic literature review analyzing various relevant scientific sources published between 2020 and 2026. The reviewed literature focuses on the technical potential, chemical conversion efficiencies, and socio-economic feasibility of utilizing Waste Cooking Oil (WCO) and microalgae as sustainable feedstocks for biodiesel production. Special emphasis is placed on the Indonesian landscape, including feedstock availability, local microalgae species, and national energy mandates.

The analysis was conducted through structured stages of data collection, selection, synthesis, and interpretation. Data were gathered from reputable electronic databases, including Scopus, ScienceDirect, and Google Scholar, using specific keywords related to transesterification, lipid extraction, and renewable energy policy. The selection process filtered articles based on their relevance to high-Free Fatty Acid (FFA) oil conversion and the scalability of algae cultivation in tropical climates. This approach was designed to gain a comprehensive understanding of the chemical mechanisms, factors influencing Fatty Acid Methyl Ester (FAME) yield, and the overall impact of these two raw materials on Indonesia's transition toward national energy security and carbon emission reduction.

3. Results and Discussion

3.1. Supply chain and characteristics of used cooking oil

The used cooking oil supply chain involves the flow of materials from households, food traders, restaurants, hotels, to biodiesel processing sites. The performance of the system depends on the ability to collect, store, and ship waste oil to remain suitable for processing. Without an organized collection system, used oil tends to be disposed of without being used optimally (8). Waste Cooking Oil (WCO) is a liquid waste whose availability in Indonesia is very abundant but has great challenges in terms of collection and quality standardization (11). Chemically, used cooking oil has undergone thermal and oxidative degradation due to repeated frying processes at high temperatures above 180°C. The process triggers complex reactions that produce polymeric compounds, high polarity, and a drastic increase in acid value due to the breaking of triglyceride chains into free fatty acids (12). Used cooking oil has suffered a decline in quality due to repeated heating, exposure to oxygen, water, and food waste. The process of degrading quality factors causes an increase in free fatty acid levels, oil viscosity, and the formation of oxidation and polymerization compounds. The process of making biodiesel, this condition needs to be considered because the high content of water and free fatty acids can trigger the formation of soap, reduce production yields, and complicate the separation process. Therefore, it is necessary to carry out an initial inspection before further processing due to the diverse quality of used cooking oil (13). The characteristics of WCO are greatly influenced by waste from the food service industry which tends to be more stable than household waste which is often mixed with water and organic spice residues. High levels of free fatty acids (FFA) make WCO a low-grade raw material that is corrosive and difficult to process through single-stage transesterification without special handling (14). The mechanism of thermal degradation of cooking oil into WCO (Waste Cooking Oil) can be seen in Figure 1.

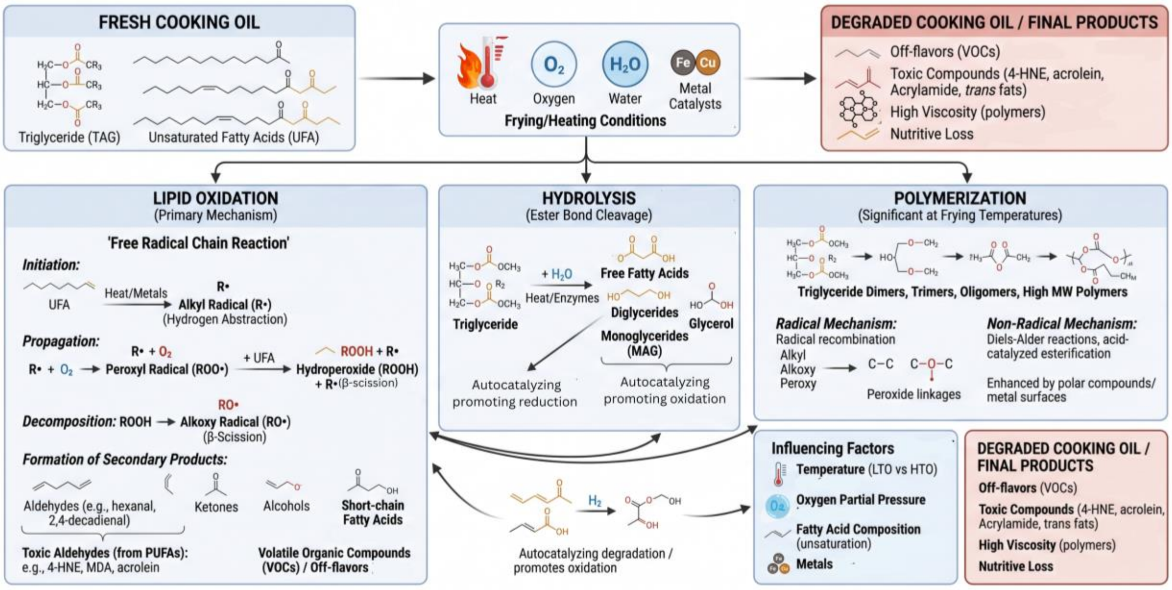

Figure 1. Mechanisms and reaction pathways of cooking oil degradation during heat and frying.

3.2. Pre-treatment stage

The pre-treatment stage is the main foundation in maintaining the purity of raw materials and extending the service life of the reactor. Pretreatment is the initial treatment to improve the quality of used cooking oil before transesterification. Commonly applied stages include solids filtration, water removal through heating or drying, precipitation, and reduction of free fatty acids through initial esterification or neutralization. The pretreatment stage needs to be carried out because the alkaline catalyst is very sensitive to water and free fatty acids, both components promote the formation of soap and decrease the efficiency of the reaction. Pretreatment adds to the cost and operating unit, but without this stage it is difficult to produce biodiesel with good yield and purity (13). The pre-treatment process begins with multi-stage filtration using a filter press or centrifuge to separate microscopic solids and carbon residues that can inhibit catalyst activity (15). Next, the oil must go through a vacuum thermal dehydration process at 110°C. The pre-treatment step is crucial because even low concentrations of water molecules can trigger a hydrolysis reaction during heating, which in turn will increase FFA levels again. In addition, the degumming technique using phosphoric acid is carried out to bind the content of phospholipids which are emulsifiers. These phospholipids if not removed will form a film layer on the heterogeneous catalyst surface, which significantly decreases the active surface area of the catalyst and inhibits the conversion reaction rate (16). The difference in esterification and saponification reactions can be seen in Figure 2.

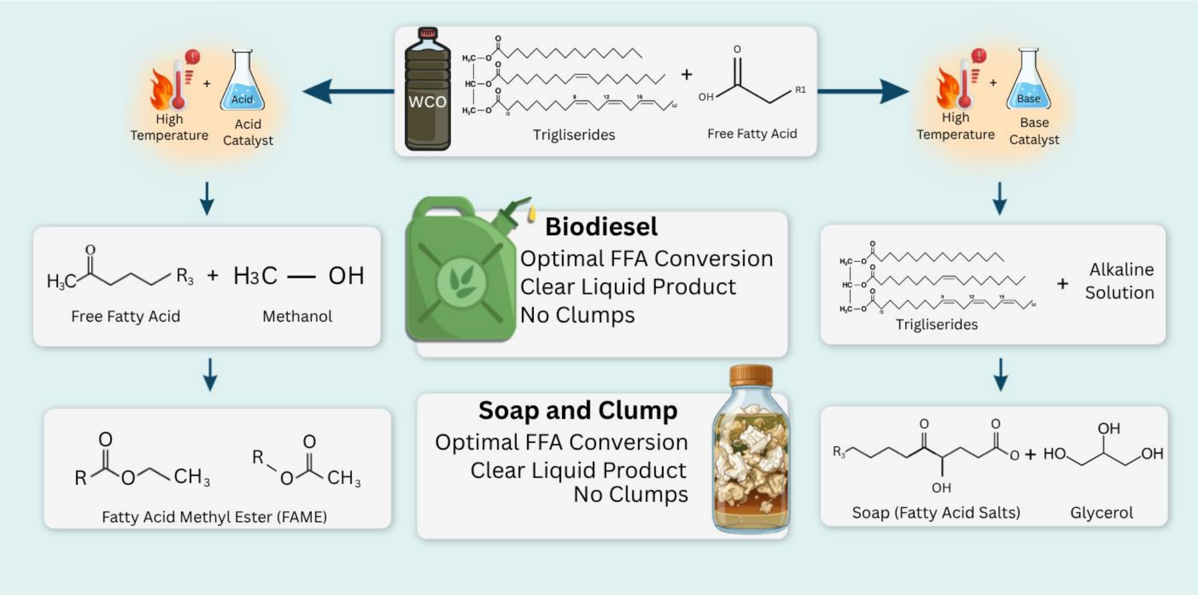

Figure 2. Differences in esterification and saponification reactions.

3.3. Phase of base transesterification and ultrasonic Innovation

Transesterification is a core reaction in which one triglyceride molecule reacts with three methanol molecules resulting in three methyl ester molecules and one glycerol molecule as a by-product of economic value. Base transesterification is the most widely used biodiesel production line because of its fast reaction and relatively mature operational technology. Oils or triglycerides react with short-chain alcohols, usually methanol, with alkaline catalysts such as NaOH or KOH, producing methyl esters and glycerol (17). The transesterification reaction can be seen in Figure 3.

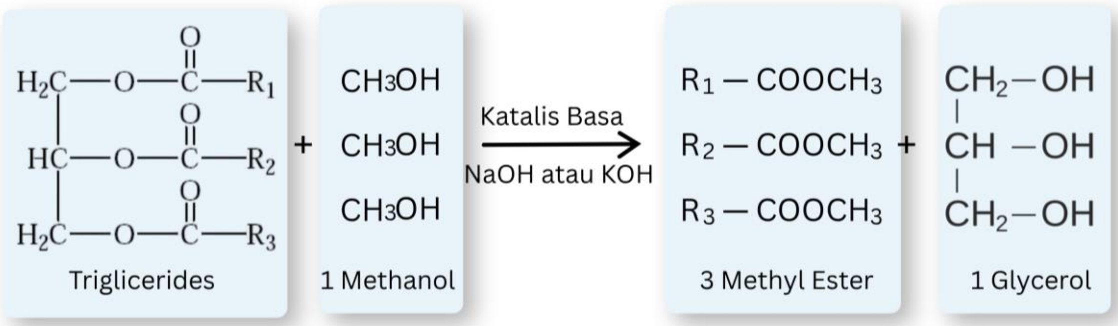

Figure 3. Core reaction of base transesterification.

Mechanistically, the alkaline catalyst forms an alkoxide species that attacks the carbonyl triglyceride group so that the initial ester bond is broken and a new ester is formed. The success of the process is highly dependent on the FFA level, moisture content, alcohol-to-oil ratio, temperature, reaction time, and mixing intensity (18). The latest innovation that has become standard in modern industry is the use of ultrasonic cavitation (9). High-frequency vibrations create a phenomenon within the liquid that generates extraordinary kinetic energy to break down oil droplets into micro-nanoscale sizes. This increases the area of contact between the hydrophobic and hydrophilic methanol phases, so that the mass transfer limitation barrier can be overcome with the help of ultrasonics, the reaction that conventionally takes 90-120 minutes can be trimmed to less than 20 minutes with a yield above 96%. The use of magnetic CaO-based nanocomposite catalysts also allows the catalyst recovery process to be carried out quickly using an external magnetic field, thereby significantly reducing operational costs (2). The ultrasonic cultivation process can be seen in Figure 4.

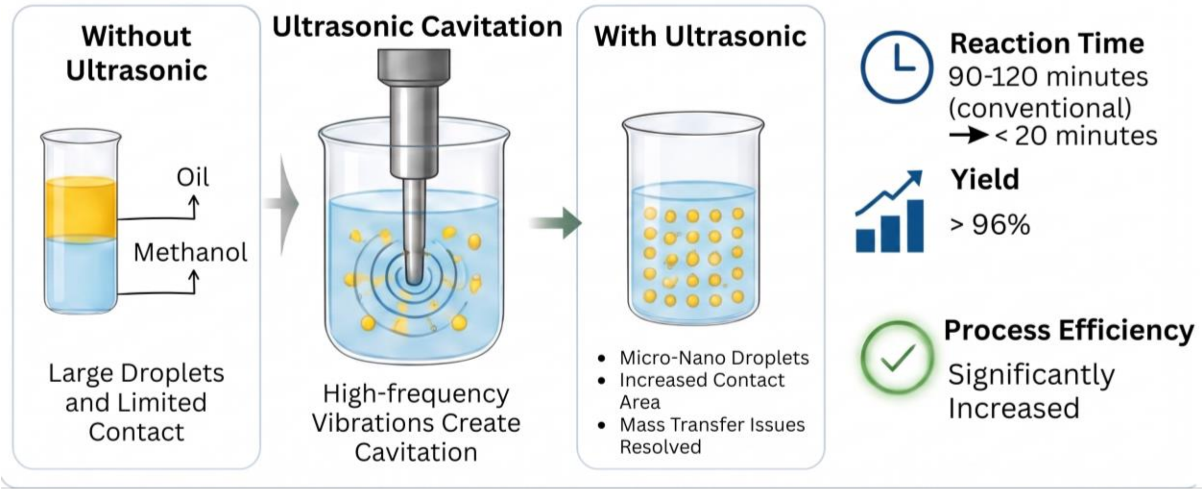

Figure 4. Ultrasonic innovation.

3.4. Potential microalgae

Indonesia has a comparative advantage in the development of microalgae as a raw material for third-generation biodiesel. Species such as *Chlorella* sp. and *Nannochloropsis* sp. has a very high rate of photosynthesis, being able to capture CO_2 from the atmosphere 10-50 times more efficiently than terrestrial plants (19). Through cultivation methods in closed photobioreactors, lipid accumulation in algae cells can be spurred to reach 50-60% of dry weight through nitrogen starvation restriction strategies (20). Although the main challenge today lies in the relatively high cost of drying and extracting oil, the development of in-situ transesterification technology in which algae biomass is directly converted into biodiesel without oil extraction first becomes a potential solution to reduce production costs (21). Microalgae are microscopic photosynthetic organisms with high lipid accumulation capabilities, so they are often positioned as raw materials for third-generation biodiesel. Microalgae cells utilize light, carbon dioxide, water, and nutrients to build biomass, when subjected to nutrient stress, part of the metabolism is directed to lipid formation. The main advantages of microalgae lie in high biomass productivity, non-competition with food land, and flexibility of cultivation in wastewater or unconventional media. The biggest obstacle lies in the high cost of cultivation, harvesting, and lipid extraction on a large scale (22). The potential of microalgae as biodiesel production can be seen in Figure 5.

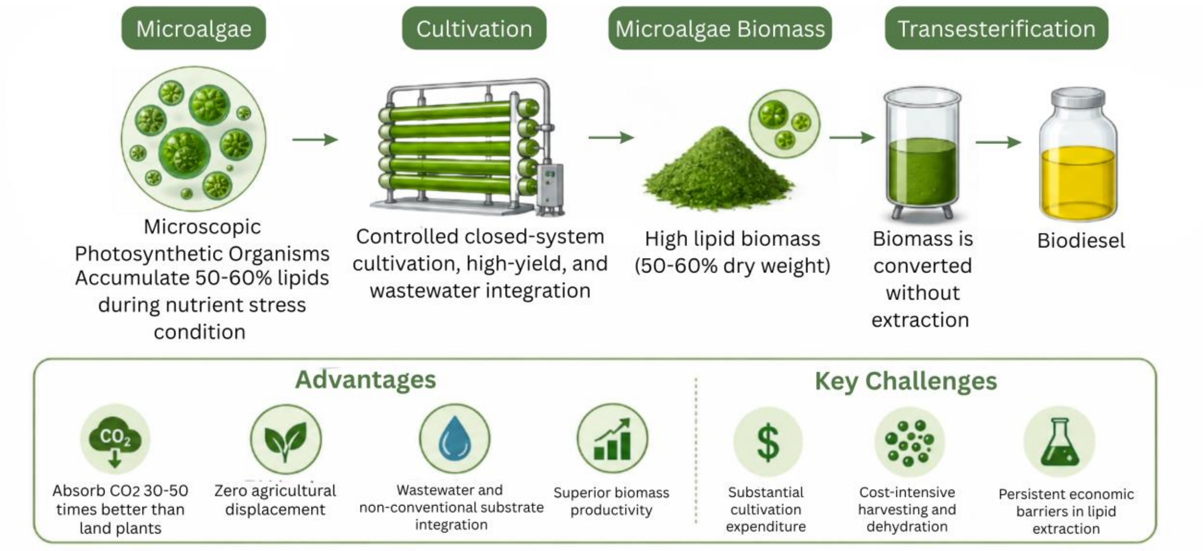

Figure 5. The potential of microalgae as raw materials for biodiesel.

3.5. Biodiesel production from microalgae

Biodiesel production from microalgae is one of the renewable energy technologies developed to partially replace the use of fossil fuels. Microalgae were chosen because they have the ability to produce high amounts of lipids or oils, fast growth rates, and can be cultivated on land that does not compete with food crops. In addition, microalgae are able to utilize carbon dioxide (CO_2) from industrial emissions as a carbon source for photosynthesis so that it has the potential to help reduce greenhouse gases (23). However, the biodiesel production process from microalgae still faces various technical and economic challenges so that it has not been widely applied commercially. The production of biodiesel from microalgae involves culture cultivation, biomass harvesting, drying, lipid extraction, and lipid conversion to biodiesel. The harvesting and dewatering stages are often the most expensive points due to the small cell size and high-water content. Once the lipid fraction is obtained, the microalgae oil can be converted into biodiesel through transesterification or other catalytic pathways. Conceptually, microalgae offer strong sustainability, but energy efficiency and process economics are still major barriers to commercialization (19). The production of biodiesel from microalgae can be seen in Figure 6.

Figure 6. Production of biodiesel from microalgae.

3.6. Comparison of used cooking oil and microalgae film

Used cooking oil and microalgae are two raw materials that have the potential to be used for biodiesel production, but they have different levels of readiness. Used cooking oil is more readily available because the raw material is readily available from household waste, restaurants, and the food industry. In addition to being cheap, the processing technology is also quite simple and widely used. This is because it is through the process of transesterification (24). Biodiesel from used cooking oil can be produced at a lower cost than other raw materials. However, the quality of used cooking oil must be controlled first because it usually contains high levels of water, dirt, and free fatty acids due to repeated use during the frying process. Therefore, pretreatment stages such as filtration and heating are required before the oil is processed into biodiesel (25).

Meanwhile, microalgae have advantages in high lipid productivity, rapid growth, and the ability to grow without the need for fertile farmland so that it is more environmentally friendly in the long term. Microalgae can be cultivated using seawater or liquid waste so that they do not compete with food needs (26). However, the production of biodiesel from microalgae still faces many obstacles, especially high production costs and complicated processing processes. Stages such as cultivation, biomass harvesting, drying, and oil extraction require a lot of energy and technology so it is not economical to be widely applied. Thus, used cooking oil is more realistic to be used as a source of biodiesel today, compared to microalgae which are more suitable to be developed as an investment in research and renewable energy technology in the future (21). The difference between used cooking oil and microalgae as potential biodiesel production can be seen in Figure 7.

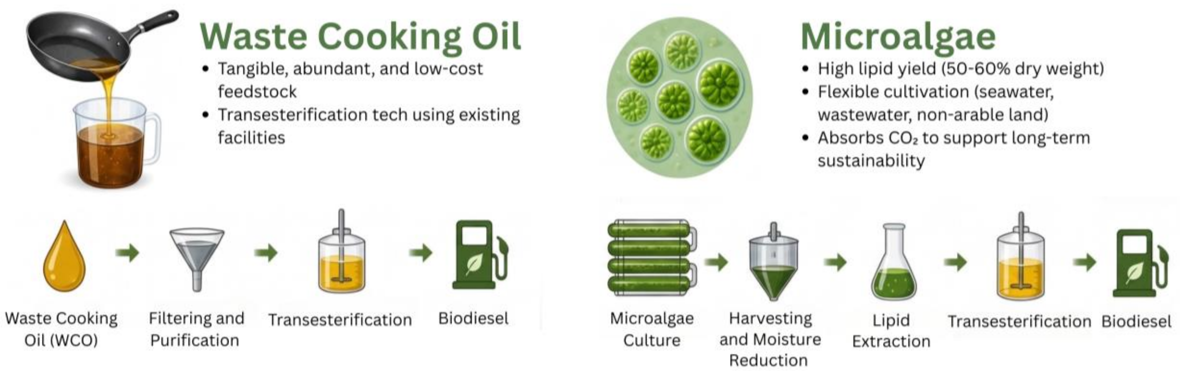

Figure 7. The difference between used cooking oil and microalgae.

3.7. Challenges and opportunities

The integration of used cooking oil (UCO) and microalgae as biodiesel feedstocks in Indonesia presents a complex landscape of distinct technological, socio-economic, and environmental trade-offs. UCO offers an abundant, non-food-competing resource that mitigates waste pollution and demonstrates technical feasibility for meeting national fuel standards at both home-industry and continuous-reactor scales (27,28). However, its widespread commercialization is constrained by fragmented reverse logistics, low community participation, and persistent socio-cultural barriers regarding waste management, necessitating optimized drop-off logistics, localized educational initiatives, and targeted digital behavioral interventions to sustain recycling compliance (29). Conversely, microalgae capitalize on Indonesia's tropical irradiance to deliver exceptional lipid yields while simultaneously facilitating carbon capture and wastewater bioremediation

(30). Despite these biological advantages, microalgal biodiesel scaling is severely bottlenecked by energy-intensive downstream processing, high operational costs, and the necessity for engineering innovations in harvesting, extraction, and photobioreactor design, such as bio flocculation, microwave-assisted methods, and hybrid algal-bacterial systems co-cultivated with agro-industrial (5). Ultimately, navigating these technical limitations requires robust system dynamics planning and comprehensive Life Cycle Sustainability Assessments (LCSA) to ensure that the transition away from palm-based biodiesel balances fiscal viability, local facility logistics, and food-energy security while meeting national emission reduction mandates (31).

4. Conclusions

The synergistic use of used cooking oil (second generation biodiesel) and microalgae (third generation) is a strategic solution for Indonesia's energy security without disrupting food. Successful production depends on proper initial processing to suppress FFA, while microalgae excel due to high lipid productivity. The support of modern technology, human resources, and an integrated supply chain system is essential for biofuels to be sustainable and competitive.

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Author Contributions

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, and visualization G.Z.S.

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Data Availability Statement

Available data are presented in the manuscript.

Conflicts of Interest

Author declared no conflict of interest.

References

1. Foo WH, Koay SSN, Tang DYY, Chia WY, Chew KW, Show PL. Safety control of waste cooking oil: transforming hazard into multifarious products with available pre-treatment processes. Food Mater Res [Internet]. 2022;2(1):1–11. Available from: https://doi.org/10.48130/FMR-2022-0001
2. Pambudi NA, Firdaus RA, Rizkiana R, Ulfa DK, Salsabila MS, Suharno, et al. Renewable Energy in Indonesia: Current Status, Potential, and Future Development [Internet]. Vol.

15, Sustainability. 2023. p. 2342. Available from: https://doi.org/10.3390/su15032342
3. Maliha A, Abu-Hijleh B. A review on the current status and post-pandemic prospects of third-generation biofuels. Energy Syst [Internet]. 2023;14(4):1185–216. Available from: https://doi.org/10.1007/s12667-022-00514-7
4. Junaidi J, Juniati AT, Prasida INT, Hasudungan HWV. Analysis biodiesel distribution in Indonesia's Kalimantan Region: A case study on the readiness of ship-to-ship floating storage mechanisms in Balikpapan to Support the B35-B40 Biodiesel Mandate. BIS Energy Eng [Internet]. 2025;2:V225014–V225014. Available from: https://doi.org/10.31603/Biseeng.354
5. Budinarta W, Ajijah N, Hermosaningtyas AA. Waste-to-Resource Strategies: The Potential of Agro-Industrial Residues for Microalgal Bioproducts in Indonesia. Phycology [Internet]. 2025;5(4):81. Available from: https://doi.org/10.3390/phycology5040081
6. Dębowski M, Świca I, Kazimierowicz J, Zieliński M. Large scale microalgae biofuel technology—development perspectives in light of the barriers and limitations. Energies [Internet]. 2022;16(1):81. Available from: https://doi.org/10.3390/en16010081
7. Suhara A, Karyadi, Herawan SG, Tirta A, Idris M, Roslan MF, et al. Biodiesel Sustainability: Review of Progress and Challenges of Biodiesel as Sustainable Biofuel [Internet]. Vol. 6, Clean Technologies. 2024. p. 886–906. Available from: https://doi.org/10.3390/cleantechnol6030045
8. Budijati SM, Astuti FH, Jatiningrum WS, Rini PL. Model Konseptual Faktor Pendorong Niat Sebagai Fasilitas Pengumpulan Minyak Goreng Bekas Sebagai Inisiasi Jaringan Reverse Logistics. JISI J Integr Sist Ind Учредители Univ Muhammadiyah Jakarta [Internet]. 2024;11(2):191–202. Available from: https://doi.org/10.24853/Jisi.11.2.191-202
9. Hajareh Haghighi F, Binaymotlagh R, Palocci C, Chronopoulou L. Magnetic Iron Oxide Nanomaterials for Lipase Immobilization: Promising Industrial Catalysts for Biodiesel Production. Vol. 14, Catalysts. 2024. p. 336.
10. Bizualem YD, Nurie AG. A review on recent biodiesel intensification process through cavitation and microwave reactors: Yield, energy, and economic analysis. Heliyon [Internet]. 2024;10(2). Available from: https://doi.org/10.1016/j.heliyon.2024.e24643
11. Febijanto I, Ulfah F, Kusrestuwardhani, Siswanto, Yuwono Trihadi SE. A Review on used cooking oil as a sustainable biodiesel feedstock in Indonesia. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing; 2023. p. 12011.
12. Baig A, Zubair M, Sumrra SH, Nazar MF, Zafar MN, Jabeen K, et al. Heating effect on quality characteristics of mixed canola cooking oils. BMC Chem [Internet]. 2022;16(1):3. Available from: https://doi.org/10.1186/s13065-022-00796-z
13. Taufik M, Atma Y. Perubahan Karakteristik Fisikokimia Minyak Selama Penggorengan Dengan Metode Deep Fat Frying: Kajian Literatur. Agrointek J Teknol Ind Pertan [Internet]. 2021;15(3):955–66. Available from: https://doi.org/10.21107/agrointek.v15i3.10436
14. Cerón Ferrusca M, Romero R, Martínez SL, Ramírez-Serrano A, Natividad R. Biodiesel production from waste cooking oil: a perspective on catalytic processes. Processes [Internet]. 2023;11(7):1952. Available from: https://doi.org/10.3390/pr11071952
15. Lim JH, Bang KS, Shin KW, Lee NH, Yu SH. Comprehensive evaluation of residual water based on vacuum drying methods. Nucl Eng Technol [Internet]. 2025;57(6):103430. Available from: https://doi.org/10.1016/J.Net.2024.103430

16. Jayaprabakar J, Dawn SS, Anish M, Giri J, Sudhakar K, Alarfaj AA, et al. Development of Free Fatty Acid (FFA) monitoring device for evaluation of oil samples used for biodiesel production. Heliyon [Internet]. 2024;10(17). Available from: https://doi.org/10.1016/j.heliyon.2024.e37118
17. Nimbkar S, Leena MM, Moses JA, Anandharamakrishnan C. Medium chain triglycerides (MCT): State-of-the-art on chemistry, synthesis, health benefits and applications in food industry. Compr Rev Food Sci Food Saf [Internet]. 2022 Mar 1;21(2):843–67. Available from: https://doi.org/10.1111/1541-4337.12926
18. Affandi AR, Ferdiansyah MK. Karakterisasi sifat fisiko-kimia dan organoleptik produk cookies tersubstitusi tepung suweg (Amorphophallus campanulatus BI). J Pangan dan Gizi [Internet]. 2017;7(1):9–16. Available from: https://doi.org/10.26714/jpg.7.1.2017.9-16
19. Udayan A, Pandey AK, Sirohi R, Sreekumar N, Sang BI, Sim SJ, et al. Production of microalgae with high lipid content and their potential as sources of nutraceuticals. Phytochem Rev [Internet]. 2023;22(4):833–60. Available from: https://doi.org/10.1007/s11101-021-09784-y
20. Sungur Ş, Atan MM. Effect of Active Packaging Films Containing Natural Antioxidant Essential Oils on the Oxidative Stability of the African Catfish (Clarias gariepinus). Nat Eng Sci [Internet]. 2020;5(3):155–66. Available from: https://doi.org/10.28978/nesciences.832984
21. Maltsev Y, Kulikovskiy M, Maltseva S. Nitrogen and phosphorus stress as a tool to induce lipid production in microalgae. Microb Cell Fact [Internet]. 2023;22(1):239. Available from: https://doi.org/10.1186/s12934-023-02244-6
22. Hasbi R, Puspanitresna P, Azkiya AAN, Sumarna O, Widhiyanti T. Optimasi Pemberian Nutrisi pada Media Kultur Mikroalga Chlorella vulgaris untuk Meningkatkan Kadar Lipid sebagai Bahan Baku Biodiesel. J Energi Baru dan Terbarukan; Vol 6, No 2 Juli 2025DO - 1014710/jebt202527858 [Internet]. 2025 Jul 20; Available from: https://doi.org/10.14710/jebt.2025.27858
23. Vinata Y, Wulandari Y. Pembuatan biodiesel dari mikroalga nannochloropsis sp. menggunakan metode transesterifikasi insitu dengan bantuan katalis asam sulfat. In: Prosiding Seminar Nasional Sains dan Teknologi Terapan. 2020. p. 507–14.
24. Tegar Setiadi R, Nanda Putri Miefthawati. Potential Analysis of Used Cooking Oil as Raw Material for Biodiesel Production in Pekanbaru City: Analisis Potensi Minyak Jelantah Sebagai Bahan Baku Produksi Biodiesel di Kota Pekanbaru. Indones J Electr Eng Renew Energy [Internet]. 2023 Jun 20;3(1 SE-):70–9. Available from: https://doi.org/10.57152/ijeere.v3i1.713
25. Suryatini KY, Made MN. Pemanfaatan Potensi Minyak Goreng Bekas (Jelantah) Sebagai Biodiesel. J Edukasi Mat dan Sains [Internet]. 2023;12(1):116–25. Available from: https://doi.org/10.5281/zenodo.7902815
26. Mishbach I, Permatasari NS, Zainuri M, Kusumaningrum HP, Hastuti ED. Potensi Mikroalga Anabaena sp. Sebagai Bahan Utama Bioetanol. EKOTONIA J Penelit Biol Bot Zool dan Mikrobiol [Internet]. 2022;7(1):69–76. Available from: https://doi.org/10.33019/Ekotonia.V7i1.3144
27. Hartulistiyoso E, Farobie O, Wulandani D, Sucahyo L, Alfariji MR. Biodiesel Production from Used Cooking Oil using KOH Catalyst and Microwave Heating. IOP Conf Ser Earth Environ Sci [Internet]. 2025;1513(1):12011. Available from:

https://doi.org/10.1088/1755-1315/1513/1/012011

28. Utama IMS, Widia IW, Arthawan IGKA, Badgery Parker J, Arya NN, Sayaka B, et al. From farm to HORECA: advancing sustainable value chains for tourism-driven agribusiness in Indonesia. Front Sustain Food Syst. 2025;Volume 9.
29. Chen C, Liang W. Behavioral drivers of waste cooking oil recycling in China's catering industry: An economic perspective. Environ Challenges [Internet]. 2025;20:101235. Available from: https://doi.org/10.1016/j.envc.2025.101235
30. Chung HH, Lim LWK, Zainol Abidin QH, Wan WW. Microalgae: Recent micro to macro-applications in South East Asia. Bioresour Technol Reports [Internet]. 2025;31:102184. Available from: https://doi.org/10.1016/j.biteb.2025.102184
31. Rahman A, Oktaufik MAM, Sasongko TW, Guntoro I, Soedjati D, Abbas N, et al. Current scenario and potential of waste cooking oil as a feedstock for biodiesel production in Indonesia: Life cycle sustainability assessment (LCSA) review. Case Stud Chem Environ Eng [Internet]. 2025;11:101067. Available from: https://doi.org/10.1016/j.cscee.2024.101067