INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XI, November 2024

Sustainable Management of Fish Gut Waste Through Transesterification

R.T.A.J.K.L. Rathnasekara, I.B. Wjethunga, E.R.J.M.D.D.P. Wijesekara, A.M.P.C. Amarasinghe and E.P.R.H.H.W. Nilmalgoda

Department of Biosystems Technology, Faculty of Technology, Sabaragamuwa University of Sri Lanka, Belihuloya, 70140

DOI : https://doi.org/10.51583/IJLTEMAS.2024.1311010

Received: 19 November 2024; Accepted: 26 November 2024; Published: 06 December 2024

Abstract: The fishing industry in Sri Lanka generates significant waste, presenting an opportunity to convert it into a sustainable energy source. This research investigates the production of biodiesel from fish waste, specifically fish oil, as an alternative fuel to reduce reliance on fossil fuels and improve waste management in the fish market. Fish waste, including non-edible parts such as fish heads, tails, fins, and internal organs, was collected from a local fish market and subjected to an extraction process using wet boiling. The extracted fish oil was then converted into biodiesel through a transesterification reaction with methanol in the presence of potassium hydroxide (KOH) as a catalyst. Two optimization experiments were conducted to determine the best methanol concentration (15%, 20%, and 25%) and KOH concentration (1g, 2g, and 3g). The results showed that the highest biodiesel yield was obtained using 20% methanol (producing 10.71g of biodiesel) and 1g of KOH as a catalyst, yielding a biodiesel production of 8.66g for 15% methanol and 6.89g for 25% methanol. The biodiesel produced exhibited promising fuel properties, with a flashpoint of 127.5°C, a calorific value of 39.248 MJ/kg, kinematic viscosity of 4.4107 mm^2/s, and density of 0.8766 g/cm^3, all of which were within the acceptable limits set by ASTM standards. Additionally, the FFA content of the extracted fish oil was initially 7%, which was reduced through a saponification process, making the oil suitable for biodiesel production. The study estimated that approximately 237 metric tons of biodiesel could be produced per month from the fish waste in Sri Lanka, based on the average monthly fish waste generated (50% of total fish production). The biodiesel production from fish oil thus holds significant potential as both a renewable energy source and a sustainable waste management solution, reducing the reliance on fossil fuels and addressing environmental challenges associated with waste disposal in the fishing industry.

Keywords: Biodiesel, Energy, Fish oil, Fish waste, Sustainable

I. Introduction

Energy is a vital input in modern societies and is crucial to our day-to-day activities, including transportation, heating and lighting [1] [2]. The quantity of energy required to support our civilization is rising as the world's population grows and people seek a higher quality of life. Global energy demand has increased by 2.9% in 2018, and current predictions indicate that consumption will be increased by 30% to 740 million TJ by 2040 [3] [4] . The primary sources of global energy consumption are fossil fuels such as coal, oil, and natural gas and these fuels account for more than 80% of the world's energy consumption [5].

Traditional sources have a finite availability, and their extraction, transportation and use cause significant environmental impacts [6][7]. Moreover, the growing global demand for energy, driven by population growth and increased industrialization, has led to a global energy crisis, marked by price volatility, supply disruption, and environmental degradation [8] [3] [9]. Presently, the global warming effect, depletion of fossil fuel reserves, and higher petroleum prices are the main issues driving worldwide interest in the development of alternative biofuels. Biodiesel is an alternative resource that is sustainable, affordable, and environmentally friendly [5] [10] [11].

Biodiesel is a mixture of long-chain mono alkylic esters from fatty acids derived from renewable resources [12] [13]. It has gained special attention over other liquid biofuels thus the market demand of biodiesel is ever-increasing due to the exponential growth in transportation vehicles and their reliance on liquid fuel [1] [14] [15]. Importantly, the use of biodiesel can ensure almost closed carbon cycles reducing CO_2 emissions by 78% can be used in current petroleum diesel engines without conversion [6] [16] [17] [18]. Edible vegetable oils such as palm oil, soybean oil, rapeseed oil, and coconut oil could be utilized for the biodiesel production [19] [20] [21]. However the use of animal fat, waste cooking oil, algal oil, or any other non-edible oil sources provides sustainability to the process providing a solution to the generated waste [22] [23] [24]. In this regard, waste cooking oil and waste animal fat have been used as feedstock for biodiesel since it does not have a conflict with food security especially when it is impossible to commit land to produce biodiesel as the world population grows denser [25] [26].

The oil from discards of marine fish which is a first generation biofuel source has been found to be a plentiful, affordable source of biodiesel [27] [28] [29]. Sri Lanka, being an island country has a long history of fish consumption dating back many centuries and its per capita fish consumption rates are one of the highest in the world [19]. Sri Lanka's per capita fish consumption was 13 kg as of 2015 and the government of Sri Lanka have taken many initiatives to increase the per capita fish consumption to 22 kg by 2020 [30] [31]. Although the fish production is rising, 40% to 50% of it is lost in handling and processing [32]. Fish waste is high in protein, low in saturated fat, and contains fatty acids that are well-known for their numerous health benefits. Sri Lanka caught 486170 MT of fish are in 2012, of which only 40–60% was utilized for production. Fish markets and fish processing sector produce enormous amounts of fish waste, which is regarded as a loss [33] [34] [35]. This includes the non-edible parts of

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XI, November 2024

the fish such as the head, viscera, tail, skin, livers, eyes, and fins [36] [37]. Researchers have found that out of fish's total body weight, its head and viscera make up 45.4% and 9.6%, respectively [8][38] [39]. Presently, most of the fish waste is used as raw materials for fish meal production by animal feed manufacturers [40] [41] [42].

This research study was conducted to evaluate the feasibility of producing biodiesel from fish waste as a sustainable energy solution for the local fishermen due to severe fuel shortage in the country as a result of the economic crisis in 2021. This study utilized the transesterification process where the lipid reacts with the alcohol in the presence of a catalyst. On the other hand, this study serves as a sustainable waste management solution for the fishing community that faces numerous health issues due to unsustainable fish waste handling.

II. Methodology

Fish waste sample preparation

The fish waste used in this current study was collected from the Negombo fish market (7º12'36" N 79º49'52 E) where less valuable nonedible parts of fish, like heads, tails, fins, and organs, were taken as fish waste to produce biodiesel (Figure 1.). Additionally, chemicals like sodium hydroxide, methanol, and potassium hydroxide were used for the experiment.

Fig 1. Fish viscera waste

Oil extraction procedure

Oil extraction from the fish waste was done using wet boiling extraction method. Firstly, 6 kilograms of fish waste was boiled for 1 hour at 100^0C. Then the mixture was kept for 24 hours to settle after which the upper layer was collected for further processing.

Analysis of fatty acid methyl ester (FAME) composition of oil

Titration method was used to analyze the FAME of the extracted soil to ensure that it is at an optimum range to continue the transesterification reaction. Initially, 5g of extracted fish oil was mixed with 15ml of ethanol. Then the solution was titrated using 100ml of 0.1M NaOH solution. If high amount of free fatty acids (FFA) was observed, it was reduced using saponification process.

Saponification process

Saponification of the extracted fat was done by mixing with NaOH solution and subject to centrifugation at 3000 RPM for 15 minutes to separate the saponified fat. In this study, saponification was done using different amounts of NaOH (2.5g, 5g and 10g) to analyze the oil extraction yield from the fish waste.

Transesterification process

Transesterification reaction process was done where fish oil was mixed with methanol and 1% w/w (KOH) to act as a catalyst. Potassium hydroxide (1g) was dissolved in a beaker containing methanol (8.7g -20% by the amount of fish oil) and agitated continuously in a magnetic stirrer till the potassium hydroxide dissolved completely and formed potassium methoxide, a strong caustic. The above-formed potassium methoxide was mixed with 45g of fish fat under agitation the fish oil is heated until it reaches 60˚C for 1 hour. Then the mixture was transferred to a separating funnel and the contents were allowed to settle down, and the two distinct layers the top layer being bio-diesel and the bottom layer of glycerol were separated. After separating the glycerol, the methyl ester was washed twice with a 1:1 volume of water for 1 hour to remove excess methanol. Using this transesterification method, two experiments were done. First experiment was to analyze biodiesel production yield using different amounts of methanol percentages (15%,20% and 25%) and the second experiment analyzed biodiesel production yield using different amounts of KOH (1g, 2g and 3g).

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XI, November 2024

Determination of biodiesel properties

Calorific value

Automatic bomb calorimeter was used to determine the calorific value of the biodiesel sample. Firstly, 1g of fish oil biodiesel was carefully weighted placed in a crucible. The crucible containing the sample was then sealed in a bomb calorimeter vessel, along with an excess of pure oxygen, forming the bomb. As the ignition source, an electrically heated wire was used to ignite the sample within the bomb. After that the sample was ignited completely in the presence of oxygen, releasing heat that was absorbed by the bomb calorimeter, typically filled with a known quantity of water. The temperature of the water within the calorimeter was monitored throughout the combustion process. The change in temperature of the water within the calorimeter was recorded as the sample burned. This temperature change was used to calculate the heat released during combustion. The Calorific Value (CV) of fish oil biodiesel was automatically displayed. CV is usually expressed in joules per gram (J/g) or, more commonly, in kilojoules per gram (kJ/g).

Density and viscosity

The viscosity is a liquid measurement of its resistance to flow due to internal friction and it is an essential feature of diesel fuel since it affects the engine's fuel injection system when it is cold. The kinematic and dynamic viscosity and density of the biodiesel samples were measured by Anton Paar SVM 3001 viscometers. The viscometer underwent thorough cleaning with an ample amount of toluene, ensuring the removal of any residues from previous analysis. Then the viscometer was calibrated meticulously according to the manufacturer's instructions. A representative and well-mixed 5 ml sample of fish oil biodiesel was obtained to perform the analysis. Then the sample was precisely loaded into the viscometer using a syringe. The automatic kinematic viscosity measurement was conducted, and both kinematic and dynamic viscosity values were accurately recorded.

Flashpoint

Measurement of the flashpoint of the biodiesel sample is a vital parameter to ensure the quality of the diesel. It is the temperature at which an ignition source will ignite when applied under specific conditions. In order to ensure that there is no methanol present, it should be noted that the biodiesel component must pass a flash point test before blending. In the present study, flashpoint of the biodiesel sample was measured by PMA 500 Pensky - Matens flash point tester. Initially, a 50ml volume of fish oil biodiesel was introduced into a test cup, which was then positioned within the apparatus. This equipment featured a heating mechanism that progressively elevated the sample's temperature. Simultaneously, a flame ignition source was applied to the sample's surface at regular intervals. With the rising temperature, vapors emanating from the sample had the potential to form an ignitable mixture with air. The flashpoint denoted the lowest temperature at which this ignition process occurred.

The Pensky-Martens apparatus incorporated a detection system designed to identify the flashpoint by recognizing the presence of a flame or other indicators of ignition. The entire procedure adhered meticulously to the ASTM-D93B standard, ensuring both consistency and accuracy in flashpoint determination. The PMA 500 tester, distinguished by its Pensky-Martens design, delivered a trustworthy and standardized approach for evaluating the flashpoint of fish oil biodiesel. While biodiesel has a higher flash point than petroleum diesel, both are safe for use in transportation where high values for flash points decrease the probability of fire.

III. Results and Discussion

Free fatty acid (FFA) test

Fish oil was extracted from the upper layer of the boiled fish waste mixture where 10% of raw oil was obtained from 6kg of fish waste. After the oil extraction, an FFA test was done to determine the FFA content of the initial raw fish oil. Titration results indicated that the initial FFA content was 7%. According to the literature, maximum biodiesel production could be achieved with a FFA content of 2.2%. The FFA content was reduced using saponification to get an optimum FFA value for the process.

Calculation of FFA

Amount of NaOH consumption

$$= \frac{0.1mol}{1000ml} \times 12.5ml$$

$$= 0.00125mol$$

$$= 1.2 \times \ 10^{-3}mol \ \times \frac{280g}{mol}$$

$$= 0.35g$$

FFA mass

$$= \frac{0.35g}{5g} \ \times 100\%$$

FFA mass %

$$= 7\%$$

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XI, November 2024

Saponification process

Saponification process was done by using different amounts of NaOH to analyze the oil extraction from raw fish oil as illustrated in Figure 2. Figure 3 presents the outcome of the saponification experiments under different NaOH quantities (Sample No. 1 - 2.5g, Sample No. 2 - 5g and Sample No. 3 - 10g). According to the results, maximum oil quantity was obtained by using minimum quantity of NaOH quantity which suggests that low NaOH concentrations are more effective in extracting fish oil from waste.

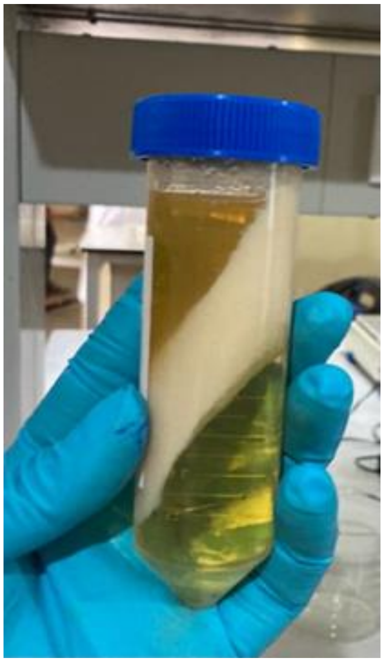

Fig 2: Centrifuged fish oil sample

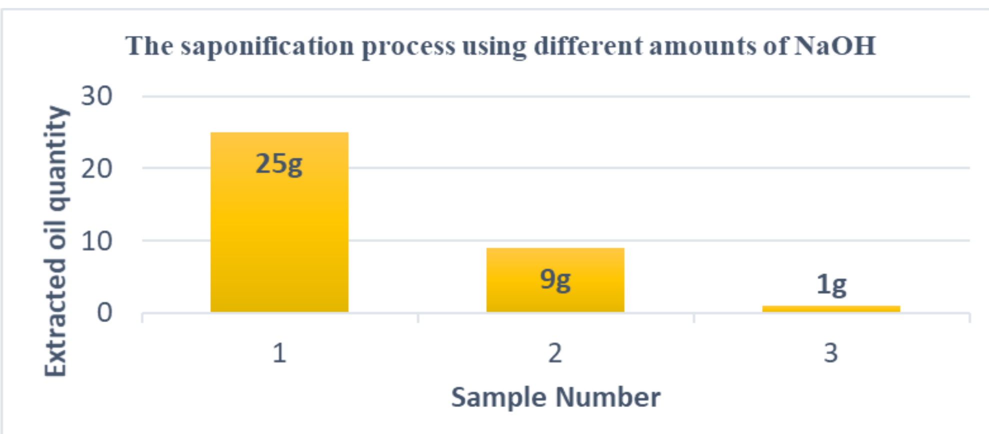

Fig 3. Amount of oil extracted using different amount of NaOH

Transesterification process

Transesterification process is the most typical process of biodiesel production from fish waste oil. It involves the reaction of lipids with alcohol in the presence of a catalyst. Methanol as a reactant serves as a key reactant in the transesterification process, converting fish fat into biodiesel and glycerol as illustrated in Figure 4. In the present study, biodiesel production yield was analyzed by using different amount of Methanol percentages (15%, 20%, and 25%) to determine the optimum methanol concentration. As presented in Table 1, effectiveness of the production has fluctuated with the amount of methanol quantity used as a reactant. According to the results, the optimum methanol concentration was 20% where there was higher biodiesel yield (10.710g) and reduced glycerol formation (17.280g). Moreover, when the methanol concentration was increased to 25% it has resulted information of glycerol thereby reducing biodiesel production.

Fig 4. Fish oil sample after transesterification

Table 1. Biodiesel production using different amounts of methanol

Experiment	Methanol* (g)	KOH	Fish oil	Glycerol	Biodiesel
1	3.75g (15%)	1g	25 g	20g	8.66g
2	5g (20%)	1g	25 g	17.28g	10.71g
3	6.25g (25%)	1g	25 g	20.28g	6.89g

* Percentage amount of fish oil used (%).

Comparison of the biodiesel properties under different NaOH concentrations

Different properties of biodiesel were measured and compared with ASTM methods to have an understanding of the product quality and purity. Two biodiesel samples were taken for the analysis where first sample was the sample using 2.5g of NaOH and second sample was the biodiesel sample using 5g NaOH used in the saponification process. Table 2 presents the viscosity and density values of the biodiesel in comparison with ASTM standards. According to the results, density values and the viscosity of sample 2 were in the range of the ASTM. However, viscosity value of sample 1 has deviated from ASTM standard value.

Table 2. Comparison of the biodiesel properties with the ASTM standards

Property	Sample 1 (2.5g NaOH)	Sample 2 (5g NaOH)	ASTM Standard
Viscosity	9.6119 mm^2/sec	4.5008mm^2/sec	1.90–6.00 mm^2/sec (D445)
Density	0.892gcm^3	0.8764 gcm^3	0.86-0.90 gcm^3

The study examined the impact of different concentrations of sodium hydroxide (NaOH) during the saponification process on the properties of biodiesel produced from fish waste oil. It was found that varying NaOH concentrations affected key biodiesel characteristics such as viscosity, density, and flashpoint, all of which influence fuel performance in diesel engines. Lower NaOH concentrations resulted in biodiesel with more desirable flow properties and better alignment with ASTM standards, ensuring compatibility with diesel engines. The findings highlight that optimizing NaOH concentration is crucial for producing biodiesel with the appropriate characteristics for both engine performance and safety.

Determination of the biodiesel properties

The properties of biodiesel produced were evaluated by testing various parameters, such as kinematic viscosity, density, calorific value, and flash point as per the ASTM standards. The values were promising when compared with the values of petroleum fuels. The comparison of fuel properties of biodiesel determined with ASTM D 6571 standards is given in Table 3. According to the results, fish oil biodiesel demonstrates favorable properties when compared to ASTM standards. The kinematic viscosity, calorific value, flashpoint, and density values align with specified ranges, indicating that fish oil biodiesel meets the necessary quality standards for safe and efficient use in diesel engines.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XI, November 2024

Table 3. Comparison of the physicochemical properties of biodiesel with ASTM standards

	Quantity
Total marine fish production in Sri Lanka in 2023 [43]	265,615 MT
Monthly average marine production	22,135 MT
Amount of fish waste generated per month (50% of the production)	11,067 MT
Amount of biodiesel produced per 1 Kg of fish waste	21.420g
Biodiesel production potential per month	237 MT

The key properties measured were kinematic viscosity, calorific value (CV), flashpoint, and density. The biodiesel exhibited a kinematic viscosity of 4.4107 mm²/s, which falls within the ASTM standard range of 1.90–6.00 mm²/s, indicating that it is fluid enough for proper engine injection and combustion. The calorific value of the biodiesel was 39.248 MJ/kg, which aligns with the ASTM standard range of 35–43 MJ/kg, confirming that the fuel provides adequate energy content similar to conventional diesel. The flashpoint was measured at 127.5°C, well above the ASTM minimum of 93°C, ensuring that the biodiesel is safe to handle and transport, with a reduced risk of ignition under normal conditions. Lastly, the density of the biodiesel was 0.8766 g/cm³, which is within the ASTM range of 0.860–0.900 g/cm³, indicating that the fuel has an appropriate energy density for effective combustion. Overall, the biodiesel from fish oil produced in this study met the essential ASTM standards, demonstrating that it is a viable and safe alternative to fossil fuels, with suitable properties for use in diesel engines.

Biodiesel production potential

The monthly biodiesel production potential in Sri Lanka was calculated using the data obtained through the experiment and the available literature data. According to the calculation, approximately 237 MT of biodiesel can be produced per month using the fish waste in Sri Lanka as presented in the Table 4.

Table 4. Calculation of monthly biodiesel production potential

Sample	Properties	Fish oil biodiesel	ASTM standard
1	Kinematic Viscosity (mm^2/sec)	4.410	1.90–6 (D445)
2	Calorific Value (MJ/kg)	39.248	35–43 (D240)
3	Flashpoint (°C)	127.5	93(Min) (D93)
4	Density(g/cm^3)	0.876	0.860-0.900

IV. Conclusion

In conclusion, through this research, it has found a potential alternative fuel that has the potential to be used in challenging economic situation in Sri Lanka. The present study estimated that there is a substantial monthly generation potential of 237 MT fish waste biodiesel. Fish oil was successfully extracted using fish waste and it has satisfactory oil characteristics as a potential alternative to fossil fuels. The samples that were prepared using 20% methanol, and 1g of KOH showed the highest product purity and yield. Its properties like Flash point (127.5°C), CV (39.248MJ/kg), Viscosity (4.410 mm^2/sec), and Density (0.876 g/cm^3) were in the close range to the ASTM standards which proves the efficiency of the produced biodiesel. The significance of this research extends beyond mere biodiesel production as a solution to the fuel shortage but also to find an effective solution to the waste management aspect of fish waste within the community. However, it is vital to conduct comprehensive compatibility studies of fish waste oil biodiesel blends and existing boat engines to ensure adherence to standards to avoid negative impacts on the environment and performance. Moreover, optimization of the blending methods is important to enhance fuel characteristics, combustion efficiency and stability

Author Contributions: E.P.R.H.H.W.: Conceptualization, methodology; R.T.A.J.K.L.: formal analysis, writing—original draft; E.P.R.H.H.W., A.M.P.C. and E.R.J.M.D.D.P: supervision, project administration; I.B.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue XI, November 2024

Acknowledgements: We would also like to thank Department of Biosystems Technology, Faculty of Technology, Sabaragamuwa University of Sri Lanka for providing the necessary resources and facilities to conduct our study. Special thanks to Mr. MMA Daumi for their technical assistance.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. K. Bhattarai, W. M. Stalick, S. Mckay, G. Geme, and N. Bhattarai, "Biofuel: An alternative to fossil fuel for alleviating world energy and economic crises," Journal of Environmental Science and Health, Part A, vol. 46, no. 12, pp. 1424–1442, Oct. 2011, doi: 10.1080/10934529.2011.607042.
2. Zulqarnain et al., "A Comprehensive Review on Oil Extraction and Biodiesel Production Technologies," Sustainability, vol. 13, no. 2, Art. no. 2, Jan. 2021, doi: 10.3390/su13020788.
3. N. Armaroli and V. Balzani, "The Future of Energy Supply: Challenges and Opportunities," Angew Chem Int Ed, vol. 46, no. 1–2, pp. 52–66, Jan. 2007, doi: 10.1002/anie.200602373.
4. M. Athar and S. Zaidi, "A review of the feedstocks, catalysts, and intensification techniques for sustainable biodiesel production," Journal of Environmental Chemical Engineering, vol. 8, no. 6, p. 104523, Dec. 2020, doi: 10.1016/j.jece.2020.104523.
5. S. N. Gebremariam and J. M. Marchetti, "Economics of biodiesel production," Energy conversion and management, vol. 168, pp. 74–84, 2018.
6. S. Adipah, "Introduction of Biodiesel as a Sustainable Resource," Journal of Environmental Science and Public Health, vol. 3, no. 1, pp. 99–103, Feb. 2019.
7. H. Esmaeili, "A critical review on the economic aspects and life cycle assessment of biodiesel production using heterogeneous nanocatalysts," Fuel Processing Technology, vol. 230, p. 107224, Jun. 2022, doi: 10.1016/j.fuproc.2022.107224.
8. V. Anu Prasanna et al., "Fish Waste: A Potential Source of Biodiesel," Fermentation, vol. 9, no. 9, Art. no. 9, Sep. 2023, doi: 10.3390/fermentation9090861.
9. M. U. H. Suzihaque, H. Alwi, U. K. Ibrahim, S. Abdullah, and N. Haron, "Biodiesel production from waste cooking oil: A brief review," Materials Today: Proceedings, vol. 63, pp. S490–S495, Jan. 2022, doi: 10.1016/j.matpr.2022.04.527.
10. I. Khan, L. Han, H. Khan, and L. T. Kim Oanh, "Analyzing Renewable and Nonrenewable Energy Sources for Environmental Quality: Dynamic Investigation in Developing Countries," Mathematical Problems in Engineering, vol. 2021, no. 1, p. 3399049, 2021, doi: 10.1155/2021/3399049.
11. Monika, S. Banga, and V. V. Pathak, "Biodiesel production from waste cooking oil: A comprehensive review on the application of heterogenous catalysts," Energy Nexus, vol. 10, p. 100209, Jun. 2023, doi: 10.1016/j.nexus.2023.100209.
12. P. Moriarty and D. Honnery, "What is the global potential for renewable energy?," Renewable and Sustainable Energy Reviews, vol. 16, no. 1, pp. 244–252, 2012.
13. J. F. Costa, M. F. Almeida, M. C. M. Ferraz, and J. M. Dias, "Biodiesel production using oil from fish canning industry wastes," Energy Conversion and Management, vol. 74, pp. 17–23, Oct. 2013, doi: 10.1016/j.enconman.2013.04.032.
14. S. Brahma et al., "Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production," Chemical Engineering Journal Advances, vol. 10, p. 100284, 2022.
15. V. G. Alfio, C. Manzo, and R. Micillo, "From Fish Waste to Value: An Overview of the Sustainable Recovery of Omega-3 for Food Supplements," Molecules, vol. 26, no. 4, Art. no. 4, Jan. 2021, doi: 10.3390/molecules26041002.
16. S. S. Jahan and C. G. Devadason, "Overview of Manufacture of Fish Waste-Derived Biodiesel," IJSR, vol. 12, no. 5, pp. 1217–1227, May 2023, doi: 10.21275/SR23515082537.
17. D. Neupane, "Biofuels from Renewable Sources, a Potential Option for Biodiesel Production," Bioengineering, vol. 10, no. 1, Art. no. 1, Jan. 2023, doi: 10.3390/bioengineering10010029.
18. L. Rocha-Meneses et al., "Recent advances on biodiesel production from waste cooking oil (WCO): A review of reactors, catalysts, and optimization techniques impacting the production," Fuel, vol. 348, p. 128514, Sep. 2023, doi: 10.1016/j.fuel.2023.128514.
19. S. Ariyawansa and G. G. Arachchi, "Utilization of fish waste in Sri Lanka An overview," Tap Chikhoahoc-Congnghe Thuy San, pp. 116–120, 2013.
20. A. Mukhtar et al., "Current status and challenges in the heterogeneous catalysis for biodiesel production," Renewable and Sustainable Energy Reviews, vol. 157, p. 112012, Apr. 2022, doi: 10.1016/j.rser.2021.112012.
21. T. Mizik and G. Gyarmati, "Economic and Sustainability of Biodiesel Production—A Systematic Literature Review," Clean Technologies, vol. 3, no. 1, Art. no. 1, Mar. 2021, doi: 10.3390/cleantechnol3010002.
22. L. Berrang-Ford, J. D. Ford, and J. Paterson, "Are we adapting to climate change?," Global environmental change, vol. 21, no. 1, pp. 25–33, 2011.
23. B. C. Holtom and B. S. O'neill, "Job embeddedness: A theoretical foundation for developing a comprehensive nurse retention plan," JONA: The Journal of Nursing Administration, vol. 34, no. 5, pp. 216–227, 2004.

24. A. Babadi et al., "Emerging technologies for biodiesel production: Processes, challenges, and opportunities," Biomass and Bioenergy, vol. 163, p. 106521, Aug. 2022, doi: 10.1016/j.biombioe.2022.106521.
25. M. Ramos, A. P. S. Dias, J. F. Puna, J. Gomes, and J. C. Bordado, "Biodiesel Production Processes and Sustainable Raw Materials," Energies, vol. 12, no. 23, Art. no. 23, Jan. 2019, doi: 10.3390/en12234408.
26. S. P. Cummings, "The role and future potential of nitrogen fixing bacteria to boost productivity in organic and low-input sustainable farming systems," Environmental Biotechnology, vol. 1, no. 1, pp. 1–10, 2005.
27. G. Pergent et al., "Climate change and Mediterranean seagrass meadows: a synopsis for environmental managers," Mediterranean Marine Science, vol. 15, no. 2, Art. no. 2, Feb. 2014, doi: 10.12681/mms.621.
28. S. S. Oncel, "Microalgae for a macroenergy world," Renewable and Sustainable Energy Reviews, vol. 26, pp. 241–264, Oct. 2013, doi: 10.1016/j.rser.2013.05.059.
29. H. Hosseinzadeh-Bandbafha et al., "Environmental life cycle assessment of biodiesel production from waste cooking oil: A systematic review," Renewable and Sustainable Energy Reviews, vol. 161, p. 112411, Jun. 2022, doi: 10.1016/j.rser.2022.112411.
30. B. Sanjay, "Non-conventional seed oils as potential feedstocks for future biodiesel industries: a brief review," Research Journal of Chemical Sciences, vol. 3, no. 5, pp. 99–103, 2013.
31. O. Tyagi, N. Atray, B. Kumar, and A. Datta, "Production, Characterization and Development of Standards for Biodiesel - A Review," Mapan - Journal of Metrology Society of India, vol. 25, pp. 197–218, Sep. 2010, doi: 10.1007/s12647-010-0018-6.
32. R. U. Baig et al., "Extraction of oil from algae for biodiesel production, from Quetta, Pakistan," IOP Conf. Ser.: Mater. Sci. Eng., vol. 414, p. 012022, Sep. 2018, doi: 10.1088/1757-899X/414/1/012022.
33. R. Guenard, "Poisson from a petri dish," Inform, vol. 32, no. 6, 2021, Accessed: Jun. 23, 2024. [Online]. Available: https://www.aocs.org/stay-informed/inform-magazine/featured-articles/poisson-from-a-petri-dish-june-2021
34. G. Plemann, M. Erdmann, M. Hlusiak, and C. Breyer, "Global Energy Storage Demand for a 100% Renewable Electricity Supply," Energy Procedia, vol. 46, pp. 22–31, Jan. 2014, doi: 10.1016/j.egypro.2014.01.154.
35. M. N. B. Mohiddin et al., "Evaluation on feedstock, technologies, catalyst and reactor for sustainable biodiesel production: A review," Journal of Industrial and Engineering Chemistry, vol. 98, pp. 60–81, Jun. 2021, doi: 10.1016/j.jiec.2021.03.036.
36. A. Harjanne and J. M. Korhonen, "Abandoning the concept of renewable energy," Energy policy, vol. 127, pp. 330–340, 2019.
37. M. A. Bashir, S. Wu, J. Zhu, A. Krosuri, M. U. Khan, and R. J. Ndeddy Aka, "Recent development of advanced processing technologies for biodiesel production: A critical review," Fuel Processing Technology, vol. 227, p. 107120, Mar. 2022, doi: 10.1016/j.fuproc.2021.107120.
38. I. Sotnyk et al., "Determining the optimal directions of investment in regional renewable energy development," Energies, vol. 15, no. 10, p. 3646, 2022.
39. R. Thirukumaran, V. K. Anu Priya, S. Krishnamoorthy, P. Ramakrishnan, J. A. Moses, and C. Anandharamakrishnan, "Resource recovery from fish waste: Prospects and the usage of intensified extraction technologies," Chemosphere, vol. 299, p. 134361, Jul. 2022, doi: 10.1016/j.chemosphere.2022.134361.
40. N. Hasan and M. V. Ratnam, "Biodiesel Production from Waste Animal Fat by Transesterification Using H2SO4 and KOH Catalysts: A Study of Physiochemical Properties," International Journal of Chemical Engineering, vol. 2022, pp. 1–7, Mar. 2022, doi: 10.1155/2022/6932320.
41. M. V. Rodionova, R. S. Poudyal, I. Tiwari, and R. A. Voloshin, "Biofuel production: Challenges and opportunities," International Journal of Hydrogen Energy, vol. 42, no. 12, pp. 8450–8461, Mar. 2017, doi: 10.1016/j.ijhydene.2016.11.125.
42. F. Toldrá-Reig, L. Mora, and F. Toldrá, "Trends in Biodiesel Production from Animal Fat Waste," Applied Sciences, vol. 10, no. 10, Art. no. 10, Jan. 2020, doi: 10.3390/app10103644.
43. "Department of Fisheries and Aquatic Resources." Accessed: May 05, 2024. [Online]. Available: https://www.fisheriesdept.gov.lk/