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# Feasibility and Environmental Considerations of Biodiesel Production from Waste Falafel Oil in Jordan

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**ABSTRACT**

This paper addresses the environmental and sustainability challenges stemming from the improper disposal of used cooking oils in popular Middle Eastern cuisines, particularly falafel. With an estimated annual waste oil production of 54 million liters from approximately 20,000 restaurants in Jordan, a multifaceted methodology is employed to convert burned falafel oil into biodiesel. The approach integrates survey data, laboratory analysis, the design of a biodiesel converter, and a feasibility study to assess the viability of this waste-to-energy initiative. Laboratory results confirm the successful transesterification process, yielding biodiesel with superior combustion properties compared to regular cooking oil, meeting standard biodiesel density criteria. The feasibility study unveils an estimated annual revenue of $54.98 million USD from selling biodiesel, with catalyst costs (methanol and KOH) amounting to $8,013,600 USD, suggesting a positive economic outlook. Beyond economic viability, this initiative aligns with global sustainability goals, emphasizing the potential for biodiesel production from waste falafel oil to be a pioneering solution in waste management and renewable energy in Jordan. Future research directions could focus on scaling up production, conducting environmental impact assessments, and exploring broader applications for biodiesel derived from waste falafel oil. This study contributes to the discourse on sustainable practices, offering a unique and transformative approach to address both environmental and economic challenges associated with waste cooking oils in the culinary industry in Jordan.

**Keywords:** Waste-to-Energy, Biodiesel Production, Waste Cooking Oil, Economic Feasibility.

## 1. INTRODUCTION

In a world increasingly driven by environmental consciousness and the pursuit of sustainable energy sources, the exploration of innovative waste-to-energy solutions has gained significant prominence. Waste-to-energy technologies offer the dual advantage of reducing environmental pollution and simultaneously harnessing valuable energy resources from waste materials. One such novel approach involves the conversion of waste cooking oils, specifically those generated from the popular Middle Eastern cuisines of falafel, into biodiesel—a clean and renewable energy source with substantial environmental benefits.

### *1.1 Biodiesel Worldwide*

Biodiesel production has garnered substantial attention worldwide due to its environmental benefits and potential to reduce dependency on fossil fuels [1]. When blended with conventional diesel, biodiesel has been shown to enhance thermal efficiency, reduce brake specific energy consumption, and improve key fuel properties such as pour point, cloud point, density, and acid value. Furthermore, biodiesel's compatibility with advanced engine technologies, such as exhaust gas recirculation (EGR) and split injection techniques, has resulted in notable enhancements in engine performance, combustion efficiency, and fuel efficiency. Additionally, biodiesel's role in effectively decreasing peak flame temperatures and regulating NOX emissions in diesel engines has garnered significant attention in the quest for cleaner and more sustainable transportation fuels.

The process typically involves the transesterification of vegetable oils or animal fats with methanol or ethanol, facilitated by alkaline or acidic catalysts [2]. This chemical transformation results in biodiesel and glycerol as co-products. Historically, Rudolf Diesel, a French thermal

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engineer, invented the diesel engine in 1893, originally designed to run on peanut oil [3]. However, diesel engines eventually shifted to petroleum-based diesel fuels due to lower viscosity and cost-effectiveness.

The innovative approach explored in this paper seeks to address these concerns by converting burned falafel oil, typically viewed as waste, into biodiesel—a process that not only recycles the oils but also transforms them into a valuable energy resource [4]. This endeavor bridges the realms of gastronomy and renewable energy, offering a sustainable solution to the culinary industry's waste oil problem while contributing to the ever-growing demand for clean and green energy alternatives.

The utilization of cooking oil as a feedstock for biodiesel production has gained considerable attention due to its economic viability and environmental benefits. Used vegetable oils, a common waste product generated during cooking and frying processes, typically contain impurities and elevated levels of free fatty acids (FFAs). To transform this waste into a valuable resource, the used oil must undergo purification, and the concentration of FFAs must be determined to facilitate the subsequent biodiesel production process [5,6].

One distinguishing factor between fresh vegetable oil and used cooking oil lies in the presence of solid particles in the latter. These solid particles can significantly affect the overall mass of sodium hydroxide (NaOH) required for the transesterification reaction, as they are not directly involved in the chemical conversion process [7]. Therefore, precise measurement and consideration of the FFA content and impurities are essential when determining the appropriate quantity of NaOH for efficient biodiesel production.

Despite the challenges posed by impurities and FFAs, used cooking oil remains a preferred feedstock for biodiesel production for several compelling reasons. One of its primary advantages is its cost-effectiveness and availability. Used cooking oil is readily accessible, and many establishments, including hotels, restaurants, and households, are eager to have it removed from their premises. In many cases, those possessing used cooking oil are willing to pay biofuel collection companies to facilitate its removal, resulting in a streamlined and cost-efficient collection process. This initial step is pivotal in the transformation of cooking oil into a sustainable biofuel source [8,9].

The commercial production and utilization of biodiesel have evolved over the years, marked by significant milestones and global adoption. Biodiesel, a renewable and environmentally friendly fuel, has a rich history that traces its roots back to various regions.

In 1985, a pioneering agricultural institution in Austria achieved a notable milestone by constructing the world's first biodiesel manufacturing unit designed explicitly for fuel production [10]. This innovation laid the foundation for the commercial production of biodiesel, marking a crucial step towards sustainable fuel alternatives.

Europe emerged as a frontrunner in commercial biodiesel production, with Germany taking the lead in 1992 [11]. Germany's early entry into the biodiesel market signaled the continent's commitment to reducing its dependence on fossil fuels and mitigating environmental impacts.

Meanwhile, in the United States, the commercial production of biodiesel commenced in 1991 in Kansas City, Missouri. A noteworthy application of biodiesel within the country's national parks gained attention when Yellowstone National Park incorporated biodiesel produced by the University of Idaho into one of its vehicles. This biodiesel-powered truck, after covering hundreds of thousands of miles, demonstrated not only the viability of biodiesel but also its engine-friendly attributes [12]. Subsequently, other national parks across the United States followed suit, adopting biodiesel for their vehicle fleets.

The global promotion of biodiesel gained momentum in the early 2000s. By 2001, worldwide biodiesel consumption had reached approximately 0.3 billion gallons [4]. Biodiesel was embraced by a growing number of nations, driven by its environmental benefits, ease of use, and various federal and state incentives. In the United States, biodiesel consumption experienced a remarkable surge, growing from approximately 10 million gallons in 2001 to around 2 billion gallons in 2016 [13]. This substantial increase was partly attributed to the federal Renewable Fuels Standard (RFS) Program, which incentivized the incorporation of biodiesel into the national fuel mix.

### *1.2 Biodiesel in Jordan*

In the context of Jordan, where culinary traditions involving falafel and shawarma thrive, the high potential of waste cooking oil as a biofuel source presents a unique opportunity. Jordan consumes about 180,000 tons of oil annually, with a notable proportion being imported [ 14]. However, the country's biomass energy sector is gradually growing, with a recent analysis indicating the generation of 3.5 MW of power from biomass resources [14]. Nevertheless, information on biofuels specifically generated in Jordan remains limited.

The Jordanian Renewable Energy and Energy Efficiency (JREEE) law no. 13 of 2012 identified bioenergy as a renewable source of energy but primarily focused on using biomass feedstock in electricity generation, omitting biofuel production (Jordanian Renewable Energy and Energy Efficiency Fund, 2012). Despite the potential of biodiesel, especially from waste cooking oils, Jordan's energy policy classifies it as a non-renewable source, potentially limiting its benefits. Additionally, the directive on regulating the activity of industrial fuel from waste makes a clear distinction between biofuel and industrial fuel, further impacting the categorization of biodiesel [15].

This study recognizes the high potential of falafel, not only as beloved culinary traditions but also as potent sources of waste cooking oil. It is a region where these culinary delights are both emblematic of cultural heritage and a thriving industry, making their waste oils a significant concern. Within the Middle East region, the consumption and popularity of falafel extend far beyond Jordan's borders, magnifying the scope and impact of this waste-to-energy initiative. The approach explored in this paper seeks to address these concerns by converting burned falafel oil, typically viewed as waste, into biodiesel—a process that not only recycles the oils but also transforms them into a valuable energy resource. This endeavor bridges the realms of gastronomy and renewable energy, offering a sustainable solution to the culinary industry's waste oil problem while contributing to the ever-growing demand for clean and green energy alternatives.

## 2. METHODOLOGY

This section outlines the methodology employed for the conversion of burned falafel oil into biodiesel, along with laboratory analysis, the design and construction of a waste oil to biodiesel converter, and a feasibility study. The study aimed to assess the feasibility of biodiesel production from waste falafel oil in Jordan.

### *2.1 Survey and Data Collection*

To estimate the annual amount of waste falafel oil generated in Jordan, a comprehensive survey was conducted. The survey included visits to a representative sample of Jordan's approximately 20,000 falafel restaurants. Data collection involved recording the monthly waste oil production, with an average of 450 liters for falafel restaurants and 360 liters for shawarma restaurants per month. Data collection involved recording the monthly waste oil production, with an average of 450 liters for falafel restaurants and 360 liters for shawarma restaurants per month.

### *2.2 Analysis of Survey Results*

The collected data was analyzed to determine the average monthly production of waste cooking oil per restaurant type. It was found that, on average, falafel restaurants produce approximately 450 liters of waste oil per month, while shawarma restaurants produce an average of 360 liters of waste oil per month.

### *2.3 Evaluation of Waste Falafel Oil Potential*

The study evaluated the cumulative potential of waste cooking oil from all falafel restaurants in Jordan. This assessment considered the total number of restaurants and the average waste oil production per restaurant type.

### *2.4 Biodiesel Production Feasibility Study and Economic Analysis*

Subsequently, a feasibility study was conducted to assess the technical, environmental, and economic aspects of converting the collected waste cooking oil into biodiesel. This involved investigating the conversion process, identifying necessary equipment and resources, and evaluating the environmental benefits and economic viability of the proposed biodiesel production.

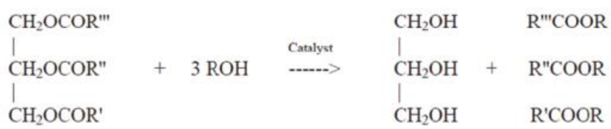
The economic analysis considered the costs and benefits of implementing a biodiesel production system using waste cooking oil. This included the estimation of initial setup costs, operating expenses, potential revenue from biodiesel sales, and any available government incentives or subsidies.

### *2.5 Laboratory Analysis of Waste Falafel Oil*

Samples of waste cooking oil from selected restaurants were collected and subjected to laboratory analysis. These analyses included assessing the quality and characteristics of the waste oil, such as acidity levels, moisture content, and impurities, to determine its suitability for biodiesel production, as shown in Fig. 1.

Fig. 1. Laboratory analysis of waste falafel oil

In the laboratory, the transesterification process was executed by mixing the waste cooking oil samples with methanol, under controlled conditions. A catalyst, potassium hydroxide (KOH), was introduced to facilitate the reaction resulting in the production of biodiesel and glycerin, as shown in Equation 1 [16].




The co-product, glycerin, holds significance in various industries, including pharmaceuticals and cosmetics, where it finds extensive use [16].

The laboratory procedure aimed to convert waste vegetable oil, obtained from two different falafel restaurants, into biodiesel. Two distinct samples of waste oil were utilized in this study: the first sample comprised soy oil, while the second was palm oil. It is noteworthy that the palm oil sample exhibited a notable presence of fat or grease, an observation that will be discussed for its potential impact in subsequent sections of this study. The soy oil sample totaled 500 ml, while the palm oil sample amounted to 474 ml.

The transesterification process requires specific quantities of potassium hydroxide (KOH) and methanol for each liter of oil used. To determine the precise amounts of KOH and methanol required for the conversion of the waste vegetable oil samples into biodiesel, the following relation was utilized:

1 l of oil → 7g of KOH and 200 ml of methanol

From this relationship, the quantities of KOH and methanol necessary for the transesterification process were calculated based on the volume of each waste oil sample. These calculations will be further detailed and discussed in the subsequent sections to provide insights into the feasibility of converting the waste cooking oil from falafel restaurants in Jordan into biodiesel.

*2.6 Prototype Design and Development*

A biodiesel production prototype was designed and developed, incorporating a control unit for efficient and controlled conversion of waste cooking oil into biodiesel. The prototype was equipped with the necessary processing equipment, reactors, and safety mechanisms to ensure the biodiesel production process adhered to established standards.

Illustrating the operational process and user comprehension of the device can be effectively conveyed through a block diagram, shown in Fig. 2. Before activation, the device must be connected to the facility's power source, and the oil filter tank should be filled with used oil. For safety reasons, the device will not operate unless the circuit breaker is engaged.

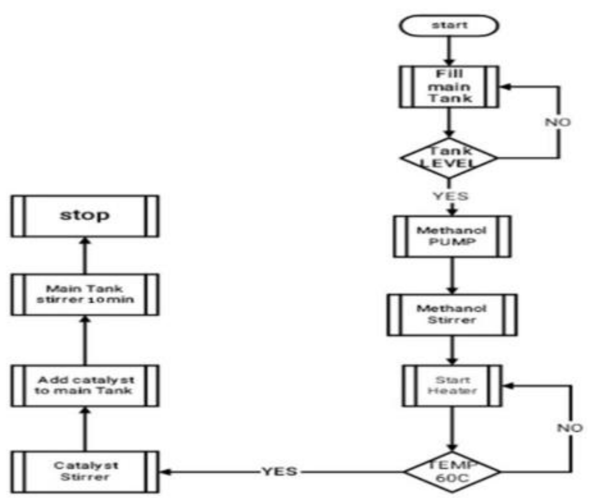



Fig. 2. Block diagram of the designed biodiesel prototype

The operational status of the device is indicated by the illuminated red light. The current temperature of the main tank is displayed as the initial temperature (PV), while the user's set temperature, in this instance 60 degrees Celsius, is also shown. Temperature control, within a range of 62 °C, is facilitated through a variable resistance mechanism. Upon entering the desired temperature, the controller prompts the user to press the start button, initiating the device and sending signals to all connected components as outlined in the block diagram.

The controller instructs the pump for filtered oil to transfer oil from the filter tank to the main tank. The oil level is continuously monitored until it reaches the predetermined goal of 8 liters. To ensure accurate measurement, a float is utilized in the main tank, serving the dual purpose of confirming the presence of 8 liters of used oil and safeguarding the heater from exposure to air, preventing potential burning and excess starting current. Once the float signals the controller that the main tank contains 8 liters, the methanol pump is activated, and the oil pump is deactivated. The methanol pump completes its task when the stirrer in the methanol and KOH tank initiates operation.

Following these steps, the heating process, a crucial component of the system, is addressed. The heater operates in cycles: heating the oil for 10 seconds, allowing it to cool for 5 seconds, and then reheating for another 10 seconds. This cycle ensures uniform temperature distribution throughout the container. Concurrently, the thermometer continually compares the current temperature with the desired temperature, maintaining precision in the heating process, with the target temperature set at 60 °C.

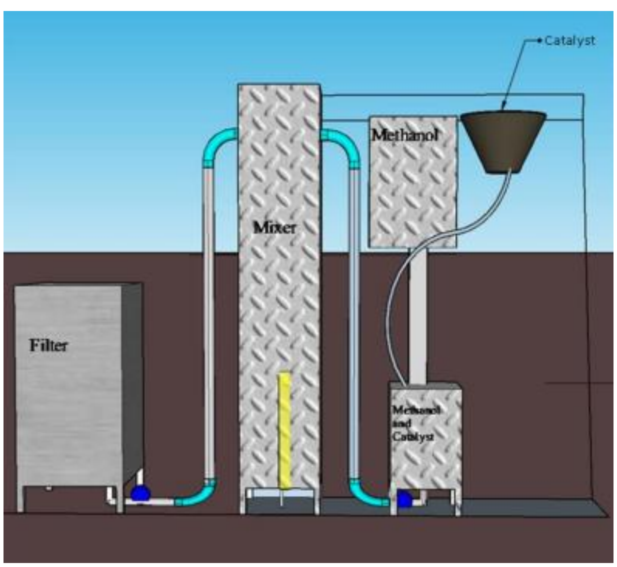


Fig. 3. Front view of the designed biodiesel prototype

## 3. RESULTS AND DISCUSSION

The results obtained from the laboratory analysis and feasibility study provide valuable insights into the potential of producing biodiesel from waste falafel oil. The transesterification process proved effective in converting burned falafel oil into biodiesel, with the separated top layer exhibiting characteristics consistent with biodiesel standards. Density measurement aligned with the standard biodiesel density of 0.87 g/ml. The flash points for the biodiesel samples were determined to be 159°C for the biodiesel produced from burned soy oil and 163°C for the biodiesel produced from burned palm oil, both of which were previously used for frying falafel.

The burning test, shown in Fig. 4, further demonstrated the combustion efficiency of the biodiesel, evidenced by a brighter flame and a stronger yellow color compared to regular unused cooking oil. This indicates the potential for the produced biodiesel to serve as a viable alternative fuel source. Additionally, the feasibility study underscores the economic viability of this waste-to-energy initiative. The revenue potential, considering the estimated annual waste oil production in Jordan and a 90% yield rate, demonstrates a positive financial outlook.

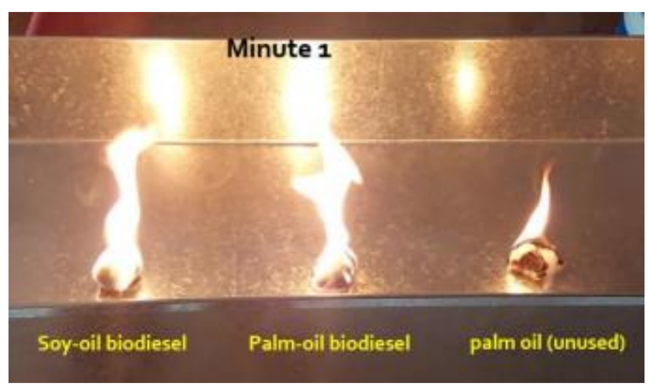
The results of the laboratory analysis and feasibility study are summarized as follows:

Laboratory Analysis Results:

Transesterification effectively converted waste falafel oil into biodiesel.

Density measurement aligned with the standard biodiesel density of 0.87 g/ml.

Burning test demonstrated superior combustion characteristics compared to regular unused cooking oil.



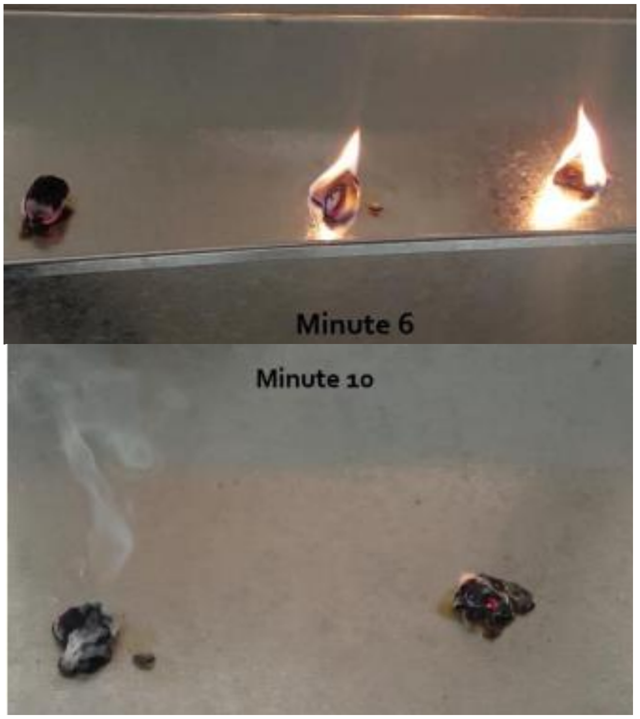



Fig. 4. Comparative combustion analysis of biodiesel produced from waste soy and palm oil used for falafel frying, alongside biodiesel from fresh palm oil.

When comparing the burning characteristics, biodiesel produced from burned soy and palm oil used for falafel frying exhibited a more favorable combustion profile compared to fresh oil. The flames of the biodiesel from waste oil demonstrated enhanced cleanliness, featuring a better flame color and reduced smoke emission, in contrast to the combustion fresh oil. Quantitative assessments of crucial parameters, including flash point and density, further underscored the improved combustion efficiency of biodiesel from used cooking oil. This comparison underscores the potential environmental advantages of repurposing waste falafel oil for biodiesel production, emphasizing its positive influence on combustion performance when compared to both traditional diesel and biodiesel derived from fresh oil sources.

Estimated annual waste oil production in Jordan is substantial, contributing to a potential revenue of approximately $54.98 million USD.

The cost of catalysts (methanol and KOH) amounted to $8,013,600 USD.

With a biodiesel price of $1.13 USD per liter and assuming a 90% yield rate, the revenue from selling biodiesel is economically viable.

Implications and Future Directions

The successful production of biodiesel from waste falafel oil holds significant implications for Jordan's energy landscape and waste management practices. This waste-to-energy solution not only addresses environmental concerns associated with improper disposal but also contributes to the country's renewable energy goals. The feasibility study suggests that this initiative can be economically sustainable, encouraging further exploration and implementation on a larger scale.

Future directions for research could include scaling up the production process to assess its viability in a larger context. Additionally, further investigations into the environmental impact, emissions profile, and long-term sustainability of biodiesel produced from waste falafel oil would enhance our understanding of its broader implications.

The need for a paradigm shift in Jordan's energy policy is evident, considering the current regulatory framework that categorizes biofuels, specifically biodiesel produced from waste resources, as a non-renewable source of energy. Despite the Jordanian Renewable Energy and Energy Efficiency (REEE) law acknowledging bioenergy as a renewable energy source in 2012, its focus on using biomass feedstock solely for electricity production leaves a critical gap. The directive on Regulating the Activity of Industrial Fuel from Waste introduces definitions distinguishing between biofuel and industrial fuel. While biofuels are broadly defined to include hydrocarbon materials from various sources, the designation of industrial fuel excludes the renewable aspect, considering the resulting oil or gas as non-renewable fuel. This classification underpins the existing policy, limiting the biofuel sector's eligibility for benefits outlined in renewable energy laws and tax redemption bylaw No. 13 for the year 2015. The exemptions specified in the bylaw, exclusively for certain biomass energy systems generating electricity, fail to align with the broader definition of industrial fuel. For instance, biomethane produced from solid waste using anaerobic digestion, a potentially sustainable process, is not covered. Even though biodiesel is recognized as a renewable energy source, its production systems and inputs are overlooked in the exemptions provided by law No. 13 for the year 2015. This incongruity in the regulatory landscape underscores the urgent need for policy amendments that embrace the potential of biodiesel, especially from waste sources, as a renewable and sustainable energy solution in Jordan.

## 4. CONCLUSION

The combination of laboratory analysis, the design and construction of a biodiesel converter, and a feasibility study collectively demonstrates the potential of converting waste falafel oil into a valuable and economically viable biodiesel. This waste-to-energy initiative aligns with global efforts toward sustainable practices and offers a unique solution to the culinary industry's waste oil problem in Jordan. The successful production of biodiesel from waste falafel oil not only addresses environmental concerns associated with improper disposal but also contributes to the country's renewable energy goals. The current Jordanian energy policy, classifying biofuels, including biodiesel from waste resources, as non-renewable, hinders their recognition under renewable energy laws. There is a pressing need for policy adjustments to acknowledge the renewable potential of biodiesel, aligning regulations with its sustainable contributions.

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**DECLARATION OF INTEREST STATEMENT**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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