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# Prospects of Synthetic Biodiesel Production from Various Bio-Wastes in Jordan

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## ABSTRACT

The main objectives of this technical experiment are to quantify the amount of various bio-wastes available for the bioenergy development in Jordan and investigate the prospects of biodiesel potentials from such bio-wastes using catalytic depolymerization technology developed in the German company ALPHAKAT. The quantification process revealed substantial quantities of bio-wastes originated from various sectors such as dairy and poultry farms, by-products of wastewater treatment plants, and agriculture by-products. The results show that olive cake provides the highest potential for biodiesel production with a ratio of 39%. Chemical analysis showed varying levels of sulfur contents, which required desulfurization unit to produce standard quality biodiesel. Chemical analysis also showed high phosphorus content, which provided another economic opportunity to use the biodiesel by-products as a fertilizer. The statistical correlation test showed a strong linear correlation between the percentage of organic content and caloric value and biodiesel output. The study also unveiled that the C:H ratio is strongly correlated with the biodiesel production model. The regression analysis generated a model for biodiesel production, which can be used to evaluate the biodiesel production based on the net dry biomass and C:H ratio in the substrate. Based on the model, the study estimated the potential of biodiesel from olive cake to reach up to 4 million liters annually. Policymakers and involved governmental institutes are advised to develop new regulations and laws to increase the share of bioenergy in the primary energy mix through attracting co-public investments accompanied by supportive economic tools such as starter loans, tax exemptions, and feedin-tariffs. Further research is needed to quantify other sources of bio-wastes such as cooking-oil wastes.

**Keywords:** Synthetic Biodiesel; Olive Cake; Depolymerization; Jordan

## 1. Introduction

Bioenergy has been increasingly viewed as a quintessential tool to produce environmentally-friendly energy to help mitigate climate change and improve the livelihoods of poor people [1-3]. This approach is of particular importance if bioenergy embraces the utilization of bio-wastes from various human's end-use sources into usable forms of energy for transportation purpose. The recently resonated opposition to bioenergy is deeply-rooted and largely explained by the use of edible crops such as maize or sugar cane or the use of edible plant oils such as date palm to produce first-generation biofuels for transportation use in the US, Brazil, and the European Union (EU). Edible oils and edible crop-based biofuels (bioethanol, biodiesel) were obstinately perceived to jeopardize staple food production and thus do not meet the predefined sustainability criteria's especially in developing countries [4-6]. However, landfill-destined, post-consumer, forests procurement and agriculture by-products bio-wastes are more appealing and widely supported by policymakers and the scientific community worldwide [1,3,7]. Proponents of bioenergy predominantly perceive it as a carbon-neutral, policy tool to encourage energy diversity, security and independence, and an attractive socio-economic tool to enhance rural livelihoods [1-3]. It presently contributes approximately 10% of global primary energy supply whilst the traditional use of biomass for cooking, space heating, and lighting presently accounts for roughly 80% of the global bioenergy use [1]. In the European Union (EU), the consumption of biofuels in transportation is continued to increase, albeit at a slower pace, standing at 14 million tons of oil equivalent (Mtoe) with biodiesel and is the prime biofuel used followed by bioethanol [8]. Globally, annual biodiesel production in-

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creased from 15 thousand barrels per day in 2000 to 289 thousand barrels per day in 2008 [9]. Biofuels are primarily prescribed and ultimately used for transportation use. The transportation sector is the second largest energy consuming sector thus responsible for the lion-share of green-house gases emissions worldwide. Furthermore, the projected increase in the number of cars per 1000 capita, especially in the Middle East and China and the demand for fossil-derived energy in this sector are expected to more than double with anticipated staggering levels of road emissions [10]. In this and other veins, developing new strains of low-carbon fuels and from biosources is an unequivocal policy approach to curb emissions, reduce urban pollution, and ultimately localize energy production [3]. Modern bioenergy processes and technologies have gained innovational stampede accompanied by scientific impetus to produce new energy carriers such as biohydrogen, bioethanol, biodiesel, and biogas to meet, at least partly, the growing demand for energy [1,3,11,12]. Biodiesel or FAME (fatty acid methyl esters) is simply defined as a chemically modified diesel-like fuel produced from mainly non/edible plant oils, microalgae, and animal fat through a series of chemical reactions using alcohols in the presence or absence of chemical catalysts [12-16]. Due to the naturally-occurring high viscosity, low volatility, and polyunsaturated characters of plant oils used in biodiesel production, a number of chemical processes are developed of which transesterfication is mostly used and preferred. Transesterfication requires the use of methanol or ethanol in the presence of catalysts to produce fatty acid esters and glycerol. Basically, it transforms long and branched triglyceride molecules into smaller esters. Other processes are used to overcome such difficulties involving blending/dilution, micro-emulsification, heating/pyrolysis, thermal cracking, and magnetically stabilized fluidized bed reactor [13-16]. Two other processes to produce biodiesel include Fischer Tropsch technology, which is currently used to convert synthetic biogas into biodiesel. The other process is the catalytic depolymerization process. Depolymerization is a process for the reduction of complex organic materials into light crude oil. It mimics the natural geological processes thought to be involved in the production of fossil fuels. Under pressure and heat, long chain polymers of hydrogen, oxygen, and carbon decompose into short-chain petroleum hydrocarbons with a maximum length of around 18 carbons [17]. The process is also used to depolymerize complex polymers such as polyethylene and lignin [14,18]. Biodiesel has a number of advantages over conventional diesel. Essentially if it is produced from non-staple food crops, if it is used as a complement to other energy sources, and if the plant oils or energy-dictated crops are grown on set-aside or degraded lands [1,3,9], it is also imperative to pacify or, preferably, overcome negative publicity through elevateing public awareness and knowledge of bioenergy and its benefits [19]. The production and use of biofuels are anticipated to increase in the coming decades through using increasingly sophisticated processes [3,11]. Therefore, cultivating greater attention to locally produced biodiesel and from local bio-wastes is an attractive policy and a future planning strategy. Jordan is a relatively small country centered in the heart of the politically instable Middle East and refered to as the Near East. Jordan lacks the prime natural resources mainly fresh renewable water resources, forests, and possesses trivial conventional fossil fuel resources. Consequently, energy for domestic and industrial purposes is predominantly fueled by permanent import of fossil fuels (crude oil) from neighboring countries particularly from Iraq and Saudi Arabia, and Natural Gas (NG) from Egypt [20]. The negative repercussions of the high oil prices and subsidies, population growth and the influxes of refugees, political instability, and poor planning have led to the paralyzed economy characterized by chronic energy crisis and alarming public debt. On the other hand, the public is obstinately opposing building nuclear power plant yet they exhibit positive attitudes toward harnessing local renewable energy and bioenergy resources [21]. The Jordanian government has set a road map for the development and deployment of renewable energy to increase its share in the primary energy mix from 7% in 2015 up to 10% in 2020 [20]. While several demonstration projects in solar and wind energy are currently taking place, however, utilization of the local bio-wastes is currently underdeveloped. Therefore, this paper will discuss the economic and technological side of testing six substrates of different organic raw materials from Jordan using the catalytic deploymerization process by using innovative technology in Germany known as ALPHAKAT. The main objectives of this search are:

1) To identify and quantify the bio-wastes resources in Jordan;

2) To conduct lab analysis for the biodiesel characteristics from such identified source;

3) To investigate the economic potentials of producing biodiesel from local resources.

At the policymaking level, this paper will assist stakeholders, decision makers, and investors to make science-based decision for establishing innovative and pilot bioenergy projects in the future. This technical paper can also be considered as a baseline study for researchers in the field of bioenergy in Jordan.

## 2. Methodology

This research project has been implemented in many stages. In the first stage, a survey of all organic wastes types and potential quantities in Jordan has been conducted. The bio-wastes potentials were estimated by contacting the relevant institutions and labor associations directly involved production operations such as the Poultry Producers Association, Fruits and Vegetables Producers and Exporters Association, Dairy Cattle Association, and some governmental institutions such as Ministry Agriculture. Geographical distribution was also performed through Geographical Information System (GIS) to generate biomass maps. After bio-wastes being identified and quantified, six organic wastes were selected for testing biodiesel production. These substrates are: olive cake, activated sludge, digested sludge, sheep manure, poultry manure, and laying hens manure. These substrates were selected according to the physical and logistic aspects such as: high potential, ease of collecting, ease of cleaning and grinding, ease of drying, and the moisture content. Chemical analysis for the selected organic materials involved testing cellulose, hemi-cellulose, and lignin contents. Other parameters were identified for the selected substrates such as moisture content, organic material content, H:C ratio, and percentage of caloric value. Due to the lack of biodiesel production and testing facilities in Jordan, a number of samples were prepared and packaged to be shipped to Germany for testing synthetic biodiesel potentials and quality. Synthetic diesel quality was later compared to quality standards for fuel in different markets and for different end-users (e.g. EN 590 the European standard for transportation diesel). During the preparation of the samples for shipping and according to the European Commission (EC) regulations, the research team acquired sterilization certificate for the animal organic wastes, health certificate from the Ministry of Agriculture/Department of Veterinary and Phytosanitary Department, and exporting and importing licenses for the sample packages. Regarding statistical analysis, *t*-test was performed to investigate correlation relationships among the study variables followed by linear regression analysis to model the biodiesel production.

### ALPHAKAT Technology

ALPHAKAT machine is a German patent and developed to produce synthetic biodiesel using catalytic depolymerization process. The catalyst used was developed and patented by Dr. Christian Koch. The machine is preheated with 350 kg of thermo-oil and 30 kg of calcium hydroxide Ca(OH)2. The process of pre-heating takes approximately 2.5 hours. The machine is heated in 2 main points: Mixer heat at 180˚C and the Reactor heat should arrive to 250˚C. As the required temperature is achieved, organic materials and calcium hydroxide are inserted through the feeder through conveyor tube, which delivers the materials to the mixer where the organic substrates and the thermo-oil as well as the calcium are well mixed. The function of calcium hydroxide has two main effects: 1) It reacts with the chloride in the organic substrate and becomes neutralized and 2) It reacts with other elements in the substrates to create the optimal catalyst for the reaction—such as calcium aluminum silicate. The mixed material is transferred through a tube to the reactor at (230 - 300)˚C and there a reaction occurs at 1/10 of a millisecond. Organic material is depolymerized and turns into gas molecules where carbon and hydrogen are converted into biodiesel gas. All gases are transferred to the distiller column to be cooled and separated at different temperatures. The biodiesel gas flows through a separate pipe and condense into biodiesel liquid, which accumulates in the biodiesel tank. The $H_2O$ gas is separated after condensation and flows into a separate tank.

## 3. Results and Discussion

**Table 1** shows the estimated quantities of organic wastes in Jordan. As indicated, there is a great potential for bioenergy production in Jordan, whether for biogas or biodiesel prospects. The largest available bio-wastes quantities stem from the municipal solid wastes, however, these wastes are not sorted, rendering utilization a difficult approach at the moment. Therefore, developing landfill sorting techniques would encourage the utilization of such underdeveloped quantities. Jordan has made a tangible progress in developing new wastewater treatment (WWT) plants using activated sludge process [22]. Therefore, the available quantities of bio-wastes are increasing steadily and provide a great potential for bioenergy development prospects. The traditional "stabilization ponds" for municipal liquid wastes still exists in Jordan; therefore, they provide another opportunity to develop bioenergy projects with vast environmental and economic benefits. The biggest challenge to bioenergy development in Jordan is the scattered wastes across the country especially regarding bio-wastes from animal husbandry and farming (sheep, dairy cattle and beef) and poultry production farms. The "*All in all out*" approach means centralizing all production facilities of poultry production in one location and that location is established away from residential areas, which centralizes the bio-wastes in one utilizable location. In this prospect, encouraging large farms to develop methods of utilizing the available bio-wastes into usable forms of energy is an attractive policy and developmental approach, which reduces the costs of production by generating part of the energy needs. Olive cake and vegetables cropping residues are currently underutilized quantities thus need to be targeted and included in future bioenergy development plans. Olive cake is presently processed and pressed to produce briquettes for space heating or charcoal-like product for grill use. When conducting the

**Table 1. Estimated organic wastes quantities from various sectors and description of the tested samples.**

| Organic waste category | Sub-category | Organic matter (ton DM/ year) | No of samples[2] | Quantity shipped (ton) | Physical status |
|---|---|---|---|---|---|
| Animal husbandry | | | | | |
| | Sheep manure | 8282 | 2 | 1.5 | Dried & milled[3] |
| | Beef farms manure | 10,036 | - | | |
| | Dairy cattle manure | 113,507 | - | | |
| | Poultry manure | 50,150 | 3 | 2.25 | Dried & milled |
| | Laying hens manure | 47,661 | 3 | 2.25 | Dried & milled |
| Wastewater (sludge) | | | | | |
| | Activated sludge | 87,383 | 3 | 2 | Dried & milled |
| | Digested | 30,801 | 3 | 2 | Dried & milled |
| Municipal solid wastes | MSW | 137,534 | | | |
| Agro-food | Olive cake | 47,203 | 2 | 1.5 | Dried & milled |
| Agriculture and forestry | Grain crops residues[1] | 40,000 | - | | |
| | vegetables crops residues | 60,000 | - | | |
| | Forests | 400 | 3 | 2 | Dried & milled |

[1] Used only for sheep and goat grazing during summer time and crop rotation-mostly rainfed thus quantities varies considerably; [2] The packaged sample that were shipped to Germany; [3] To less than 0.2 mm particle size.

chemical analysis, it was assumed that the chemical compounds and the production efficiency are correlated. The percent of organic matter combined with the H:C ratio is indicative of the Syn-diesel production potential. The H:C ratio is strongly dependent upon the relative percentages of lignin (ADL), cellulose (CEL) and Hemicellulose (HC), which forms the Total Crude Fiber (TCF). Neutral Detergent Fiber (NDF) is made up of four main chemical components. Quantitatively the largest, cellulose and hemicellulose, the other main components of NDF are lignin and cutin. Acid Detergent Fiber (ADF) is basically NDF without the hemicellulose, which can be removed by boiling NDF in acid detergent solution. **Table 2** shows the results of the chemical analysis for five selected substrates. As indicated, olive cake obtained the highest caloric value, and therefore contains the largest amount of energy potential. Digested sludge, on other hand, showed low organic value, and clearly low NDF fraction, therefore results in low calorific value and low energy potential. Furthermore, animal derived substrates, such as sheep and chicken manure, obtained high energetic values because they contain relatively high organic fraction, however contains low potential for biodiesel production due to the low NDF fraction. Further chemical analysis was conducted to investigate the concentrations of approximately 31 minerals. **Table 3** shows the results of some selected minerals with considerable importance to this study. The olive cake showed the highest concentrations of carbon and hydrogen compared the rest of organic bio-wastes. Sludge materials (activated & digested) showed highest concentrations of sulfur compared to the rest of biowastes. Olive cake on the other hand, showed the lowest concentration of sulfur. These high levels will be taken into account, when evaluating the final cost of the Syndiesel product. A desulfurization unit is therefore needed to eliminate the high levels of sulfur to adjust to EU590 Bio-Diesel standard. This will add further costs to produce standardized biodiesel up to 5%. Regarding the elements required for the formation of the catalyst. The concentrations of aluminum (Al), calcium (Ca) and silicate (Si) are in sufficient amount for the formation of Calcium-aluminum-Silicate. The high phosphorus concentrations are indicative for the potential use of the biodiesel by-products as an agricultural fertilizer.

The final stage of this study is to evaluate the biodiesel potential from each of the selected substrates. As indicated by **Table 4**, olive cake showed the highest potential for biodiesel production. The rest of organic bio-wastes showed relatively lower potential of biodiesel potentials. These results can be explained by the high concentration of carbon and hydrogen in both olive cake and agriculture residues. As mention earlier, olive cake resources are currently scattered and underutilized; therefore, such source provides greater potential for biodiesel production in Jordan. Municipal solid wastes were excluded from the

**Table 2. Chemical analysis of bio-wastes substrates.**

| Type of biowaste | Caloric value | Dry matter (%) | Organic matter (%) | Ash (%) | ADF (%) | NDF (%) | ADL (%) | HC (%) | CEL (%) | TCF (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Olive cake | 4553 | 94.1 | 93.6 | 6.4 | 57.1 | 63.8 | 25.9 | 6.6 | 31.2 | 63.7 |
| Digested sludge[1] | 1696 | 89.5 | 23.5 | 42 | 10 | 24.1 | 1.8 | 14.1 | 8.2 | 24.1 |
| Sheep manure | 3007 | 93.9 | 53 | 47 | 29.4 | 51 | 13.2 | 21.6 | 16.2 | 51 |
| Laying hens manure | 2797 | 95.6 | 69.5 | 30.5 | 21.3 | 44.2 | 4.8 | 22.9 | 16.5 | 44.2 |
| Poultry manure | 3312 | 92.1 | 84.3 | 15.7 | 22.3 | 45.8 | 5.5 | 23.5 | 16.8 | 45.8 |

[1] Activated sludge assumed to have similar chemical composition to digested sludge in terms of organic matter content.

**Table 3. Selected minerals concentrations in selected bio-wastes (mg/Kg dry matter).**

| Element | Olive cake | Activated sludge | Digested sludge | Laying hens manure | Sheep manure | Poultry manure |
|---|---|---|---|---|---|---|
| Phosphorus | 3795.0 | 11493.0 | 15778.0 | 19500.0 | 7512.0 | 16548.0 |
| Sulfur | 3436.0 | 8026.0 | 10782.0 | 4410.0 | 4300.0 | 6480.0 |
| Calcium | 23780.0 | 56020.0 | 163600.0 | 95500.0 | 43220.0 | 30860.0 |
| Aluminum | 1535.0 | 4500.0 | 6733.0 | 319.0 | 2500.0 | 783.0 |
| Silica | 123.0 | 224.0 | 222.0 | 123.0 | 253.0 | 289.0 |

**Table 4. Synthetic diesel quantity and percentage from various substrates using catalytic depolymerization.**

| Type of biowaste | Input amount (Kg) | Diesel output (Liter) | Mixer temp (˚C) | Reactor temp (˚C) | Catalyst ($Ca(OH)_2$) Kg | Diesel output (Kg) | Diesel output (%) |
|---|---|---|---|---|---|---|---|
| Olive cake | 72.5 | 34.5 | 197 | 280 | 2.81 | 28.29 | **39.02** |
| Activated sludge | 30.3 | 5.5 | 180 | 225 | 1.5 | 4.51 | 14.88 |
| Digested sludge | 29 | 4.5 | 200 | 240 | 1.5 | 3.69 | 12.72 |
| Sheep manure | 30 | 5.3 | 190 | 235 | 1.5 | 4.346 | 14.49 |
| Laying hens manure | 31 | 5.4 | 192 | 220 | 1.5 | 4.428 | 14.28 |
| Poultry manure | 30 | 5.5 | 180 | 262 | 0.8 | 4.51 | 15.03 |

[1] Catalyzer inserted in the beginning of the process = 30 Kg; [2] Thermo oil inserted in the beginning of the process = 350 Kg.

process of biodiesel production due to difficulties to sort and mechanically prepare it for analysis. It also contains other waste materials such as plastics, metals, and broken glasses. The correlation and linear regression tests were deployed using SPSS statistical package to reveal links between the study variables and the production of biodiesel and generate a regression model based on the analysis. The results showed that under 85% organic content, there is a strong linear correlation between the percentage of organic content ($R^2 = 0.677$) and caloric value ($R^2 = 0.893$) and the biodiesel production from a given substrate. However, above 85% organic content the production of biodiesel is affected by the C:H ratio in the organic matter ($R^2 = 0.607$), which is highly correlated to the NDF in the organic substrate. Plant-derived organic substrates contain high NDF thus high C:H ratio, which increases the biodiesel potential. In order to obtain the final correlation equation between the organic substrate and the biodiesel output, a conversion of the original material into the dry organic material was calculated as follow:

Net Organic Dry mass = (%) Organic biomass × Dry matter × (%) Organic matter

The result of the net organic dry mass can be used in the correlation between C:H ratio and the diesel output as follow:

$y = 0.033x + 0.005$

Where: y expected diesel output from single unit (1 Kg) of the net dry organic biomass, and x is the C:H ratio of the organic weight.

**Table 5** summaries the economic potentials of biodiesel production from various biosources. As indicated, the volume of biodiesel quantities may reach up to 14 million liters, which demonstrates a very attractive in-

**Table 5. Summary of biodiesel production potentials and estimated costs based on the regression model.**

| Type of biowaste | Annual weight of ORM (ton DM/yr) | Total processing cost $US/ton[1] | Diesel output liters/ton | Total diesel output (liters) | Processing cost of liter ($US) |
|---|---|---|---|---|---|
| Olive cake | 47,203 | 127 | 475.0 | 4,248,270 | 0.19 |
| Activated sludge | 30,801 | 62 | 181.5 | 1,232,040 | 0.22 |
| Digested sludge | 87,383 | 62 | 155.0 | 3,495,320 | 0.26 |
| Sheep manure | 8282 | 78 | 183.0 | 455,510 | 0.30 |
| Laying hens manure | 47,661 | 78 | 174.0 | 2,621,355 | 0.32 |
| Poultry manure | 50,150 | 78 | 183.0 | 2,758,250 | 0.30 |

[1] The cost of processing includes the purchasing cost of raw material (the highest was for olive cake).

vestment opportunities especially in the light of the current fossil fuel prices. The costs of purchasing olive cake may associate with the higher costs of biodiesel production; however, the processing cost of one liter appeared the lowest.

## 4. Conclusion

The study indicates relatively high bio-wastes potentials in Jordan, especially from animal husbandry and farming, olive cake, and wastewater treatment plants. Municipal solid wastes provide a potential if sorting techniques are deployed or household recycling is encouraged. In this study, olive cake appeared the best option for biodiesel production while other biosources might be tested for biogas production. Other sources of biodiesel production potentially arise from utilizing cooking-oil at the domestic level and particularly in restaurants, which are used in substantial quantities on daily bases, therefore, further research is needed to quantify such wastes quantities and investigate biodiesel production opportunities. In terms of the policy development, policymakers and the government are encouraged to develop new sets of regulations and laws to navigate the pathway to the bioenergy development through encouraging private investments and using economic instruments such as taxexemptions, starter loans with low interest rates, and issuing distinguished bioenergy certificates. More investments in R & D are required to embark on economic analysis and environmental impact assessment. Training and outreach campaigning for large scale dairy and poultry farms to develop in-site bioenergy production facilities are win-win approaches with various economic and environmental benefits to the enterprises and the local economy. At the education level, new lines of bioenergy education are required to prepare well-trained and educated personnel to fill-in new employment opportunities in bioenergy sector. These prospect projects can also utilize the financing tools of climate change such as Clean Development Mechanism (CDM) and emissions trading schemes (ETS).

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