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Abstract

The aim of this study was to provide business plan for implementing a biodiesel production company from used cooking oil in Algeria. Biodiesel could be considered as an excellent renewable fuel and an effective alternative fuel for conventional diesel. It has many positives like high biodegradability, reduction in greenhouse gas emissions, non-sulfur emissions, non-particulate matter pollutants, low toxicity, excellent lubricity and is obtained from renewable source. In the current study, Transesterification was used for producing biodiesel using cooking oil which was collected free of charge from local restaurant in Saida. From 400 ml of used cooking oil, 380 ml of biodiesel and 60 ml of glycerol (by-product) were obtained. The density value of this biodiesel was 870.8 kg/m^3 which meets EN 14214 (860-900 kg/m^3); whereas, viscosity was found to be 6.314 mm^2/s at 30°C just out of the standard range of 1.9-6.0 mm^2/s. Used cooking oil is a cost effective and promising feedstock. Instead of being wasted, we recommend it for producing biodiesel, which can be directly used as fuel in a diesel engine in pure form or as blends without any modifications to the engine.

Key words: Biodiesel, Renewable fuel, used cooking oil, Transesterification, Glycerol, Business plan.

Résumé

L'objectif de cette étude était de fournir un plan d'affaires pour la mise en place d'une société de production de biodiesel à partir d'huile de cuisson usagée en Algérie. Le biodiesel peut être considéré comme un excellent combustible renouvelable et une alternative efficace aux carburants diesel conventionnels. Il présente de nombreux avantages tels qu'une biodégradabilité élevée, une réduction des émissions de gaz à effet de serre, l'absence d'émissions de soufre, de particules polluantes, une faible toxicité, une excellente lubrification et est obtenu à partir de sources renouvelables. Dans cette étude, la transestérification a été utilisée pour produire du biodiesel à partir d'huile de cuisson récupérée gratuitement dans un restaurant local à Saida. À partir de 400 ml d'huile de cuisson usagée, 380 ml de biodiesel et 60 ml de glycérol (sous-produit) ont été obtenus. La valeur de densité de ce biodiesel était de 870,8 kg/m^3, ce qui répond à la norme EN 14214 (860-900 kg/m^3) ; tandis que la viscosité était de 6,314 mm^2/s à 30°C, juste au-dessus de la valeur standard de 1,9-6,0 mm^2/s. L'huile de cuisson usagée est une matière première rentable et prometteuse ; au lieu d'être gaspillée, nous la recommandons pour la production de biodiesel, qui peut être utilisé directement comme carburant dans un moteur diesel sous forme pure ou en mélange, sans aucune modification du moteur.

Mots clés : Biodiesel, Carburant renouvelable, Huile de cuisson usagée, Transestérification, Glycérine, Plan d'affaires.

ملخص

هدفت هذه الدراسة إلى تقديم خطة عمل لتنفيذ شركة لإنتاج وقود بيولوجي (البايوديزل) من زيت الطهي المستعمل في الجزائر. يمكن اعتبار الوقود بيولوجي وقودًا متجددًا ممتازًا وبديلاً فعالًا للديزل التقليدي. يتمتع بخصائص فريدة مثل التحلل الحيوي العالي وتقليل انبعاثات غازات الاحتباس الحراري وعدم وجود انبعاثات الكبريت والملوثات الناتجة عن المواد الجسيمية وانخفاض السمية وقدرته الممتازة على التشحيم واستمداده من مصدر متجدد.في الدراسة الحالية، تم استخدام عملية الأسترة التحويلية لإنتاج البايوديزل باستخدام زيت الطهي الذي تم جمعه مجانًا من مطعم محلي في سعيدة. تم الحصول على 380 مل من البايوديزل و60 مل من الجليسيرول (المنتج الفرعي) من 400 مل من زيت الطهي المستخدم. قيمة الكثافة لهذا البايوديزل كانت 870.8 كجم/م^3 وهي تفي بمعايير البايوديزل لاتحاد الأوروبي (900-860 كجم/م^3)، بينما تم العثور على قيمة اللزوجة أنها 6.314 ملم^2/ثانية عند درجة حرارة 30 درجة مئوية، وهي قريبة من النطاق القياسي الموصى به الذي يتراوح بين 1.9-6.0 ملم^2/ثانية.زيت الطهي المستعمل هو مادة خام فعالة من حيث التكلفة وواعدة. بدلاً من تبذيره، نوصي باستخدامه لإنتاج وقود البيولوجي الذي يمكن استخدامه مباشرةً كوقود في محركات الديزل على شكل نقي أو كمزيج دون أي تعديلات على المحرك.

الكلمات المفتاحية: وقود بيولوجي، وقود متجدد، زيت الطهي المستخدم، عملية الاسترة، الغليسرين، خطة عمل.

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General introduction

1.0 Background

In the 21st century, the world has been confronted with several challenges, including energy sustainability, environmental problems, and the continuous rise of fuel prices. Conventional fuels are known for contribution to air pollution, releasing harmful emissions such as sulfur dioxides, carbon dioxides, particulate matter and other gases. The transportation sector worldwide has considerably increased the fuel consumption reaching 61.5% of the total, especially in the last decade (1). Consequently, sustainable fuel alternatives are becoming a high priority for many countries and are bound to play a major role in the fuel industry in the immediate future. Among these alternatives, liquid biofuels are gaining recognition as a highly sustainable option to address the ever-increasing demand and mitigate environmental concerns, such as the depletion of fossil fuel reserves and the threat of global warming.

Biodiesel has emerged as a leading sustainable alternative to traditional petroleum-based fuels due to its similar combustion characteristics as petroleum diesel (2) (3). It can be produced from both edible and non-edible oils, both of which include renewable sources like vegetable oils, animal fats, and used cooking oils (UCO) via the transesterification reaction (4).

Developing countries possess a comparative advantage for biodiesel production due to the great availability of land, favorable agricultural climatic conditions and lower labor costs (5). Developed countries are increasingly adopting modern technologies and efficient bioenergy conversion processes that utilize a variety of biofuels. These biofuels are becoming more cost-competitive with fossil fuels, leading to a growing trend in their use (6).

The global success and commercialization of biodiesel have been accompanied by the establishment of standards to guarantee high product quality and user confidence. Several standards exist for biodiesel, including ASTM D6751 (American Society for Testing and Materials) and EN 14214 (European norm) (7).

Biodiesel is gaining increasing attention globally as a blending component or a direct substitute for diesel fuel in vehicle engines (8).For example, B5 used in Europe contains 5 % of biodiesel and 95 % of petro diesel. Biodiesel blends up to B20 can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment. These low-level blends generally do not require any engine modifications (9).

Table 1. Biodiesel standards (10)

Country/Area	Specifications	Title
EU	EN 14213	Heating fuels - Fatty acid methyl esters (FAME) - Requirements and test methods
EU	EN 14214	EN 14214 Automotive fuels - Fatty acid methyl esters (FAME) for diesel engines - Requirements and test methods
U.S	ASTM D 6751	ASTM D6751 - 11a Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
Australia	-	Fuel Standard (Biodiesel) Determination 2003
Brazil	ANP 42	Brazilian Biodiesel Standard (Agência Nacional do Petróleo)
India	IS 15607	Bio-diesel (B 100) blend stock for diesel fuel - Specification
Japan	JASO M360	Automotive fuel - Fatty acid methyl ester (FAME) as blend stock
South Africa	SANS 1935	Automotive biodiesel fuel

2.0 Aims and objectives

The main objectives of this business project is:

- To provide an in-depth understanding of the principles and concepts of biodiesel production.
- To develop a comprehensive business plan for a biodiesel production company.
- To create a clear representation of the business model for the biodiesel production venture.
- To design and develop a working prototype.
- To conduct a feasibility analysis on producing and utilizing biodiesel for small and medium-sized business.

3.0 Project plan structure

The business project is structured in a) theoretical background part, where the fundamental concepts and principles of biodiesel and its significance as a sustainable fuel alternative are discussed, Followed by, glycerol chapter, where we examined the properties of glycerol and explored its biotechnological applications in various industries, b) the business plan chapter, where detailed suggestions for the incorporation of a biodiesel production company are given, including production plan, financial plan, marketing strategy and experimental prototype which describes the design and testing of the product. Finally, c) the conclusion chapter, which summarizes the main findings of the study followed by concluding remarks about the feasibility of the proposed business.

Theoretical background

Chapter 1: Biodiesel Production and Properties

1.0 Introduction to biodiesel

As petroleum resources used to produce fuel are dwindling, the demand for alternative fuels is increasing. In combination with the increasingly stringent regulations, this poses a major challenge for science and technology. The use of bioenergy has provided an effective approach to address the scarce availability of petroleum and its influence on the environment (11). Biodiesel is a lucrative commodity in the global economy as there is mounting concern related to the environment and oil depletion related to petroleum production. Biodiesel is environmentally friendly, sustainable, and possesses similar combustion characteristics as petroleum diesel (12) (13).

Chemically, biodiesel is defined as the monoalkyl esters of long-chain fatty acids derived from renewable biolipids. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol or ethanol in the presence of a catalyst to yield methyl or ethyl esters (biodiesel) and glycerine (14).

Biodiesel can be derived both edible and non-edible oils, both of which include renewable sources, such as vegetable oils, animal fats, and waste cooking oils through trans-esterification reaction (15). The most common method to produce biodiesel is trans-esterification of vegetable oils, waste animal fats, and waste restaurant greases with a short-chain alcohol (16). As a renewable, sustainable and alternative fuel for compression ignition engines, biodiesel is widely accepted as comparable fuel to diesel in compression ignition engines (17).

Table 2: Technical properties of biodiesel

Common name	Biodiesel (bio-diesel)
Common chemical name	Fatty acid (m)ethyl ester
Chemical formula range	C14−C24 methyl esters or C15−25 H28−48 O2
Kinematic viscosity range(mm2/s, at 313 K)	3.3−5.2
Density range (kg/m3, at 288 K)	860−894
Boiling point range (K)	>475
Flash point range (K)	430−455
Distillation range (K)	470−600
Vapor pressure (mm Hg, at 295 K)	<5
Solubility in water	Insoluble in water
Physical appearance	Light to dark yellow, clear liquid
Odor	Light musty/soapy odor
Biodegradability	More biodegradable than petroleum diesel
Reactivity	Stable, but avoid strong oxidizing agents

2.0 Used cooking oil as feedstock for biodiesel production

Used cooking oil refers to the used vegetable oil obtained from cooking food. Repeated frying for preparation of food makes the edible vegetable oil no longer suitable for consumption due to high free fatty acid (FFA) content (18). Waste oil has many disposal problems like water and soil pollution, human health concern and disturbance to the aquatic ecosystem (19) (20), so rather than disposing it and harming the environment, it can be used as an effective and cost efficient feedstock for biodiesel production as it is readily available (21) (22) (23) (1) (24) (25) (26) (27)

UCOs have different properties from those of refined and crude vegetable oils (28).The chemical and physical properties of UCO are different from those of fresh oil since some changes due to chemical reactions - such as hydrolysis, oxidation, polymerization, and material transfer between food and vegetable oil occur during the frying process .The typical chemical and physical characteristics of UCO are shown in Table 3.The usual values for properties like density, kinematic viscosity, saponification value, acid value and Iodine value are shown in the table (1).

Table 3: Main properties of used cooking oil (1)

Property	Units	Value
Density	g /cm^3	0.91-0.924
Kinematic viscosity	mm^2/s	36.4-42
Saponification value	mgKOH/g	188.2-207
Acid value	mgKOH/g	1.32-3.6
Iodine number	gI2/100g	83-141.5

UCO as a feedstock offers the twin advantages of breaking the food supply chain that is causing harmful diseases and providing a cheaper alternative to the growing demands of fossil fuels. Also, using UCO as a feedstock helps to reduce the production cost of biodiesel (29).

3.0 Biodiesel production process

Biodiesel can be produced from a great variety of feedstocks. These feedstocks include most common vegetable oils (e.g., soybean, cottonseed, palm, peanut, rapeseed/canola, sunflower, safflower, coconut) and animal fats (usually tallow) as well as waste oils (e.g., used frying oils). The choice of feedstock depends largely on geography. Depending on the origin and quality of the feedstock, changes to the production process may be necessary.

To obtain biodiesel, the vegetable oil or animal fat is subjected to a chemical reaction termed transesterification. In that reaction, the vegetable oil or animal fat is reacted in the presence of a catalyst (usually a base) with an alcohol (usually methanol) to give the corresponding alkyl esters (or for methanol, the methyl esters) of the fatty acids mixture that is found in the parent vegetable oil or animal fat (30).

The transesterification reactions the most common method of converting triglycerides (TAG) from oils into methyl esters (biodiesel). The conversion of UCO into biodiesel through the transesterification process reduces the molecular weight to one-third, reduces the viscosity by about one-seventh, reduces the flash point slightly, increases the volatility marginally and reduces pour point considerably (31). Then, the fuel produced has approximately the same property of petrodiesel and can be used in conventional diesel engines without any change in this last. The main factors affecting transesterification reaction and produced esters yield are: the molar ratio of alcohol: oil, type of alcohol, type and amount of catalyst, reaction temperature, pressure and time, mixing intensity as well as the contents of FFA and water in oils (32). Figure 1 depicts the transesterification reaction.

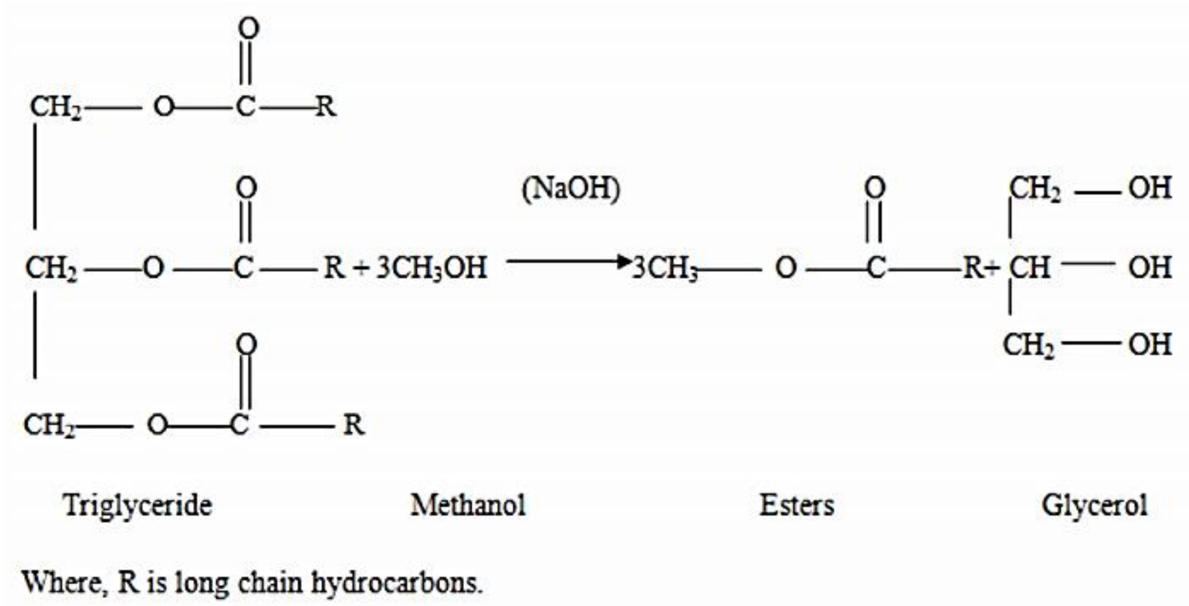

Figure 1: A schematic representation of the transesterification reaction (33)

4.0 Biodiesel properties

Biodiesels are characterized by their viscosity, density, cetane number, cloud and pour points, distillation range, flash point, ash content, sulfur content, carbon residue, acid value, copper corrosion, and higher heating value (HHV). The most important variables affecting the ester yield during the transesterification reaction are the molar ratio of alcohol to vegetable oil and reaction temperature. The viscosity values of vegetable oil methyl esters decrease sharply after transesterification. The flash point values of vegetable oil methyl esters are significantly lower than those of vegetable oils. There is high regression between the density and viscosity values of vegetable oil methyl esters. The relationships between viscosity and flash point for vegetable oil methyl esters are considerably regular (34).

4.1 Density

Density is another important property of biofuel. Density is the mass per unit volume of any liquid at a given temperature. Specific gravity is the ratio of the density of a liquid to the density of water. Density has importance in diesel-engine performance since fuel injection operates on a volume metering system (35). Also, the density of the liquid product is required for the estimation of the cetane index (36).

The range stipulated by EN 14214 standards for biodiesel at 15C° is from 860 to 900 kg/m^3. Fuel that exceeds the density limit specification causes the fuel pump to inject a greater mass of biodiesel, which affects the air-fuel ratio, engine performance, and combustion characteristics of the fuel (37) (38). Biodiesel fuel is denser than petrodiesel but less compressible due to its higher molecular weight (39) (40). Biodiesel density is also dependent on the oil extraction method, the composition of fatty acids in the feedstock, and the degree of fuel purity (41).

4.2 Kinematic viscosity

Viscosity is a measure of resistance to flow of a liquid due to internal friction caused by one part of a fluid moving over another (42).

The properties of biodiesel are similar to those of diesel fuels. Viscosity is the most important property of biodiesels since it affects the operation of fuel injection equipment, particularly at low temperatures when an increase in viscosity affects the fluidity of the fuel. High viscosity leads to poorer atomization of the fuel spray and less accurate operation of the fuel injectors. The lower the viscosity of the biodiesel, the easier it is to pump and atomize and achieve finer droplets (43).

Acceptable limits of kinematic viscosity at 40C° for biodiesel are 1.9-6.0 and 3.5-5.0 mm^2/s based on the American and European standards, respectively. The upper limit ensures smooth flow in cold weather conditions, while the lower limit prevents potential power loss in the engine (44). The value of kinematic viscosity is higher by a factor of around 1.6 in biodiesel compared to petrodiesel, and this value is higher at low temperatures (45). An increase in temperature decreases the viscosity of biodiesel samples because weak intermolecular forces allow molecules to flow more freely (38). The lower the viscosity, the easier it is to pump, atomize, and achieve finer droplets (46).

4.3 Acid number (Acid value)

Acid number or neutralization number is a measure of the amount of free fatty acids contained in a fresh fuel sample and of free fatty acids and acids from degradation in aged samples. This test is used to determine the acidic constituents in the biodiesel. If mineral acids are used in the production process, their presence as acids in the finished fuel is also measured with the acid number. It is expressed in mg KOH required to neutralize 1 g of the fatty acid methyl ester (FAME) (47).

The acidic compounds that could possibly be found in biodiesel are: 1) residual mineral acids from the production process, 2) residual free fatty acid from the hydrolysis process or the post-hydrolysis process of the esters and 3) oxidation byproducts in the form of other organic acids (48).

4.4 Flash point

Flash point measures the flammability of fuels. It is the minimum temperature at which fuel ignites on exposure to flame or air. It is a critical property for evaluating hazards during transport and storage. Usually, biodiesel has high flash point than petrodiesel making it less volatile and safer to transport and store in enclosed areas such as underground mines (49) (50).

A higher flash point may cause incomplete combustion in diesel engines as compared to petrodiesel, resulting in the formation of carbon deposits in the combustion chamber (50). Flash point specification is intended to meet insurance and fire regulations. It serves to protect the engine against residual methanol, which should not exceed 0.20% (m/m) according to the European biodiesel standard (45).

4.5 Cetane number

Cetane number is a dimensionless parameter related to the time required for liquid fuel to auto ignite rapidly after injection into a compression ignition engine (41) (51). It significantly influences ignition delay. Cetane number is determined by comparing ignition delay of fuel sample to that of hexadecane with a cetane number of 100 and heptamethylnonane with a cetane number of 15 based on an established standard cetane scale (52) (51). A high cetane number indicates a short ignition delay, which is favorable for good engine performance (51). High cetane numbers enhance working performance in cold weather conditions, promote complete combustion, and minimize the formation of white smoke, carbon monoxide, hydrocarbon, nitrogen oxides (NOx), and particulate matter emissions (53) (38) (54).

4.6 Cloud point and pour point

Initially, cooling temperatures cause the formation of solid wax crystal nuclei that are submicron in scale and invisible to the human eye. Further decreases in temperature cause these crystals to grow. The temperature at which crystals become visible [diameter (d) $\geq$ 0.5 μm] is defined as the cloud point (CP) because the crystals usually form a cloudy or hazy suspension. At temperatures below CP, larger crystals (d ~ 0.5–1 mm × 0.01 mm thick) fuse together and form large agglomerates that can restrict or cut off flow through fuel lines and filters and cause start-up and performance problems the next morning. The temperature at which crystal agglomeration is extensive enough to prevent free pouring of fluid is determined by measurement of its pour point (PP) (55).

Pour point defines the lowest temperature at which biodiesel losses its flowability when tested in a controlled environment. Cessation of flow may result from an increase in viscosity or due to the crystallization of wax from the oil. Cloud point is the lowest temperature at which the first crystal formation in biodiesel begins. The pour point and cloud point of biodiesel depend on the fatty acid profiles of the parent feedstock. These values for biodiesel tend to be higher than that of petrodiesel, especially the long-chain, saturated fatty acid esters (37) (46) (52).

4.7 Calorific value

Calorific value, sometimes called heating value or heat of combustion, is a standard that measures the total energy content produced in the form of heat when a substance is combusted completely with air or oxygen (41) (46). It is a standard for the optimal operation of an engine. The calorific value of FAME is relatively lower, 10 and 12% lower energy content (MJ/kg) on a mass basis compared with petrodiesel (38) (56).This is due to the higher oxygen content of the biodiesel, which aids its proper combustion in an engine, and helps to decrease its oxidation potential (56) (49).

4.8 Sulfur content

Generally, biodiesel has an almost negligible sulfur content (57) (45). According to EN and ASTM standards, maximum sulfur content should be 10 mg/kg and 15 ppm, respectively. Sulfur content is determined in ASTM D6751 according to D5453 by observing ultraviolet fluorescence of fuel sample during combustion which signals the amount of sulfur emitted in the sample. The sulfur content limit set for biodiesel is important for engine operation since high content affects automotive catalyst systems negatively, and it has detrimental effects on human health and the environment through sulfur dioxide emissions (49).

4.9 Phosphorus content

Phosphorus in FAMEs stems from phospholipids (animal and vegetable material) and inorganic salts (used frying oil) contained in the feedstock (58). Phosphorus can damage catalytic converters used in emission-control systems and its level must be kept low. Catalytic converters are becoming more common on diesel-powered equipment as emissions standards are tightened, so low phosphorus levels are gaining importance (47).

ASTM D6751 and EN 14214 specify maximum phosphorous content as 0.001% and 4.0 mg/kg, respectively. High levels of phosphorous in biodiesel poison the catalytic converter in vehicles, leading to high particulate emission and decreased engine combustion efficiency (45). The presence of phosphorous in oil leads to a considerable reduction in biodiesel yield by 3%-5% (59), but can be reduced by increasing stages of purifications (60).

Table 4. European biodiesel standard (EN 14214) (10)

Property	Test method	Limits		Unit
		min	max	
Ester content	EN 14103	96.5	-	% (m/m)
Density at 15°C	EN ISO 3675, EN ISO 12185	860	900	kg/m^3
Viscosity at 40°C	EN ISO 3104, ISO 3105	3.5	5.0	mm^2/s
Flash point	EN ISO 3679	120	-	°C
Sulfur content	EN ISO 20846, EN ISO 20884	-	10.0	mg/kg
Carbon residue (in 10% dist. residue)	EN ISO 10370	-	0.30 %	(m/m)
Cetane number	EN ISO 5165	5 1	-	-
Sulfated ash	ISO 3987	–	0.02	%(m/m)
Water content	EN ISO 12937	-	500	mg/kg
Total contamination–	EN 12662	-	24	mg/kg
Copper strip corrosion (3 hours, 50°C)	EN ISO 2160	-	1	class
Oxidative stability, 110°C	EN 14112	6.0	-	hours
Acid value	EN 14104	-	0.50	mg KOH/g
Iodine value	EN 14111	-	120	g I/100 g
Linolenic acid content	EN 14103	-	12	% (m/m)
Content of FAME with ≥4 double bonds		-	1	% (m/m)
Methanol content	EN 14110	-	0.20	% (m/m)
Monoglyceride content	EN 14105	-	0.80	% (m/m)
Diglyceride content	EN 14105	-	0.20	% (m/m)
Triglyceride content	EN 14105	-	0.20	% (m/m)
Free glycerine	EN 14105 ; EN 14106	-	0.02	% (m/m)
Total glycerine	EN 14105	-	0.25	% (m/m)

Alkali metals (Na + K)	EN 14108; EN 14109	-	5.0	mg/kg
Earth alkali metals (Ca + Mg)	EN 14538	-	5.0	mg/kg
Phosphorus content	EN 14107	-	10.0	mg/kg

Table 5. Biodiesel standard ASTM D6751 (United States) (10)

Property	Test Method	Limits		Units
		min	max	
Calcium & Magnesium, combined	EN 14538	-	5	ppm (µg/g)
Flash Point (closed cup)	D 93	93	-	°C
Alcohol Control (one to be met): 1. Methanol Content 2. Flash Point	 EN 14110 D93	 - 130	 0.2 -	 % (m/m) °C
Water & Sediment	D 2709	-	0.05	% (v/v)
Kinematic Viscosity, at 40 °C	D 445	1.9	6.0	mm^2/sec.
Sulfated Ash	D 874	-	0.02	% (m/m)
Sulfur: S 15 Grade S 500 Grade	 D 5453 D 5453	 - -	 0.0015 0.05	 % (m/m) % (m/m)
Copper Strip Corrosion	D 130	-	3	No.
Cetane	D 613	47	-	-
Cloud Point	D 2500	report		°C
Carbon Residue, 100% sample	D 4530	-	0.05	% (m/m)
Acid Number	D 664	-	0.05	mg KOH/g
Free Glycerin	D 6584	-	0.020	% (m/m)
Total Glycerin	D 6584	-	0.240	% (m/m)
Phosphorus Content	D 4951	-	0.001	% (m/m)
Distillation Atmospheric equivalent temperature 90% recovery	D 1160	-	360	°C
Sodium/Potassium, combined	EN 14538	-	5	ppm (µg/g)
Oxidation Stability	EN 15751	-	3	hours
Cold Soak Filtration For use in temperatures below -12 °C	D7501 D7501	-	360 200	seconds seconds

5.0 Biodiesel blends

Blends of biodiesel and conventional hydrocarbon-based diesel are produced by mixing biodiesel and petroleum diesel in suitable proportions under appropriate conditions. Much of the world uses a system known as the "B" (61) factor to state the amount of biodiesel in any fuel mix:

- 100% biodiesel is referred to as B100, while
- 20% biodiesel, 80% petrodiesel is labeled B20
- 5% biodiesel, 95% petrodiesel is labeled B5
- 2% biodiesel, 98% petrodiesel is labeled B2

5.1 Mixing of biodiesel blends

Blending biodiesel with petroleum diesel may be accomplished by (62):

1. Mixing in tanks at manufacturing point prior to delivery to tanker truck
2. Splash mixing in the tanker truck (adding specific percentages of biodiesel and petroleum diesel)
3. In-line mixing, two components arrive at tanker truck simultaneously.
4. Metered pump mixing petroleum diesel and biodiesel meters are set to X total volume, transfer pump pulls from two points and mix is complete on leaving pump

5.1.1 Splash mixing method

The most common and least accurate method of blending used for biodiesel is splash blending (63). Splash blending is done when a truck is already having diesel pumped with biodiesel. The temperature of biodiesel should be 18 to 20 degree Celsius when diesel is colder than 8 degree Celsius (62).

5.1.2 In line mixing method

Inline blending is done with two storage tanks containing biodiesel components and refinery-produced diesel or diesel components passing through a pipe and hose, mixed in a particular ratio and collected in a third, final product tank (62). This method allows large volume blends in one go. To avoid the risk of shock crystallization, it is better to have biodiesel temperature 6 degrees Celsius above cloud point. Keeping biodiesel in a diesel tank for a long time is not advisable (62). Although this method offers better blend consistency for biodiesel than splash blending, density and viscosity changes in the biodiesel require adjustments to the meters for an accurate blend (64).

5.1.3 Injection mixing

Injection mixing is the blending of fuels in tanks at a manufacturing point prior to delivery to the tanker truck. In this method, valve controls ensure that a particular quantity of biodiesel components is injected along with the diesel product in a particular ratio (62).

5.2 Biodiesel B100

B100 is 100% biodiesel. It has a solvent effect and it can clean a vehicle's fuel system and release deposits accumulated from previous petroleum diesel use. The release of these deposits may initially clog filters and require filter replacement (61). It may require special handling and equipment modifications. To avoid engine operational problems, B100 must meet the requirements of ASTM D6751 (62).

5.3 Biodiesel B20

B20 is a common blend because it represents a good balance of cost, emissions, cold-weather performance, materials compatibility, and ability to act as a solvent. Generally, B20 and lower-level blends can be used in current engines without modifications. In fact, many diesel engine original equipment manufacturers (OEMs) approve the use of B20.

Engines operating on B20 have similar fuel consumption, horsepower, and torque to engines running on petroleum diesel. B20 with 20% biodiesel content will have 1% to 2% less energy per gallon than petroleum diesel, but many B20 users report no noticeable difference in performance or fuel economy. Biodiesel also has some emissions benefits, especially for engines manufactured before 2010 (65).Biodiesel blend B20 must meet prescribed quality standards—ASTM D7467 (66).

5.4 Biodiesel B5

A B5 blend is 5% biodiesel and 95% petroleum based diesel. It is one of the most common blends associated with biodiesel because of the use of a B5 blend in state or municipal mandates. Most major engine manufactures have approved of the use of a B5 blend in their engines. The American Standard for Testing and Materials (ASTM) which sets the international standards for diesel fuel has revised its statements so that a B5 blend is treated the same as conventional diesel ASTM D97508a (62).

5.5 Biodiesel B2

B2 is a blend of 2% biodiesel, 98% petrodiesel. It is one of the most common blends associated with biodiesel. It is used in fleets, tractor trailers, off road heavy equipment, on road light duty fleets (67).

6.0 Transportation and storage of biodiesel

6.1 Transportation

Transportation of products from their point of production to the distribution centers/ end-users may account for up to 10% of the final product cost. Biodiesel can be transported in the same way as diesel. Long-distance transportation of liquid fuels by pipelines is undoubtedly one of the most efficient approaches, but the transportation of biodiesel or its blends over long distances via pipeline is yet to become a mainstream method. The biodiesel industry currently relies on trucks, rail, and, in some places, on barge modes of transportation. The relative cost of different modes of transport is affected by two major factors, the distance to be traveled and the quantity of biodiesel to be transported. For short distances, transport trucks offer better economics and greater flexibility as they offer a faster loading and delivery schedule. The rail and barge modes are more appropriate when large volumes of biodiesel are to be transported over long distances. Besides cost, the other important considerations when envisaging transportation of biodiesel include introduction of contaminants, material compatibility, freezing of biodiesel under cold conditions, and the flammability of biodiesel blends (68).

The temperature required to induce gelling (freezing) in biodiesel is generally higher than that of conventional diesel fuel and depends on the composition of the biodiesel. In particular, saturated methyl esters will have higher freezing points than unsaturated methyl esters. The composition of the biodiesel is, of course, dictated by the oil feedstock used for its production (69).

The material compatibility is also an important property to consider with biodiesel. Biodiesel should be transported in a clean and sufficiently dry container to prevent the inadvertent introduction of impurities and moisture. Only the biodiesel and diesel are acceptable as residues, and the container should preferably be made of stainless steel, carbon steel, or aluminum. Because biodiesel is corrosive to certain metals, prolonged contacts with such metals are to be avoided. Contact of biodiesel with moisture is known to be conducive to the growth of microorganisms and may lead to its degradation. The hoses and seals should be made of materials compatible with biodiesel and must be dry and clean. Insulation systems may be required when biodiesel is to be transported through cold regions as the fuel tends to freeze under low-temperature conditions. Alternatively, an in-built heating system may be incorporated to be used during offloading of biodiesel as it would ensure the fuel crystals return to the liquid state. Biodiesel blends (in kerosene or diesel) can be transported similarly. For biodiesel blends, additional safety measures are required as the flashpoint of biodiesel blends is midway between that of diesel or kerosene and biodiesel. For neat biodiesel, no warning signs and placards are required as its flammability is low (68).

6.2 Storage

Storage of biodiesel generally does not pose any significant challenge except concerning the fuel stability when it is to be stored for prolonged durations. Obviously, the storage tanks should be made of compatible metals. Underground storage tanks avoid crystallization of the fuel as underground temperatures are usually higher than the crystallization onset temperature for biodiesel. These challenges are prevalent in cold climatic conditions when biodiesel is to be kept in aboveground storage tanks. Insulation, in-built heating systems, and cold property enhancers can be used to prevent the crystallization of biodiesel when stored in aboveground tanks (70).

To avoid the formation of crystals, biodiesel should be stored at a temperature at least 15˚F higher than the pour point of the fuel. For most pure biodiesel storage temperatures of 45-50˚F are generally adequate. Blends of biodiesel with standard diesel can frequently be stored at lower temperatures. These blends still need to be stored at least 15˚F above pour point temperature for the blend. The formation of crystals is reversible as heating of the biodiesel can be used to melt the crystals. Alternatively, the crystals can be filtered from the biodiesel (69).

Stability of the biodiesel is an important attribute if the biodiesel is to be stored for a prolonged period. Poor stability can lead to increasing acid numbers, increasing fuel viscosity, and the formation of gums and sediments. Information about the stability of the stored biodiesel can be achieved by monitoring the acid number and viscosity. Storage stability of biodiesel has not been extensively examined relative to its composition. Therefore, the current best practice involves not storing biodiesel or biodiesel blends for more than six months. The stability of stored diesel fuels can be enhanced by using antioxidants. Examples of acceptable antioxidants include t-butylhydroquinone (TBHQ), Tenox 21, and tocopherol. Water contamination must be minimized in the stored fuel as it can lead to biological growth in the fuel. If water contamination occurs, biological growth can be mitigated by using biocides (69).

7.0 Advantages of the use of biodiesel

The advantages of biodiesel as a diesel fuel are its portability, ready availability, renewability, higher combustion efficiency, lower sulfur and aromatic content (71) (72), higher cetane number, and higher biodegradability (73) (74) (75).

7.1 Availability and renewability of biodiesel

Biodiesel is the only alternative fuel in which low-concentration biodiesel-diesel blends run on conventional unmodified engines. It can be stored anywhere that petroleum diesel fuel is stored.

The risks of handling, transporting, and storing biodiesel are much lower than those associated with petrodiesel. Biodiesel is safe to handle and transport because it is as biodegradable as sugar and has a high flash point compared to petroleum diesel fuel. Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel, or B20 in recent scientific investigations; however, in Europe the current regulation foresees a maximum 5.75% biodiesel (34).

7.2 Higher combustion efficiency of biodiesel

Oxygen content of biodiesel improves the combustion process and decreases its oxidation potential. Structural oxygen content of a fuel improves combustion efficiency due to the increase of the homogeneity of oxygen with the fuel during combustion. Because of this the combustion efficiency of biodiesel is higher than petrodiesel as well as the combustion efficiency of methanol/ethanol is higher than that of gasoline. A visual inspection of the injector types would indicate no difference between the biodiesel fuels when tested on petrodiesel. The overall injector coking is considerably low. Biodiesel contains 11% oxygen by weight and contains no sulfur. The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel. Biodiesel has got better lubricant properties than petrodiesel. The higher heating values (HHVs) of biodiesels are relatively high. The HHVs of biodiesels (39–41 MJ/kg) are slightly lower than that of gasoline (46 MJ/kg), petrodiesel (43 MJ/kg) or petroleum (42 MJ/kg), but higher than coal (32–37 MJ/kg) (76).

7.3 Lower emissions from biodiesel

The combustion of biodiesel alone provides over a 90% reduction in total unburned hydrocarbons and a 75 to 90% reduction in polycyclic aromatic hydrocarbons. Biodiesel further provides significant reductions in particulate matter and carbon monoxide than petroleum diesel fuel. Biodiesel provides a slight increase or decrease in nitrogen oxides depending on the engine family and testing procedures (77).

Burning of biodiesel produces 78% less carbon dioxide (CO2) on a lifecycle basis when compared to conventional diesel fuel. It also produces less smoke due to free soot (78).

The use of biodiesel to reduce nitrous oxide (N2O) is attractive for several reasons. Biodiesel contains little nitrogen, as compared with petrodiesel, which is also used as a reburning fuel. The N2O reduction is strongly dependent upon initial N2O concentrations and only slightly dependent upon temperature, where increased temperature increases N2O reduction. This results in lower N2O production from fuel nitrogen species for biodiesel. In addition, biodiesel contains trace amounts of sulfur, so sulfur dioxide (SO2) emissions are reduced in direct proportion to the petrodiesel replacement (77).

The use of biodiesel in a conventional diesel engine dramatically reduces the emissions of unburned hydrocarbons, carbon dioxide (CO2), carbon monoxide (CO), sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, ozone-forming hydrocarbons, and particulate matter (77).

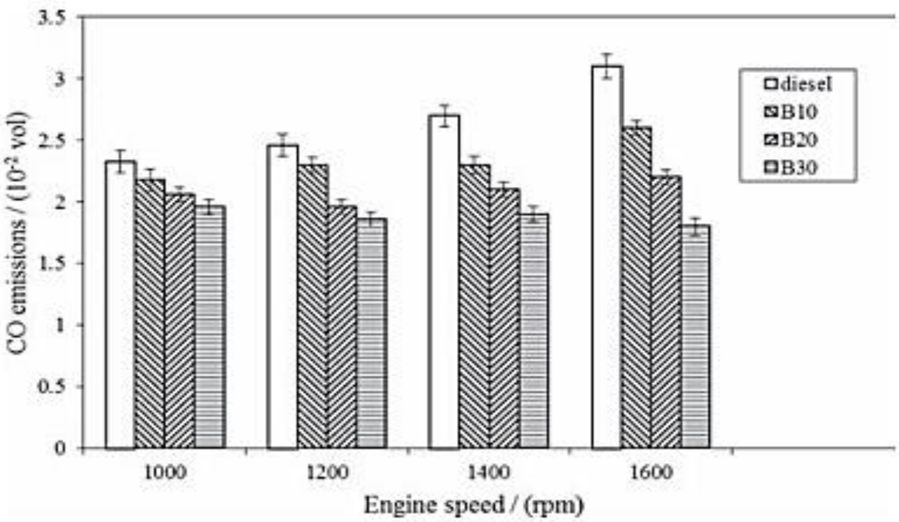

Figure 2 : Carbon monoxide (CO) emissions of pure diesel and the fuel blends (79).

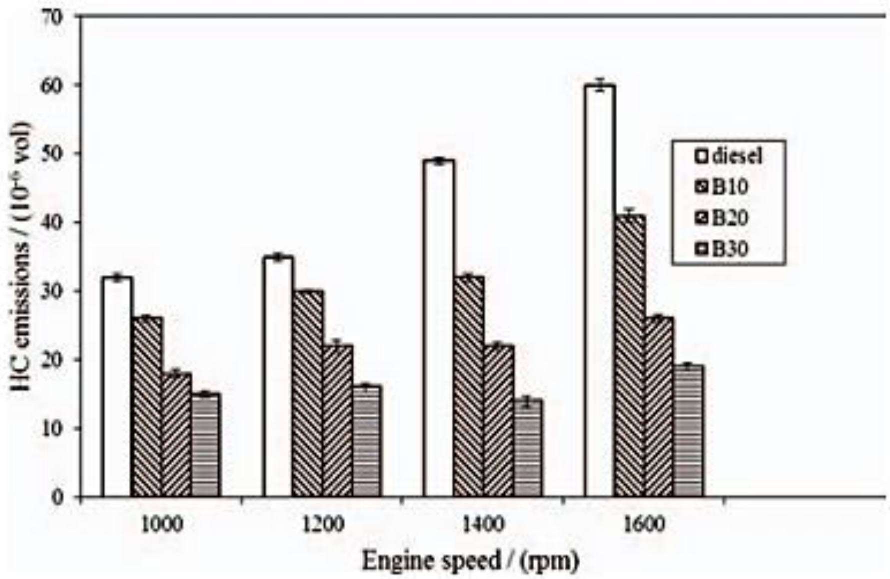

Figure 3: Hydrocarbon (HC) emissions of pure diesel and the fuel blends (79).

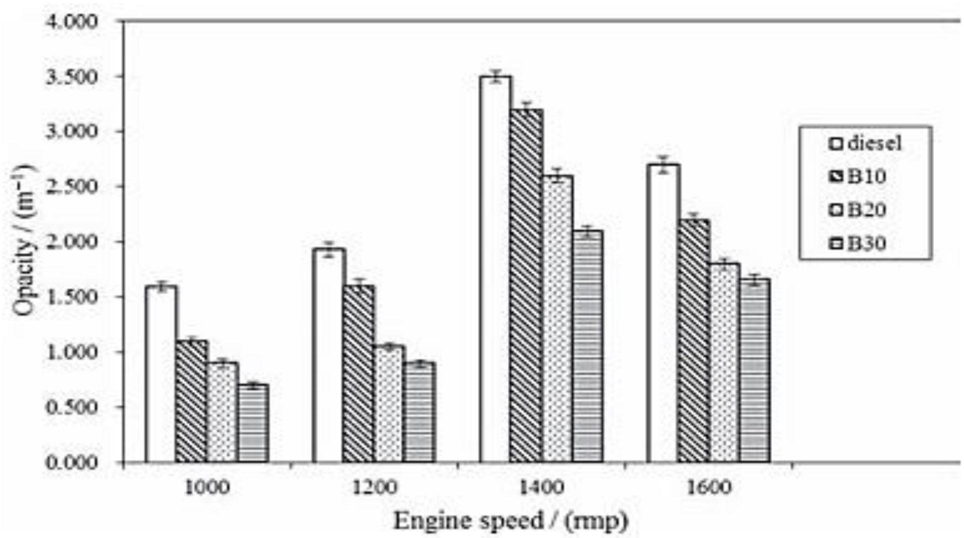

Figure 4: Smoke opacity of pure diesel and the fuel blends (79).

7.4 Biodegradability of biodiesel

Biodiesel is non-toxic and degrades about four times faster than petrodiesel. Its oxygen content improves the biodegradation process, leading to a decreased level of quick biodegradation. In comparison with petrodiesel, biodiesel shows better emission parameters. It improves the environmental performance of road transport and reduces greenhouse emissions (mainly of carbon dioxide) (77).

As biodiesel fuels are becoming commercialized their existence in the environment is an area of concern since petroleum oil spills constitute a major source of contamination of the ecosystem (80). Among these concerns, water quality is one of the most important issues for living systems. It is important to examine the biodegradability of biodiesel fuels and their biodegradation rates in natural waterways in case they enter the aquatic environment in the course of their use or disposal. Chemicals from biodegradation of biodiesel can be released into the environment. With the increasing interest in biodiesel, the health and safety aspects are of utmost importance, including determination of their environmental impacts in the transport, storage or processing (71).

Biodegradation is degradation caused by biological activity, particularly by enzyme action, leading to significant changes in a material's chemical structure. There are many methods of biodegradation. Among them, the carbon dioxide (CO2) evolution method is relatively simple, economical, and environmentally safe. Another method is to measure the biochemical oxygen demand (BOD) with a respirometer (81).

The biodegradability of several biodiesels in the aquatic environment show that all biodiesel fuels are readily biodegradable. After 28 days all biodiesel fuels were 77%–89% biodegraded, diesel fuel was only 18% biodegraded (82). The enzymes responsible for the dehydrogenation/oxidation reactions that occur in the process of degradation recognize oxygen atoms and attack them immediately (83). Gasoline is considerably biodegradable (28%) after 28 days. Vegetables oils and their derived methyl esters (biodiesels) are rapidly degraded to reach biodegradation of between 76 and 90% (83) (84).

Chapter 2: The co-product of biodiesel: Glycerol

1.0 Global information about glycerol

From the stoichiometry of the transesterification of triglycerides, glycerol is formed in about 10 wt% mass balance. The crude glycerol of biodiesel production has water, methanol and dissolved salts as major impurities; other components, such as mono- and diacylglycerides, can also be present in small amounts. Table 6 shows the average composition of the crude glycerol, also named glycerine (85). The results of elemental analysis of crude glycerol obtained from biodiesel production are summarized in Table 7 showing that carbon, balanced oxygen, and hydrogen are the main elemental components (86).

The glycerol of biodiesel production can be refined for further applications. After transesterification, soap may be formed and remains dissolved in the glycerol phase. Hence, acid treatment is necessary to transform soap into free fatty acids, which can be easily separated from the top because they are not soluble in glycerol. Excess methanol can be recovered by distillation to be reused in the transesterification process. The salts remaining in the glycerol phase are deleterious impurities that limit the use of glycerol in some chemical processes (87).

Table 6: Average composition of crude glycerol from a Brazilian biodiesel plant (85).

Composition	Wt%
Glycerol	80
Water	7
Methanol	1
NaCl	12

Table 7: Typical elemental analysis of crude glycerol (86).

Elements	wt%
Carbon (C)	52.77
Balance oxygen (O)	36.15
Hydrogen (H)	11.08
Nitrogen (N)	<0.0001
Sulfur (S)	—

2.0 Properties of Glycerol

Glycerol (1,2,3-propanetriol, Figure 5) is a colorless, odorless, viscous liquid with a sweet taste, derived from both natural and petrochemical feedstock's. The name glycerol originates from the Greek word for ''sweet'', glykys, and the terms glycerin, glycerine, and glycerol tend to be used interchangeably in the literature. On the other hand, the expressions glycerin and glycerine generally refer to a commercial solution of glycerol in water, of which the principal component is glycerol. Crude glycerol is 70–80% pure and is often concentrated and purified prior to commercial sale to 95.5–99% purity (88).

Some properties of glycerol are shown in Table 8. It is a polar, viscous, transparent liquid at ambient temperature, soluble in water and polar media and insoluble in hydrocarbons and other non-polar media. Although the melting point is near 18°C, small amounts of dissolved water impair the crystallization of glycerol, which remains as liquid at significantly lower temperatures (85).

Glycerol is one of the most versatile and valuable chemical substances known, with more than a thousand uses and applications. It is used in a wide range of products on account of its distinctive characteristics. Its physical and chemical properties make it a versatile organic compound (89).

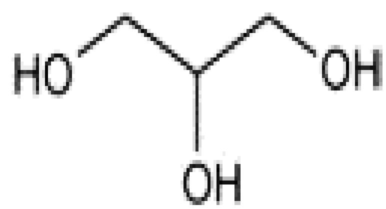

Figure 5: Structure of glycerol (88).

Table 8: Selected glycerol properties (85).

Description value	Description value
Molecular formula	C3H5(OH)3
Molecular weight (g)	92
Melting point (°C)	17.8
Boiling point (°C)	290
Viscosity (Pa s^{-1})	1.5
Vapour pressure at 20°C (mmHg)	<1
Density at 20°C (g mL^{-1})	1.261
Flash point (°C)	160 (closed cup)
Surface tension (N m^{-1})	64,000

3.0 Crude glycerol recovery and purification

A variety of practicable techniques and methods are available for recovering crude glycerol from transestérication reaction, such as centrifugation, bleaching, and chemical treatment. In chemical treatment, the neutralization reaction using a strong acid to remove the catalyst and soaps is the most common method used in the pretreatment process of crude glycerol (90). The salts produced from neutralization can be removed by decantation and filtration. The bleaching procedure effectively reduces the large amount of free fatty acids (FFA), odor, and pigmented compounds (e.g., carotenoids and chlorophyll) contained in crude glycerol (91). Maximum yields can be achieved using bleaching recovery techniques for glycerol (92) since bleaching not only recovers the glycerol but also saponifies the free triglycerides. (93).

In the third recovery process, crude glycerol is first recovered by centrifugation, and then any contaminated soap is converted to acid or salt by treatment with hydrochloric acid (94) (95). Water and methanol in the glycerol phase can be separated by distillation through a simple distillation process (96).

Table 9 shows that glycerol can be divided into three main categories, namely, crude glycerol, purified glycerol, and commercially synthesized glycerol. The properties of crude glycerol and purified glycerol differ greatly from each other, but the differences between purified and synthesized glycerol are minimal. Actually, purified glycerol is usually prepared of a quality close to that of commercial synthetic glycerol. Depending on the potential end use and purity, purified glycerol can be classified into three grades (Table 10) (97).

Table 9: Characteristics of different types of glycerol (98).

Parameter	Crude glycerol	Purified glycerol	Commercially synthesized glycerol
Glycerol content (%)	60–80	99.1–99.8	99.2–99.98
Moisture content (%)	1.5–6.5	0.11–0.8	0.14–0.29
Ash content (%)	1.5–2.5	0.054	<0.002
Soap content (%)	3.0–5.0	0.56	N/A
Acidity (pH)	0.7–1.3	0.10–0.16	0.04–0.07
FAME	Residue	Residue	Residue
Color (APHA)	Dark	34–45	1.8–10.3
Chloride (ppm)	ND	1.0	0.6–9.5

Table 10: Commercially available basic grade of purified glycerol (99).

Grade	Type of glycerol	Preparation and application
Grade-I	Technical grade ——————————99.5%	Prepared by the synthetic process and used as a base material for various chemicals but not for food or pharmaceutical formulations.

Grade-II	USP grade 96–99.5%	Prepared from vegetable oil sources or animal fat, applicable to food, pharmaceuticals, and cosmetics.
Grade-III	Kosher or USP/FCC grade 99.5–99.7%	Prepared from vegetable oil sources, suitable for use in kosher foods and drinks.

4.0 Biotechnological Applications of Glycerol

4.1 Food and Beverages

At present, glycerol is mostly utilized as an intermediate chemical for the production of a wide range of products. Glycerol can be converted into other valuable compounds such as sweetener in foods and soft drinks which is important in food industries by conventional or fermentation process (100). For example, a production of a higher-value product, D-lactic acid (D-lactate) and L-lactic acid (L-lactate) which exhibits a number of applications in the food, pharmaceutical, and polymer industries, was reported from engineered strains of *Escherichia coli* (E. coli) under optimized conditions (101).

Osmophilic yeast, *Candida magnolia* was also capable to convert cheap raw material of glycerol into mannitol under gaseous condition (102). Mannitol, a type of sugar alcohol, is widely used as sugar substitutes in food industry. The production of mannitol by fermentation technology is preferable due to the problems encountered with its production via chemical process (103). The Polyalcohol, L- or D-arabitol, can be produced by yeasts via bioconversion or biotransformation of glycerol (104). In the food industry, arabitol can be used as a natural sweetener, a texturing agent, a color stabilizer and a low-calorie sweeteners (only 0.2 kcal g^{-1}) which also act as low-glycemic, low-insulinemic, anticariogenic, and prebiotic agent that suitable for diabetic patients (105). Glycerol can be converted into glycerol monolaurate that is important in food industry as a surfactant, preservative and emulsifier. Glycerol monolaurate is a product of esterification process of glycerol with lauric acid with the help or support of an acid or base catalyst (106).

Another excellent food emulsifier agent is reported from polyglycerol ester group. Polyglycerol is a combination of glycerol oligomers produced from the reaction of metal-based catalyst for instance potassium hydroxide with glycerol at high temperature (range from 250 to 300 °C). Recently, the long-carbon fatty acid polyglycerol esters exhibited the most excellent properties as a food emulsifier compared to medium- and short-carbon fatty acid polyglycerol esters (107). Humectants in foods are considered as additives that capable to increase water holding capacity also manage water activity. The addition of humectants to food products can increase the product stability, lessen microbial activity and protect the food texture. Glycerol is categorized as one of the most effective humectant polyols. The moisturization effect of glycerol in foods is owing to the capability of its hydroxyl groups to attach and retain water. Glycerol is an ideal ingredient in food due to several properties including nontoxic, digestible, safe to environment and provides a good flavor and pleasant odour (108).

4.2 Drugs and pharmaceuticals

Crude glycerol formed from trans-esterification reaction for biodiesel production can be used after several purification processes. By using the complex process and distillation, 99% purity of glycerol can be achieved (109) (110). Glycerol assists to maintain the texture and adds humectancy, controls the water activity and prolongs the life span in a host of applications (111). In pharmaceuticals, it provides lubrication and smoothness to many cough syrups, ointments, expectorants, anaesthetics, lozenges, gargles and elixirs. Moreover, the glycerol also used in ear infection medicines and plasticizers for medicine capsules as well as a carrier for antibiotics and antiseptics (112). The glycerol is applied in medical grade nitroglycerin production as well, which is used to widen the blood vessels. The glycerol and its aqueous solutions have showed various promising applications as lubricants and heterogeneous catalytic reactants (113) (114).

4.3 Cosmetics and Toiletries

The hygroscopicity and hydrophilicity nature of glycerol (by having three alcoholic hydroxyl groups) and its solubility in water makes this versatile compound a great humectant in cosmetics. Glycerol provides hydration, an important properties required for most topical application of cosmetic products. Mice model deficient in the epidermal water/glycerol transporter aquaporin-3 showed recovery in the skin hydration, elasticity and barrier function after topical application of glycerol. In other study, a skin hydration test proved a significant skin hydration and skin barrier function after 24 hours after applying hyaluronic and Centella asiatica stem cells extract moisturizing fluid in glycerol (115). In addition, glycerol has wound healing properties, induces keratinocyte proliferation and reduces melanin intensity (116). It also acts as skin barrier. Glycerol is reported to enhance physical texture of the skin. Glycerol is also used as humectant in toothpaste to keep the toothpaste wet and also protect gingiva and dental tissue (117).

4.4 Anaerobic fermentation using glycerol

A few technologies (118) (119) are being sought on the basis of biological and chemical conversions to add value to crude glycerol. A number of microorganisms can be used naturally to produce methane through anaerobic digestion using purified glycerol as their sole source of carbon and energy (120). Unlike chemical conversion, biotransformation can transform glycerol into a bulk product devoid of high pressure and/or temperature. Compared to aerobic fermentation, anaerobic fermentation is also advantageous in terms of lower operating costs and capital.

At current crude glycerol price of (121) $1.07 per gal (10 cents per lb), glycerol is used as a substitute for sugar in the production of fuels and chemicals through microbial fermentation. Compared to sugar, the use of glycerol fermentation for fuel production and chemical reduction has many advantages (122). One advantage is that the high reduction of carbon atoms in glycerol produces higher fuel yields and reduces the chemicals in glycerol. The conversion of glycerol to the pyruvate or glycolytic intermediates phosphoenolpyruvate (PEP) produces twice the amount of reducing equivalents from glucose or xylose metabolism. Thus, fermentative metabolism will be able to obtain higher fuel yields and fewer chemicals from glycerol than those obtained from common sugars, such as xylose or glucose metabolism (123).

4.5 Glycerol Transformation to valuable Chemicals

4.5.1 Glycerol to Ethanol

Bioethanol is an important biofuel used worldwide. In 2015, the world's production of ethanol accounted for more than 97 billion litres. Besides being used as biofuel, ethanol also finds applications in various industry sectors. It is possible to produce ethanol from glycerol using microorganisms of the type *Citrobacter spp., Klebsiella spp., Enterobacter spp. and Escherichia spp.* Under anaerobic conditions (124).

Jarvis et al. (125) successfully obtained ethanol by glycerol fermentation with a *Klebsiella planticola* strain isolated from red deer. It was reported that glycerol dissimilation by *Klebsiella planticola* led to the production of ethanol at levels of 30 $mmoll^{-1}$. As comparison, Temudo et al. (126) investigated the glycerol fermentation by mixed cultures at alkaline pH. Their studies indicated that ethanolformate and 1,3-propanediol-acetate were the primary catabolic product formation pathways. The substrate limiting conditions were the main affecting factors for ethanol formation. Under these conditions, up to 60% of the substrate carbon was converted into ethanol and formate in a 1:1 ratio. Dharmadi et al. (127) reported that *Escherichia coli* can anaerobically ferment glycerol in a pH-dependent manner. According to the authors, within 84 h of active growth, glycerol was almost completely consumed, achieving a maximum cell concentration of 486.2 mg/L. Ethanol accounted for about 80% (molar basis) of the products. CO2 is necessary in this fermentation process in order for glycerol fermentation to proceed. This study revealed that at acid pH conditions, in which the availability of of CO2 required for cell growth could be facilitated, glycerol fermentation could proceed optimally.

4.5.2 Glycerol to Lactic Acid

Lactic acid (2-hydroxypropanoic acid) is normally produced from sugar fermentation by lactic bacteria. The use of lactic acid is present in several industrial branches, such as in the food industry, where it acts as a preservative and emulsifiers. In the pharmaceutical industry, lactic acid is employed in the preparation of lotions and cosmetics. It also finds applications in the chemical industry as a building block for the production of acrylic acid and propylene glycol (128).

Hong et al. (129) conducted the study of some fundamental problems of lactic acid production from glycerol, aiming at to select a strain suitable for producing high concentration and productivity of lactic acid from glycerol. Among the eight bacterial strains investigated, the strain AC-521, a member of *Escherichia coli*, was found to be the most suitable one for lactic acid production from glycerol based on its 16S rDNA sequences and physiological characteristics. Optimal fermentation conditions were deduced: 42 ºC, pH 6.5, and 0.85 min^{-1} (KLa). Maximum lactic acid concentration and glycerol consumption were reached after 88 h of fed-batch fermentation, achieving a yield of 0.9 mol mol^{-1} glycerol and 85.8 g L^{-1} of lactic acid with a productivity of 0.97 g L^{-1} h^{-1}.

4.5.3 Glycerol to Citric Acid

The amount of citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid) produced annually in the world is greater than the production of any other organic acid obtained by fermentative processes. This market increases at a rate of 5% per year, especially because of the food and beverage sectors. Citric acid shares 50–65% of the food and beverage acidulants market, against 20–25% of phosphoric and 5% malic acid. In the pharmaceutical industry, citric acid is used as an effervescent agent (130).

Rymowicz et al. (131) examined the potential for citric acid biosynthesis by three acetate mutants of the yeast species *Yarrowia lipolytica*, including Strain K-1, Strain AWG-7, and Strain 1.31, under batch cultivation conditions on raw glycerol. The experimental results demonstrated that the strain *Y. lipolytica* 1.31 was the most suitable for citric acid production. Using this strain, the citric acid production of 124.5 gdm^{-3}, yield of 0.62 gg^{-1}, and productivity of 0.88 g dm^{-3} h^{-1} could be obtained at the initial concentration of glycerol of 200gdm^{-3}.

Business plan

1.0 Project overview

1.1 Project idea (proposed solution)

Energy requirements are increasing rapidly due to fast industrialization and the increased number of vehicles on the roads. Massive consumption of fossil fuels leads to environmental pollution, along with the increased amount of waste generated everyday due to human activities, that causes severe water, air and soil pollution. All of this is expected to increase in the near future due to urbanization and economic development. In order to reduce these risks, it is crucial to explore alternative energy sources that are environmentally friendly and implement waste recycling initiatives to reduce the amount of waste generated.

Our project offers a solution to reduce the waste at the source and convert it into a sustainable and environment friendly fuel called “biodiesel”." Specifically, we focus on producing biodiesel from one of the most frequently generated and polluting form of waste “the used cooking oil (UCO)" collected from restaurants. This project lies at the intersection of two very promising sectors of the economy, the biofuels industry and the waste management industry.

To manufacture biodiesel; we chose a fast chemical process termed transesterification that converts UCO to biodiesel within minutes, with glycerol as byproduct to be used in making soap, candles and skincare/cosmetic products. In that reaction the UCO is mixed with an alcohol (methanol or ethanol), and a catalyst (NaOH or KOH) to form fatty acid methyl esters (FAME), which is the chemical name of biodiesel.

Biodiesel created from our systems will provide the same performance as that of conventional petro diesel, but at a very competitive price and ecologically safe alternatives to regular diesel. Market is still at initial stage but expected to expand rapidly due to growing concerns about levels of environmental pollution.

1.2 Value proposition

Our product offers a genuinely viable and sustainable substitute to petroleum-based diesel fuels, and it does so while being cost-effective. The value proposition of our product is based on:

Environmental Sustainability: Using biodiesel in place of petroleum diesel significantly lower levels of harmful emissions such as sulfur dioxide, particulate matter and carbon dioxide, which contributes to reducing the impact of climate change. The chemical structure of biodiesel also makes it less toxic, biodegradable and more efficient in combustion, reducing the amount of unburned fuel and pollutants released into the atmosphere. These factors make biodiesel an environmentally friendly fuel.

Cost-Effective: Biodiesel production from used cooking oil can be cost-effective in several ways. Firstly, used cooking oil can be obtained at a low cost or even for free from local restaurants or households. This reduces the cost of raw materials for biodiesel production. Additionally, the production process is relatively simple and requires only basic equipment, which can also be obtained at a low cost. These factors makes biodiesel production from UCO a cost-effective option.

Waste Reduction: Biodiesel production from used cooking oil reduces waste by providing a valuable use for a material that would otherwise be disposed of. Used cooking oil is a significant source of waste in many communities, and disposing of it can be expensive and environmentally harmful. By converting used cooking oil into biodiesel, we can reduce the amount of waste in landfills and minimize the risk of oil spills.

1.3 Work team

The team consists of two final-year master’s students in Applied Microbiology with a strong academic background in biochemistry, industrial microbiology, and environmental microbiology. While we may not have extensive professional experience, our academic training and internships has equipped us with the necessary knowledge and skills to carry out the technical aspects of biodiesel production. We are both eager to apply our theoretical knowledge to practical applications and are committed to achieving the project goals with dedication and teamwork.

Regarding our roles in the team, I (student 1) take the lead in developing the project plan and refining the business model, while my teammate (student 2) concentrates on the theoretical aspects of the project .We both equally contributed to the success of the experimental prototype by working collaboratively. Together, we bring a unique blend of technical and business skills (table1) that we believe will be essential for the success of our project.

Table 11: Team's skills and training courses

	Speciality	**Training courses-internship's**	**Skills**	**Planned project tasks**
Student 1: younes chohra	Applied microbiology	English B2 (CEFR) Central laboratory-public hospital institution, Ahmed Madghari-Saida Quality control laboratory-"Saida natural mineral water"	Research and analysis skills Time management skills Presentation skills	Planning and scheduling Managing the collection of raw materials Monitoring the production process Bank Loans application
Student 2: oussama boukhaloua	Applied microbiology	English B1 "GIP lait la source" – Saida Quality control laboratory-"Saida natural mineral water"	Adaptability Communication skills Analytic thinking	Market research and marketing Managing the collection of raw materials Developing and maintaining relationships with suppliers and customers

1.4 Objectives

Main objectives for our business are:

- Invite and secure investment for the creation of a small-scale production plant.
- Start production of biodiesel within a year using a functioning biodiesel mini-plant.
- National and international partnerships with companies and organizations working on biofuels.

1.5 Project realization timeline

A suggested timeline for the major start-up activities is provided in Table 2. The entire start-up process is anticipated to take approximately 10-11 months.

The start-up activities can be categorized into two phases: The initial phase, which does not involve significant cash flows, and the final phase, where all major cash flows take place.

It is estimated that the duration of initial phase to be at least 4 months. This phase includes:

- Company incorporation with minimum required share capital
- Reaching tentative agreements with UCO suppliers (local restaurants)
- Reaching tentative agreements with chemical and fuels companies

After the successful completion of the initial phase, the final phase may start. The final phase is expected to take approximately 7 months, after which the operations may start. This phase includes:

- Increase the company's share capital through additional investments or partnerships.
- Securing funding for working capital needs through bank loans (e.g.: from Algeria Startup Fund)
- Rent offices/warehouse
- Procuring necessary equipment and chemicals
- Leasing vehicles for UCO collection and transportation
- Hire personnel
- Finalizing contract agreements with chemical & fuel companies
- Start-up operations

Table 12: Start-up activities timeline.

	Activity description	Duration	Start	Finish
1	Biodiesel production start-up	378 days	1/8/2023	11/8/2024
2	**Company incorporation**			
3	Sign Incorporation Agreement	7 days	1/8/2023	8/8/2023
4	Increase Share Capital	2 days	8/8/2023	10/8/2023
5	**Bank Loans**			
6	Investigate Eligibility Criteria	10 days	10/8/2023	20/8/2023
7	Loan Application & Approval	30 days	20/8/2023	19/9/2023
8	**Rent Offices/Warehouse**			
9	Investigate Market	30 days	19/9/2023	19/10/2023
10	Rent Offices/Warehouse	1 day	19/10/2023	20/10/2023
11	Revamp Offices/Warehouse	15 days	20/10/2023	3/11/2023
12	**Purchase equipment**			
13	Investigate Market	10 days	3/11/2023	13/11/2023
14	Purchase Equipment	30 days	13/11/2023	12/12/2023
15	**Lease vehicles**			
16	Investigate Market	7 days	12/12/2023	19/12/2023
17	Lease Vehicles	7 days	19/12/2023	26/12/2023
18	**Collection activities licensing**			
19	Investigate Eligibility Criteria	30 days	26/12/2023	25/1/2024
20	Activities Licensing	20 days	25/1/2024	14/2/2024
21	**Contractual agreement-UCO wholesalers**			
22	Investigate eligible Collaborators	30 days	14/2/2024	15/3/2024
23	Sign a tentative agreement	10 days	15/3/2024	25/3/2024
24	Sign a contract agreement	5 days	25/3/2024	30/3/2024
25	**Contractual agreement-chemicals companies**			
26	Investigate Eligible Collaborators	60 days	30/3/2024	29/5/2024
27	Sign a Tentative agreement	30 days	29/5/2024	28/6/2024
28	Sign a Contract agreement	10 days	28/6/2024	8/7/2024
29	**Hire Personnel**			
30	Investigate Eligible Employees	30 days	8/7/2024	7/8/2024
31	Hire Accountant	1 day	7/8/2024	8/8/2024
32	Hire Secretary	1 day	8/8/2024	9/8/2024
33	Hire Drivers	1 day	9/8/2024	10/8/2024
34	**Start-Up Operations**			
35	Start Operations	1 day	10/8/2024	11/8/2024

2.0 Innovative aspects

2.1 Nature of innovations

When it comes to innovation, there are different types of innovations that can be classified based on their nature. In the case of our project, we believe that it offers a unique blend of radical and sustainable innovation.

Radical innovation:

Radical innovation refers to a new product, service, or process that significantly changes the existing market and creates a new market or industry.

In the case of our project, the production of biodiesel from used cooking oil by transesterification reaction is a radical innovation in Algeria, as it completely transforms the way in which we produce fuels. Furthermore, the production process yields a valuable byproduct, glycerol.

This innovation has the potential to:

- Enter the transportation fuel market by providing biodiesel a fuel product. Biodiesel can be used in diesel engines alone or blended with petroleum-based diesel.
- Create a new market for glycerol, which can then be sold to various industries that use it as a raw material in their production processes such as pharmaceutical industry.
- Create a new market for UCO as a sustainable feedstock for biodiesel production.

Sustainable innovation:

At the heart of our project lies a sustainable innovation that utilizes waste (used cooking oil) to produce a renewable and sustainable fuel source (biodiesel).this helps reduces the amount of waste going to landfills or being dumped into waterways ,reduce greenhouse gas emissions, lowers dependence on fossil fuels and support the development of a circular economy.

2.2 Fields of innovations

The production of biodiesel from used cooking oil offers a triple-facet solution; economic, environmental, and waste management. Our project is unique in that it incorporates several different fields of innovation, each of which contributes to its overall value proposition.

New offers

Our project offers two new innovative products, the main product is biodiesel, which is a renewable and sustainable alternative to petroleum-based diesel. This can be used in a variety of applications, including transportation and electricity generation. Additionally, the biodiesel production process also generates glycerol as a co-product, which can be used in various industries, such as food and pharmaceuticals. It has many valuable properties including being a good moisturizer, plasticizer, emollient, thickener, solvent, dispersing medium, lubricant, sweetener and an anti-freeze agent.

New features

Our products have some remarkable features including portability, ready availability, renewability, and environmental friendliness due to their chemical properties and source of production. Moreover, our primary product, biodiesel, has a variety of unique features that distinguish it from traditional petroleum-based diesel and other fuels.

- Biodiesel is non-toxic and biodegradable (degrades about 4 times faster than petrodiesel).
- The risks associated with handling, transporting, and storing biodiesel are significantly lower compared to petrodiesel. Biodiesel can be stored in anywhere where petroleum diesel fuel is stored (132).
- Usage of biodiesel can reduce significantly a number of air pollutants like particulate matters, sulfur, hydrocarbons, and carbon monoxide (133).
- Another feature of biodiesel is its ability to run in diesel engines-cars, buses, truck and boats without the need for any modifications. Its physical properties are similar to those of petroleum diesel. Biodiesel can be used alone (B100) or blended with petroleum diesel in many different concentrations, including B100 (pure biodiesel), B20 (20% biodiesel, 80% petroleum diesel), B5 (5% biodiesel, 95% petroleum diesel) and B2 (2% biodiesel, 98% petroleum diesel) (134).

New customers

Our project reach out to various new customers. It specifically targets individuals and organizations who are environmentally conscious and seek sustainable energy sources to reduce their carbon footprint. Additionally, we aim to serve industries and companies in the food, cosmetics, and pharmaceutical sectors that use glycerol as a raw material for their production, since glycerol can be used in those industries. By targeting these various customer segments, our project can offer a diverse range of benefits to different industries and consumers.

3.0 Market analysis

3.1 Market segment display

The company's potential marketing segments will be based on the product and its type of application.

Based on application, marketing opportunities for biodiesel can be segmented into transportation and power generation. The transportation acts as the major application segment for biodiesel where diesel-powered vehicles are commonly used (e.g. light duty vehicles, heavy duty vehicles, commercial vehicles, off-road vehicles, buses and boats). The market may also be segmented by blend level: B2, B5, and B100 (percentage of biodiesel). While for glycerol, the market is segmented into personal care & pharmaceuticals, food & beverages, tobacco humectants and other biotechnological applications like conversion of glycerol into valuable product such as lactic acid and ethanol.

The project is to serve selected segments in selected states at the beginning of the operations. The firm will focus on providing quality B100, B20, B5, but mostly B2 biodiesel blends to regional fuel distributors and large fleet operators as key target markets. The first prospective customers will be city public transportation organization (ETUS Saida), independent gas station owners and large diesel distributor's e.g.NAFTAL, who need and want to use non-polluting, ecologically friendly fuel. To ensure rapid growth, we plan to sell glycerol to soap companies e.g. SARL SOADET and pharmaceuticals companies e.g. SIDAL that need glycerol for their production process. The company will have extra income from this additional business activity.

3.2 Competitor analysis

The competition in the biodiesel production industry in the target area (west region of Algeria) simply do not exist at that time as there are no existing companies that produce biodiesel. The biggest competition will be from existing petroleum diesel producers who are already recognized by the market. If these petroleum diesel companies perceive us as a threat, it could pose a problem. However, since biodiesel can be blended with petroleum diesel and used in diesel engine cars, our company is not in any direct competition with these companies. In fact, we intend to pursue partnerships with these companies and establish mutually beneficial relationships. Thus, it is unlikely that they will view us as a threat.

3.3 Marketing strategy

Our marketing strategy aims to establish strong distribution channels that ensure stability in production and sales. For this reason we have planned the following marketing mix:

Product strategy

The provided products are biodiesel, a nonpolluting and ecologically friendly fuel, and glycerol, a versatile chemical building block. We're positioning these two products to environmentally conscious consumers, and businesses through social media, events, and partnerships. The firm will emphasize the products being environmentally safe.

Placement strategy (distribution)

The place term, includes the marketing channels through which the company contacts the customers. In the case of biodiesel, the main marketing channel will be indirect, through the services offered at the authorized fuel retailers and gas stations, where biodiesel will be blended with fossil diesel up to 5% and sold anonymously, distinguishing it as a high-quality product that is highlighted by a quality seal. As for glycerol, we plan on establishing a direct marketing channel, targeting soap, cosmetics and pharmaceutical companies, through our sales representatives or through their purchasing department.

Promotion and sales plan

Our company has a long-term plan of opening distribution channels all around Saida province, which is why we will deliberately build our brand to be well accepted and recognized in Saida City before venturing out. As a matter of fact, our publicity and advertising strategy is not solely for winning customers over but to effectively communicate our brand. Here are the platforms we intend to leverage for promoting and advertising our company:

- Introduce our business by sending introductory letters and brochures to retailers, factories, facility managers, hotels, households and key stakeholders in and around Saida province.
- Place adverts on community based newspapers, radio and TV stations.
- Encourage the use of word of mouth publicity from our loyal customers.

- Leverage on the internet and social media platforms like; YouTube, Instagram, Facebook, Twitter and other platforms to promote our business.
- Position our banners and billboards in strategic places all around province of Saida.
- Distribute our fliers and handbills to create awareness about our business; these will include information about the company's contact details, web page address, the company's mission and the environmental impact of its activities.
- Brand all our official cars and distribution vans / trucks and ensure that all our staff wear our branded shirt or cap at regular intervals.
- Meet with the city public transportation organization, (E.T.U.S), and convince them to try biodiesel for a period of time on selected vehicles and buses, in order to increase awareness of biodiesel and market the business.

Pricing strategy

To establish a profitable pricing strategy for our products, we plan to adopt a cost-plus pricing approach. This method involves calculating the total cost of producing and delivering the products, and adding a reasonable profit margin to determine the final price. The total cost includes the expenses incurred in the production process, such as raw materials, labor, and overhead costs, as well as marketing and distribution expenses. This pricing strategy allows us to cover our costs, earn a reasonable profit, and remain competitive in the market.

An exception is made for biodiesel, which we plan to sell it slightly lower than current market price for petro diesel. This is in order to insure rapid growth, and eliminate market risk. Additionally, we will offer volume discounts for bulk orders and establish long-term contracts with our customers to ensure stability in sales and revenue.

4.0 Production plan and organization

4.1 The production process

The production of biodiesel is relatively simple from a technical standpoint, also allowing the construction of small decentralized production units without excessive extra costs. This limits the need to transport raw materials long distances and permits operations to start with modest-sized installations.

We propose to secure a suitable site in the Northwest of Algeria (Saida, Oran or Tlemcen).The ideal site would contain an existing manufacturing plant with equipment that can be adapted for use in biodiesel production. The ideal site would also have rail and truck access and storage suitable for feedstock, process chemicals, finished product and co-products. Our major intention is to keep levels of monthly production, sales, and collections together. For this reason we planned storage capacities only for one month's production.

Raw materials

Used cooking oil (UCO), methanol and sodium hydroxide are the raw materials being used for the production of biodiesel. Using methanol in the transesterification process has the advantage that the resulting glycerol can be separated simultaneously during the transesterification process. The end products of the transesterification process are raw biodiesel and raw glycerol.

Manufacturing

The manufacturing process starts with the collection and storage of used cooking oil. The oil undergoes a transesterification reaction, where it is treated with methanol and sodium hydroxide (NaOH) to convert it into biodiesel. The process involves precise temperature control, mixing, and separation steps to ensure high-quality biodiesel production. Glycerol, the co-product of biodiesel production, is also extracted during this stage. We aim to produce 4000L of biodiesel in the first year, to produce this quantity we need 4000L of UCO, 740L of methanol and 20kg of NaOH.

Figure-6 shows the layout and photograph of pilot plant, a pilot plant is composed of stainless steel reactor jacketed of 100 liters capacity R1. UCO or waste cooking oil (WCO) is filtered through filter F1 before it is loaded to the reactor, this process is an automatic process. Catalyst and reagent are placed into two tanks, D1 and D2, and are automatically moved to the reactor depending on the volume and the Free Fatty Acid percentage. The produced biodiesel is passed through an ionic resin filter F2 in order to remove residues of waste material and wastes resulting from the reaction are removed from the bottom of the reactor. All parameters are monitored by a computerized system with a touch screen interface (135).

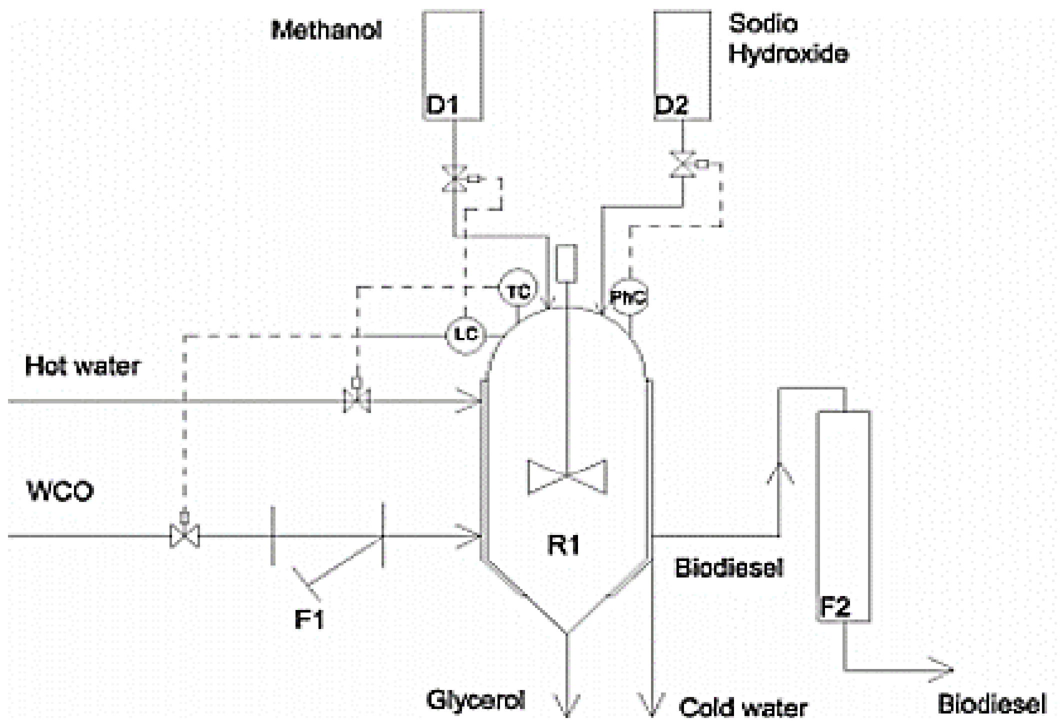

Figure 6: Pilot Plant layout (136).

There will also be ten tanks in the plant that need to be kept warm, and be protected from extremely high temperature.

- Methanol (1) 8000 liters tank and it will be horizontal.
- Feedstock (3) 17000 liters tanks these tanks will be vertical.
- Catalyst, it will be vertical.
- Biodiesel (3) 17000 liters tanks. The dimension of these three tanks is for each of them 11' diameter x 14' straight side each. These tanks will be horizontal.
- Glycerin (2) 5000 liters tanks. It will be vertical.

Products adaptation

Once biodiesel and glycerol are produced, they undergo conditioning to meet the required quality standards. Biodiesel is subjected to a purification process to remove any impurities and contaminants, ensuring it meets the necessary specifications for use as a fuel. Glycerol is refined and purified through processes like centrifugation, bleaching or distillation to achieve the desired quality for its various applications.

Water and methanol in the glycerol phase can be separated through a simple distillation process. Methanol can be recovered and potentially reused in the biodiesel production. Reusing methanol can help improve the overall efficiency and sustainability of the biodiesel production process by reducing the need for new methanol procurement and minimizing waste generation.

Packaging

After conditioning, both biodiesel and glycerol are packaged in appropriate containers, such as drums or tanks, to facilitate storage, transportation, and distribution. The packaging is designed to ensure the integrity and safety of the products during handling and delivery.

4.2 Supply

As the company, we prioritize establishing strong relationships with reliable suppliers to ensure a steady and consistent supply of raw materials for our biodiesel production. The most important suppliers for us are the ones who can provide high-quality feedstocks.

We source the main raw material, used cooking oil, from various local establishments such as restaurants, and university of Saida canteens at a low cost or even for free. This ensures a consistent supply of feedstock for our production.

Methanol, an important component in the biodiesel production process, is sourced from chemical manufacturing companies or specialized chemical distributors. Due to safety considerations, it is crucial to select reliable suppliers adhering to safety standards. The purchase policy for methanol may involve bulk purchasing, contract agreements, and adherence to safety protocols. Payment terms are typically negotiated and can include upfront payments, credit terms, or other arrangements based on mutual agreement.

Catalysts, used in the transesterification process, can be sourced from chemical suppliers or catalyst manufacturers. Suppliers offering high-quality catalysts meeting industry standards are preferred. Purchase policies involve considering the required catalyst formulations, and payment terms can vary, including upfront payments or credit terms.

The payment policies established with these suppliers aim to ensure a smooth supply chain and foster strong relationships. Factors such as order volume, supplier reputation, delivery schedules and long-term partnership potential are considered in negotiating favorable payment terms. Cash payments, credit terms, partial prepayments, or installment payments are common payment options.

4.3 Labor

The projected company size is envisioned to be comprised of a workforce consisting of 10 employees. To effectively manage the operations and ensure smooth workflow, a proposed organizational structure is presented in figure 7. This structure delineates the various business units within the company and assigns specific responsibilities and tasks to each unit. The following sections outline the roles and duties associated with each business unit.

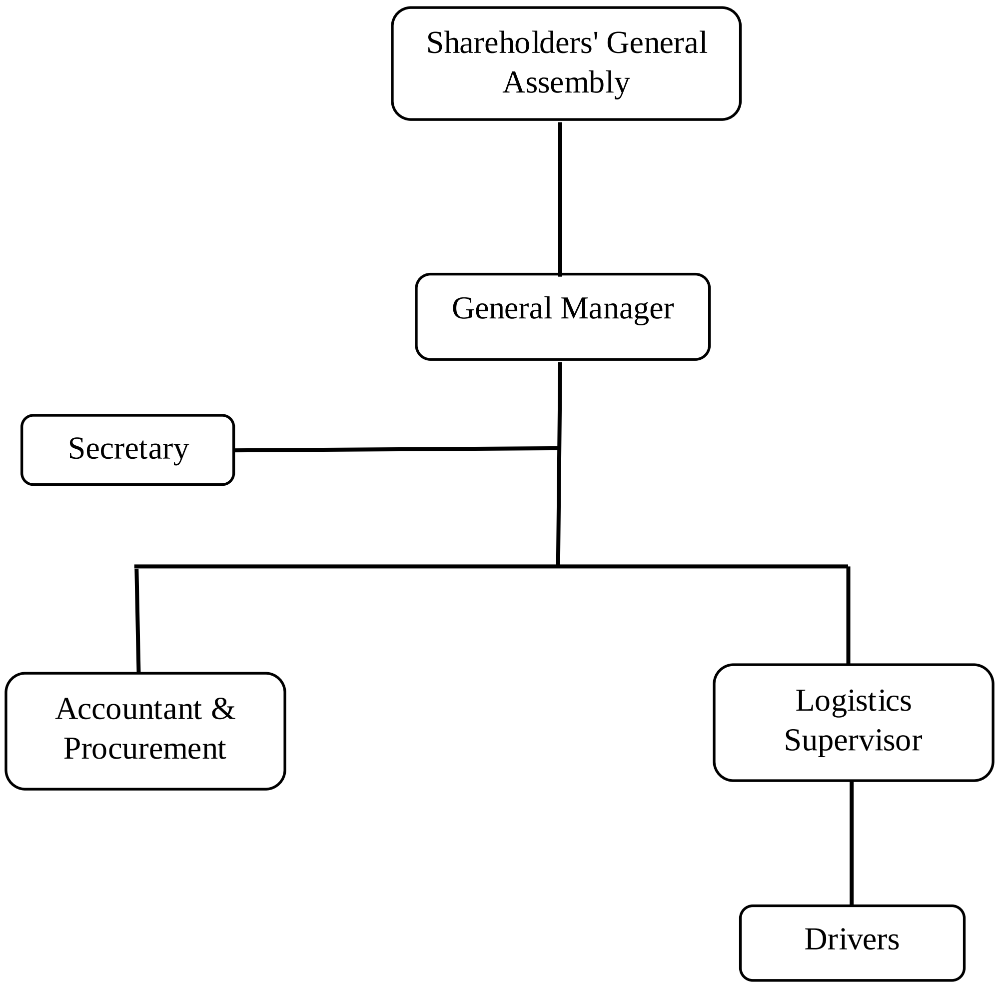

Figure 7: Organizational structure

The Shareholders' General Assembly plays a pivotal role in making significant decisions concerning the company's structure, form, the distribution of dividends and significant strategic decisions.

The General Manager oversees the company's day-to-day operations, acts as the company's representative in interactions with authorities, supervises the accountant and procurement officer, and is responsible for managing the company's marketing activities.

The Logistics Supervisor assumes responsibility for the efficient management of the company's logistics on a daily basis. This entails organizing and optimizing logistical processes and overseeing the implementation of certification systems to ensure compliance and quality control.

The Accountant & Procurement Officer maintains accurate financial records using the double-entry accounting method. They manage and handle the company's procurement processes efficiently.

The Secretary will offer comprehensive secretarial support to all mentioned officers and will also oversee the management of the company's call center.

The Drivers will be responsible for the collection, transportation, and delivery of raw materials.

4.4 Major partnerships

Raw Material Suppliers: The Company will form strategic alliances with leading chemicals companies to secure a reliable and high-quality supply of methanol and catalysts, essential for the biodiesel production process. These partnerships will ensure a steady flow of necessary chemicals, enabling the company to meet production demands and maintain product quality. We will also collaborate with local restaurants and university of Saida canteens to source UCO for our production.

Financial Institutions: The Company plans to forge partnerships with reputable banks to secure necessary funding through bank loans and financial assistance. These collaborations will enable the company to invest in its production infrastructure, equipment, and working capital.

5.0 Financial plan

5.1 Cost and burdens

To accurately determine the funding needs for the proposed business initiative, a thorough assessment of expected cash inflows and outflows is essential. This analysis will be conducted by examining a five-year projection outlined in Table B- through table F of the Appendix. By reviewing these tables, a comprehensive estimation of the financial requirements can be made, enabling informed decision-making and effective financial planning for the business venture.

The following funding sources have been considered to cover the start-up investments:

1. Government funding opportunity that are available for start-up companies.
2. Bank loans.
3. Attracting investors.
4. Offering shares.
5. Financial savings.

See table G (Appendix)

5.2 Business number

Business number is the table that shows the sales of the total goods sold multiplied per unit selling price.

Table 13 : Business number of biodiesel.

	Total(DZD)				
	Year				
	1	**2**	**3**	**4**	**5**
Quantity of the items sold	3980	5290	7000	8000	9500
Selling price per unit	28	28	28	28	28
Global Business Figures (A)	111440	148120	196000	224000	266000

Table 14: Business number of glycerol.

	Total(DZD)				
	Year				
	1	2	3	4	5
Quantity of the items sold	2500	3400	5700	6200	7600
Selling price per unit	140	140	140	140	140
Global Business Figures (B)	350000	476000	798000	868000	1064000
Total Global Business Figures (A+B)	461440	624120	994000	1092000	1330000

5.3 Expected results calculation table

It is the summary statement of the charges and products achieved by the firm during the financial year, and it highlights profit/ gain or loss. See table H of the Appendix.

5.4 Treasury plan

The Treasury plan outlines the financial management strategies and practices implemented by our company to ensure effective cash flow management and optimal utilization of financial resources. It encompasses various aspects, including cash inflows and outflows, budgeting and liquidity management. The Treasury plan focuses on maintaining a healthy cash position, ensuring timely payments to suppliers and employees, managing debt and financing options, and optimizing investment opportunities. By closely monitoring and managing our company's cash flow, we aim to enhance financial stability, meet financial obligations, and support sustainable growth and development. See Table i of the Appendix.

6.0 Experimental prototype

6.1 Introduction

Transesterification is the method of our choice for producing biodiesel. It is a process in which vegetable oil is mixed with an alcohol (ethanol or methanol) in the presence of a catalyst (sodium or potassium hydroxide). Transesterification chemically break the molecule of the oil into methyl ester with glycerol as a by-product.

The Used cooking oil was collected free of charge from a local restaurant in Saida. Methanol was used as alcohol for the transesterification reaction, sodium hydroxide (NaOH) was used as base catalyst. Both of them were obtained from biology laboratory- University of Saida and the water used was pure distilled deionized.

6.2 Materials and methods

6.2.1 Materials

Table 15: Materials and products used in the production process

Products	Materials
Used cooking oil	Separating Funnel 1000ml
Pure methanol	500 ml beaker
Sodium hydroxide NaOH	500ml conical flask
	A balance
	Magnetic stirrer
	Thermometer
	Pycnometer
	Ostwald Viscometer

6.2.2 Method

6.2.2.1 Procedure of production: transesterification

1. About 400 ml of the used oil is first poured into a 500 ml capacity conical flask, and the oil is heated to 50°C, which is the optimum temperature for the transesterification process.
2. Next, a solution of Sodium methoxide is prepared in a 500 ml beaker using 1.95 g of NaOH pellets in 75 ml of methanol.
3. The solution is then stirred thoroughly to completely dissolve the hydroxide pellet, and the solution is kept at 60°C in the oven for 5 min.
4. Once the solution is ready, it is poured into the pre-warmed oil and placed on a hot plate. The mixture is warmed and vigorously stirred using a magnetic stirrer for 1 hour.
5. To speed up the reaction, the reaction mixture is kept near the boiling point of the alcohol (64.7°C for methanol and 78.4°C for ethanol).
6. Finally, the mixture is poured into a separating funnel fixed on a beaker and allowed to cool overnight for proper settling of the fractions. The biodiesel will form the upper layer, while the lower layer will comprise glycerol and soap.

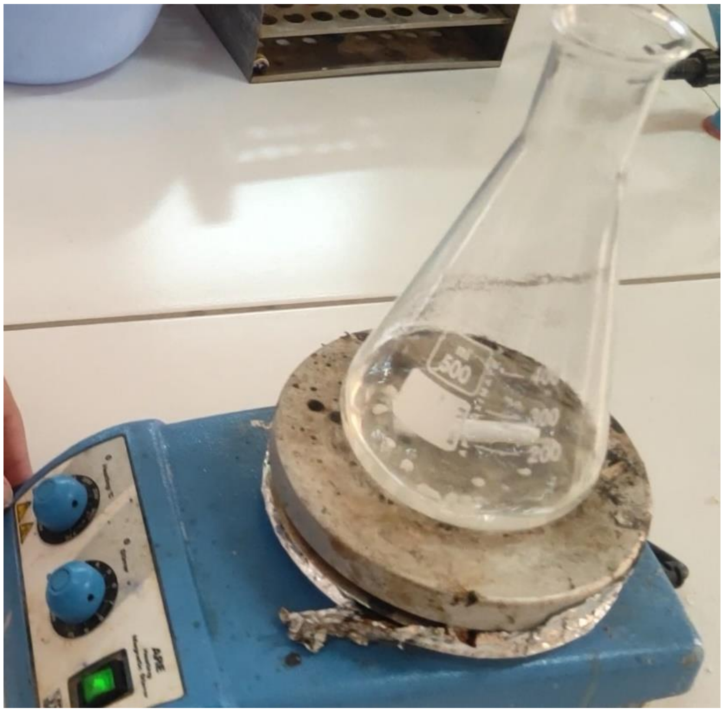

Figure 8: preparation of solution Sodium methoxide

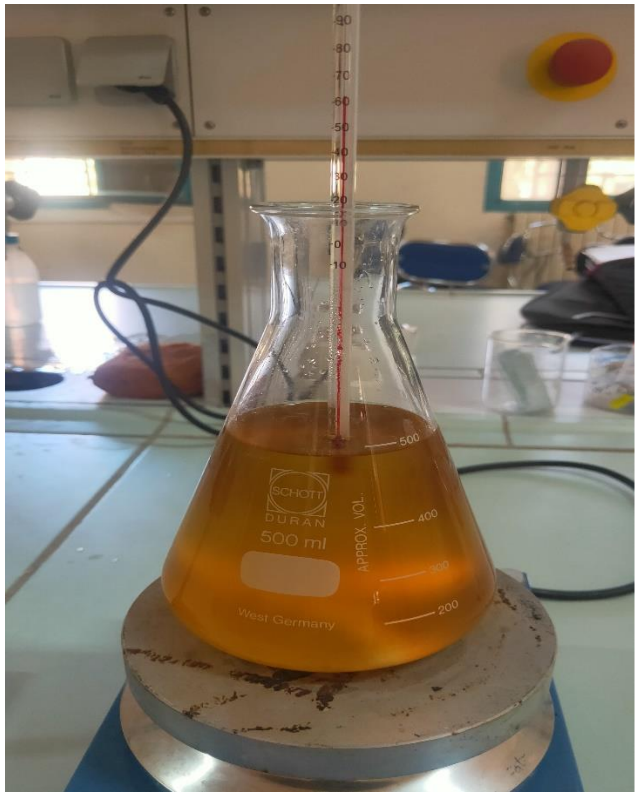

Figure 9: mixture of Sodium methoxide solution with used cooking oil

6.2.2.2 Separating the reaction products

1. The density of the glycerol is higher than that of the biodiesel, causing the biodiesel to float on top.
2. To separate the two products, we used settling vessel or separating funnel, relying on gravity to separate them.
3. The glycerol can be drawn off from the bottom of the vessel or funnel, while the biodiesel can be drawn off from the top.

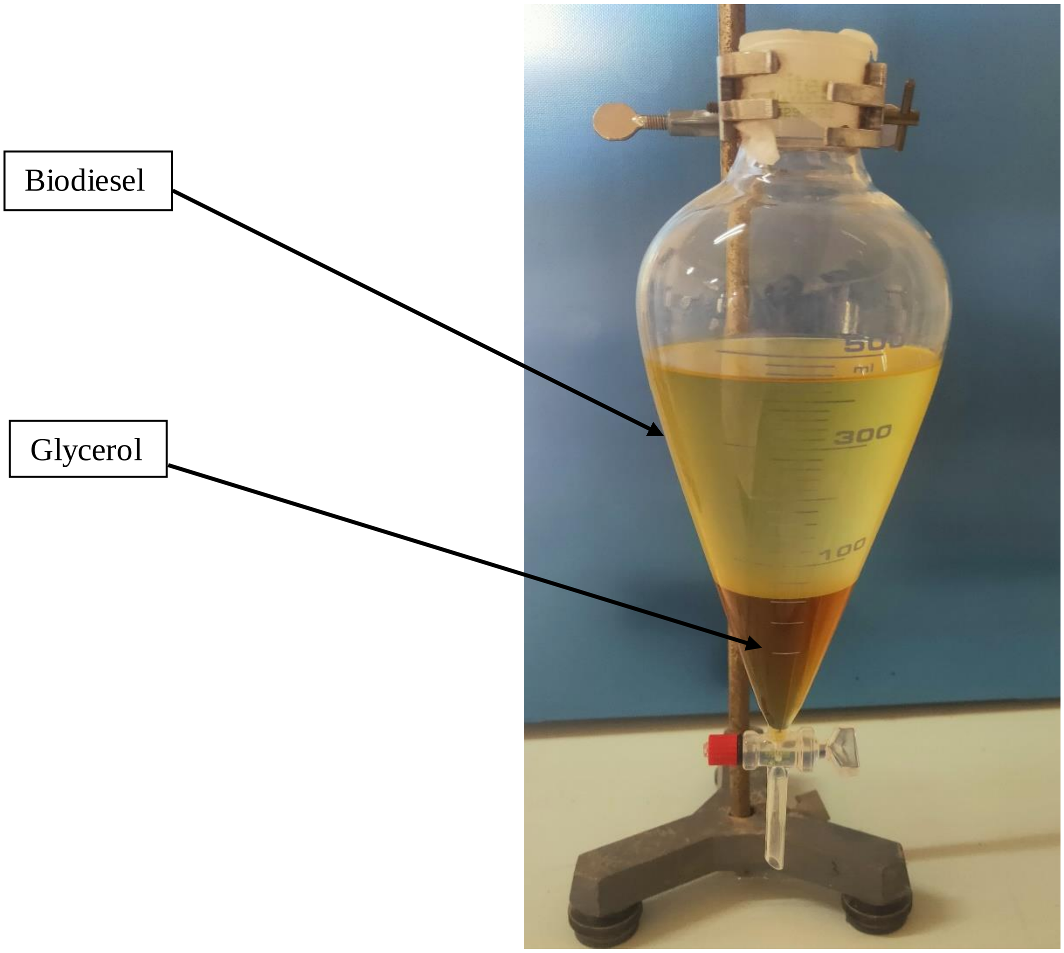

Figure 10: separation of glycerol from biodiesel

6.2.2.3 Purification of the Biodiesel

1. The biodiesel is washed by spraying warm water (50°C) over it, and this step is repeated until clear water is seen beneath the biodiesel in the separating funnel.
2. After the washing process, the biodiesel may still contain some traces of water, so it is heated to 115°C to remove any water molecules.

Figure 11: Biodiesel purification

6.3 Results

About 380 ml of biodiesel was produced from the previous experiment and about 60 ml of glycerol, pictures of the two products are shown below.

Figure 12: Crude glycerol (brown color) and biodiesel (yellow color)

6.3.1 Characteristics of biodiesel

6.3.1.1 Density

Density is a very important property of any fuel, as it directly affects engine performance characteristics. The density value of biodiesel should be between 860-900 kg/m^3. One common method for measuring the density of biodiesel is by using a pycnometer. The Pycnometer was weighed empty and then weighted full of Biodiesel. The difference between the two weights was divided by 10 ml to get the density. The observed density of biodiesel was found to be 0.8708 g/cm^3 (870.8 kg/m^3).

6.3.1.2 Viscosity

Viscosity is another important property of biodiesel since it influences the operation of the injection system. Absolute viscosity of biodiesel was determined by using Ostwald Viscometer and was found to be 6.314 mm^2/s (6.314 centistokes (cSt)) at 30°C just out of the standard range of 1.9-6.0 mm^2/s. The kinematic viscosity was calculated by taking the ratio of absolute viscosity and density and was found to be 7.25 mm^2/s.

6.4 Conclusion

According to the results obtained, we found that the biodiesel produced from the used cooking oil in the laboratory has approximately the same characteristics as petroleum diesel, particularly in terms of density and viscosity.

General conclusion

Biodiesel is an important renewable fuel. It can be produced by converting the waste stream from a restaurant “UCO” into usable fuel for diesel engines. There are significant advantages in the use of biodiesel as a replacement of diesel fuel and in blends, like low toxicity and reduction in greenhouse gas emissions.

Biodiesel is a better fuel than petrodiesel and meets most of the chemical/physical standards of petrodiesel. It has the potential to offer a series of perceived benefits such as economical, agricultural, as well as environmental (due to its biodegradability, less toxicity, renewability) and health (greenhouse gas-saving, less harmful exhaust emissions). Biodiesel can be considered as the best option, showcasing immense potential to fulfill fuel requirements and secure a sustainable fuel supply in the future.

The proposed business will facilitate in judicious waste utilization through a green novel technology operated through a community-centered enterprise to reduce the emission locally in an economic way. Glycerol is the by-product generated from this process, which is of high value. The size of the company falls into the microenterprise category. It will employ up to 10 employees (including the company’s partners) and the expected annual revenues at the end of the third year of operation will be about 100.0000DA. The estimated payback time of the investment is 2-4 years, but it may be even shorter regarding the business partners when considering the after tax compensation they receive for the management and supervision services.

In conclusion, the findings of this thesis underscore the importance and viability of biodiesel production from used cooking oil. The proposed business initiative presents a sustainable and economically promising solution to the challenges of waste disposal and the demand for cleaner fuels. With the right implementation, this project has the potential to make a positive societal and environmental impact while driving economic growth and fostering partnerships for a greener future.

While this thesis has made significant strides in understanding the production, properties, and market potential of biodiesel, there are avenues for further exploration. Future research could focus on optimizing the production process, investigating new feedstock sources, and exploring emerging markets for biodiesel.

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Appendix – Supplementary tables

Supplementary table A: Business model canvas

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
Small and medium Restaurants (as supplier of used cooking oil). Chemical Industries (raw material suppliers). Government.	Purchasing of raw material. Collection of used cooking oil. Manufacturing of biodiesel. Sale and distribution.	Biodiesel is more eco-friendly. Waste reduction. Offering suitable solution by providing quality product at very less price. Produce high quality products from low grade feedstock.	In-person. Trust based relations. Long term focused relation.	Local transport users. International transport users. large fleet operators Independent gas station owners large diesel distributor’s Soap & Cosmetics companies Pharmaceuticals companies
	Key Resources		**Channels**	
	Human resources. Technological Infrastructure. Used cooking oil from Restaurants. Chemicals.		Direct Communication/ dealing with customers and suppliers. Sales representatives Website / Social Media.	

Cost Structure	Revenue Streams
Raw materials cost for making biodiesel. Workers salary. Sales and Marketing. Warehouse rent cost.	Selling biodiesel (main product). Selling glycerol (by-product).

Table B: Start-up investment requirements.

	Number of Units	Cost per Unit (DZD)	Total Cost (DZD)
Industrial equipment	1	600000	600000
Containers	10	10000	100000
Office Furniture	4	38000	152000
PCs & Peripherals	3	30000	90000
Warehouse	1	50000	50000
Office Rent	1	20000	20000
Vehicles Leasing	3	35000	105000
		Total investment requirements	**1117000**

Table C: Costs & Expenses.

a) It is Assumed that the distance covered by vehicles is 120 thousands km in aggregate for all 3 vehicles per year

	Units					**Price per Unit(DZD)**					**Total(DZD)**				
	Year					**Year**					**Year**				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Costs of goods															
Labour Cost	5	5	5	5	5	27000	27000	27000	27000	27000	135000	135000	135000	135000	135000
Vehicles Operating Leasing	3	3	3	3	3	35000	35000	35000	35000	35000	105000	105000	105000	105000	105000
Transport Fuel Consumption (a)	120	120	120	120	120	29	29	29	29	29	3480	3480	3480	3480	3480
Administrative expenses															

Manager	1	1	1	1	1	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000
Accountant	1	1	1	1	1	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000
Secretary	1	1	1	1	1	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000
Overhead expenses															
Office/ Warehouse Rent	1	1	1	1	1	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000
Electricity/ Heating	1	1	1	1	1	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
Total of Cost & Expenses											417480	417480	417480	417480	417480

Table D: Projected revenues of biodiesel.

	Units					Price per Unit(DZD)					Total(DZD)				
	Year					Year					Year				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Revenues	4000	5300	7000	8200	9600	28	28	28	28	28	112000	148400	196000	229600	268800

Table E: Projected revenues of glycerol.

	Units					Price per Unit(DZD)					Total(DZD)				
	Year					Year					Year				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Revenues	2500	3400	5700	6200	7600	140	140	140	140	140	350000	476000	798000	868000	1064000

Table F: Profits.

	Total(DZD)				
	Year				
	1	2	3	4	5
Total Revenues	462000	624400	994000	1097600	1332800
Expanses	417480	417480	417480	417480	417480
Profit before taxes	44520	206920	576520	680120	915320
Taxes	-	-	-	-	-
Net Profit	44520	206920	576520	680120	915320

Note: The startups have been exempted from taxes for a period of five years, starting from the date of obtaining the start-up enterprise label.

Table G: Startup budget

	Year (DZD)				
	1	2	3	4	5
Assets					
Building	175000	175000	200000	200000	280000
Other tangible assets (A)	600000	480000	360000	240000	120000
Raw materials-Methanol (B)	37000	49025	64750	75850	88800
Raw materials-NaOH (B)	9000	11925	15750	18450	21600
Clients	60000	50000	65000	35000	60000
Treasury (C)	1354000	1239050	1119500	1005700	869600
Total Assets	2235000	2005000	1825000	1575000	1440000
Charges					
Equity	500000	600000	700000	800000	880000
Borrowings and financial debts	900000	700000	500000	300000	100000
Other Debts	26000	30000	29000	38000	40000
Total Charges	1426000	1330000	1229000	1138000	1020000

Verification of the Assets/Charges balance (D)	809000	675000	596000	437000	420000

Notes:

A: To find out the rate at which the value of the machine is depreciating, we divided its price (600000 da) by 5, and we get 120000 da. Then, in order to find how much the cost of the machine will be for the next year we only have to do the following : 600000- 120000 = 480000 da.

B: we plan to produce 4000L of biodiesel, it’s going to cost us 37000da of methanol and 9000da of NaOH.

For second year (5300L) we will need 49025da of Methanol and 11925da of NaOH

For third year (7000L) we will need 64750da of Methanol and 15750da of NaOH

For forth year (8200L) we will need 75850da of Methanol and 18450da of NaOH

For fifth year (9600L) we will need 88800da of Methanol and 21600da of NaOH

C: (Equity+ Borrowings and financial debts)-(Raw materials Methanol + Raw materials NaOH)

D: Total Assets- Total Charges

Table H: Expected results calculation table

	Year (DZD)				
	1	2	3	4	5
Sales and Related Products(A)	461440	624120	994000	1092000	1330000
Financial year production (1) (B)	461440	624120	994000	1092000	1330000
Consumed purchases (C)	46000	60950	80500	94300	110400
External services and other consumption (D)	198480	198480	198480	198480	198480
Consumption during the Financial year (2) = C+D	244480	259430	278980	292780	308880
Operating added value (1-2)	216960	364690	715020	799220	1021120
Staff costs (E)	219000	219000	219000	219000	219000
Gross Operating Surplus (F)	-2040	145690	496020	580220	802120
Other operating products (G)	350000	476000	798000	868000	1064000
Amortization expense (H)	829400	299800	634200	536600	439000

Operational results (I)	-481440	321890	659820	911620	1427120
Financial expenses (J)	945000	735000	525000	315000	105000
The net result for the fiscal year	463560	1056890	1184820	1226620	1532120

Notes:

A: is the sum of global business figure of biodiesel and glycerol; example: 111440+350000=461440

B: Change in finished and work-in-progress inventories + operating grant

C: in the biochemistry market, the cost of 740L of methanol is 37000da and cost of 20kg of NaOH is 9000da which is the quantity needed to produce 4000L in the first year. The second year we consume 60950da to produce 5300L

D: it includes the vehicles operating leasing, transport fuel consumption, Office/Warehouse Rent and Electricity/Heating costs.

E: is the sum of labor Cost+ Manager +Accountant +Secretary Salaries

F: Operating added value - Staff costs (E)

G: is the projected revenues of glycerol.

H: Amortization rate varies from one installation to another, but in general, institutions use the following rates:

Buildings 2% (e.g. 70000-(70000*2%) = 68600)

Equipment and tools 10% (e.g. 600000-(600000*10%) = 540000)

Transportation equipment 20% (e.g. 105000-(105000*20%) = 84000)

Office equipment 10% (e.g. 152000-(152000*10%) = 136800)

Amortization expenses for the first year = 68600+540000+84000+136800 = 829400

I: is Gross Operating Surplus (F) + other operating products - Amortization expense (H)

J: We assume that the interest on loans granted by the Algerian startup fund is 5%, starting from the second year we will have to pay the original borrowed money plus an additional fees (Borrowings and financial debts * 5%).

Example: 700000da + (700000da*5%) = 735000da

Table i: Treasury plan

	Year (DZD)				
	1	**2**	**3**	**4**	**5**
Cash flow from operational activities					
The net result for the fiscal year	463560	1056890	1184820	1226620	1532120
+Amortization and provisions (A)	600000	480000	360000	240000	120000
-change in inventory (B)	442000	596400	944000	1045600	1273800
-change in clients and other receivables (C)	20000	19000	20000	5000	17000
+change in suppliers and other payables (D)	4499	5961	7873	9223	10798
Cash flow generated by the activity (E)	606059	927451	588693	425243	372118

Cash flow from operations financing					
Capital increase/ASF share	900000	700000	500000	300000	100000
Capital increase/ startuper share	500000	600000	700000	800000	880000
ASF capital repayments	-	500000	250000	100000	50000
Cash flow from operating activities financing (F)	1400000	800000	950000	1000000	930000
Change in cash for the period (E+F)	2006059	1727451	1538693	1425243	1302118
Opening cash (beginning of period) (G)	1400000	1300000	1200000	1100000	980000
Closing cash (end of period) (H)	1028720	1506920	1776520	1780120	1895320
Change in cash (I)	371280	164360	-412160	-1092280	-2007600

Notes:

A: To find out the rate at which the value of the machine is depreciating, we divided its price (600000 da) by 5, and we get 120000 da. Then, in order to find how much the cost of the machine will be for the next year we only have to do the following : 600000- 120000 = 480000 da.

B: Total Revenues- expected stock

C: is the rest of money after the customers pay their debts

D: change in suppliers and other payables= forecast annual purchases * (TVA 19%+1) * (payment period/365)

E: Through the model of the treasury liquidity schedule in the direct way stipulated by the Algerian legislator, we find that it consists of the following categories:

The net result for the fiscal year

+ Amortization and provisions

- Change in inventory

- Change in clients and other receivables (if its balance is positive, it is subtracted)

+ change in suppliers and other payables (if its change gives a positive balance, it is added, and if it gives a negative balance, it is subtracted).

F: Capital increase/ASF share + Capital increase/ startuper share - ASF capital repayment

G: it's the money we started our production period year with.

H: Opening cash + Total Revenues - Expanses

I: Opening cash - Closing cash (for the first year)

For the rest of the years: Change in cash of the first year + Opening cash - Closing cash.