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BIODIESEL FROM NATURAL RESOURCES: A COMPREHENSIVE REVIEW OF FEEDSTOCK PRODUCTION AND SUSTAINABILITY

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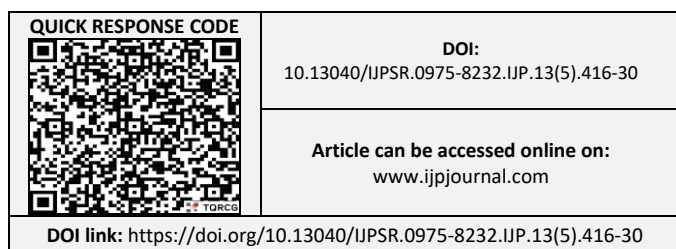
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ABSTRACT: Biodiesel is a non-toxic and renewable source based on, mainly, petroleum-derived products which are often produced from domestic natural sources like soybean, rapeseed, and coconuts, and also derived from cooking oils that are recycled for natural use. Vegetable oils gave the idea of substituting fuels for diesel engines. But due to their characteristics of low cold flow, low volatilities, and increasing viscosity, this led to the research of different derivatives. Transesterification is a process in which the monoalkyl esters of vegetable oils and fats, mostly called biodiesels, are used to gain energy for fuel. Biofuels are fuels derived from organic materials such as plants, algae, or farm waste. They offer an attractive alternative to fossil fuels by providing a renewable and high-power source of energy. Jatropha, Jojoba, Soyabean, etc., are used as the raw materials for the generation of biofuels from 1st generation biofuels. Alcohols, Dimethyl Furan are also used in generating biofuels as 2nd generation biofuels. Some types of engines are also used for producing biofuels for natural use. Chemically, the oil/fats consist of 90-98% triglycerides and small amounts of mono and diglycerides. Thus, these biofuels will help us to provide energy in high amounts by using feedstocks as renewable sources of energy. This will help us to build a suitable structure of energy production by replacing fossil fuels in the future.

INTRODUCTION: A century ago, Rudolf Diesel experimented with some vegetable oil for the first time as engine fuel on 10th August 1893. Thus, for improved research during the 1930s and 1940s, vegetable oils were introduced as emergency fuels. In the year August 1982, at Fargo, North Dakota, an international conference on vegetable oils and biofuels was conducted ¹. The word biofuel is denoted as the gaseous form of fuels or liquid fuels which will importantly be manufactured from biomass.

Variation of fuels manufactured from biomass sources containing liquid fuels, like bioethanol, methanol, biodiesel, Fischer-Tropsch diesel, and other gaseous fuels, like hydrogen and methane. First of all, the main discussion was on the cost-effectiveness of biofuels or biodiesels, the effect of vegetable oils used in fuel production and specialization, and the additives. The process of seed production and extraction of oils was also included as the primary discussion at that meeting.

Vegetable oils gave the idea of substituting fuels for diesel engines. But due to their characteristics of low cold flow, low volatilities, and increasing viscosity, this led to the research of different derivatives ². Fatty acids of Methyl esters, which are known as biodiesels, are extracted from or derived from triglycerides by the process of



transesterification with the help of methanol, which shows more intensity in the focus of everyone's eyes³. With the increasing population in the world, it is predicted that the population will rise to over 9 billion by the year 2050. In these circumstances, the energy demand and the global prices of fuel will rise immensely, and also give rise to pressure on natural energy reserves, which will cause a large amount of exhaustion. Using fossil fuels has many disadvantages, including environmental degradation, which leads to the release of greenhouse gases (GHG), and also the production of high amounts of Carbon dioxide (CO₂)⁴. Biodiesel is now a day proposed by everyone as a sustainable substitute for fossil fuels. Biodiesel is a non-toxic and renewable source based mainly on petroleum-derived products, which are often produced from domestic natural sources like soybean, rapeseed, and coconuts, and also derived from cooking oils that are recycled for natural use⁵. This mainly helps reduce the use of fossil fuels, which will help us get energy without using them. The atomization or the functional characteristics of vegetable oils are distinctly and importantly different from those of those derived petroleum diesel fuels, which mainly result in a high-viscosity substance. In our modern days, engines have viscous fuel-injection systems that are sensitive to changes. So, to avoid these problems, there is a way that is to change the viscosity of vegetable oils for their betterment on performance. The main method used in this technology is Transesterification.

Transesterification is a process in which the monoalkyl esters of vegetable oils and fats, mostly called biodiesels, are used to gain energy for fuel. The component methyl ester produced by the

transesterification method of usable vegetable oils contains a maximum number of cetane with low viscosity, and also gives an improved characteristic of emitting heat values compared with that of pure vegetable oils⁶. This leads to the increasing duration of combustion and also results in a delay of a lower ignition rate, thus showing the least particulate emission of energy⁷. The edible oils are of different types, which are now processed and used as biodiesel substitutes for diesel fuels in different countries, and used as natural sources of energy that can be used as fuel⁸. Depending upon climatic and soil characteristic properties of different plants and animals are used as source material for biodiesel production. The high-yielding strains of phototropic microorganisms of biomass, which diligently gather lipids, show auspicious unconventional basic material for providing bioenergy with the production of biodiesel⁹. Due to the use of fossil fuels, energy consumption has increased quickly in daily life. Thus, industrialization and the luxury life-leading tendency took it to another level of wasting energy resources. Some developing countries like Brazil, South Asian countries, and South Africa need about 12-24 gigajoules (GJ)/capita of energy each year to have a luxurious lifestyle for living. Recently, over 80% of the world's energy consumed comes from fossil fuels, that comprises including natural gas, petroleum, crude oils, and coal, and over 98% of energy is generated through the emission of carbon from fossil fuels. Whereas the Southeast Asian countries of Asia give the utmost focus on the export of biofuel. To reduce the dependency on petroleum, economically stable countries like India and China are looking forward to biofuel production¹⁰.

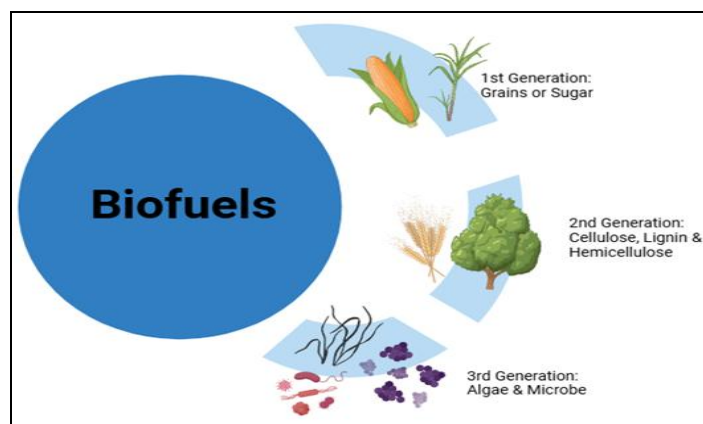


FIG. 1: TYPES & GENERATIONS OF BIOFUELS

The standard majority have similar limits for parameters like glycerol content, copper strip corrosion, acid number, and sulfated ash; both fatty acid ethyl esters (FAEE) and fatty acid methyl esters (FAME), which were introduced first in the Brazilian and US biodiesel standards, but the most applicable biodiesel for standard use is fatty acid methyl esters. Therefore, biodiesels are nowadays used as a natural fuel for energy production. These are mainly produced to prevent the use of fossil fuels. Fossil fuels exist in limited amounts and are non-renewable, thus it would be better to use biofuels over fossil fuels. Biodiesel is a renewable source of energy that we can use for a lifetime, as it comes from natural sources¹¹.

Types and Generation of Biofuels: Biofuels are fuels derived from organic materials such as plants, algae, or farm waste. They offer an attractive alternative to fossil fuels by providing a renewable and high-power source of energy. Biofuels are classified into four generations, which are first,

second, third, and fourth, which are based on the sources and also the various biomaterials production¹².

First-Generation Biofuels: These First-generation biofuels are referred to as conventional biofuels, which are usually produced from two edible feedstock types, titled starch-based (i.e., potato, corn, barley, and wheat) and sugar-based (i.e., sugarcane and Sugar beet). The major benefits of raw materials of the first generation are crop availability and easy comparative conversion processes¹³. Due to these reasons, the utilization of edible crops to produce biodiesel will decrease the food supply, and this can increase food prices. The second issue is to divert farm production for fuel production. Utilizing a large quantity of fertilizer and pesticides for farm production may damage the environment. Various forms of traditional biofuels depend on the technological method by which they are produced.

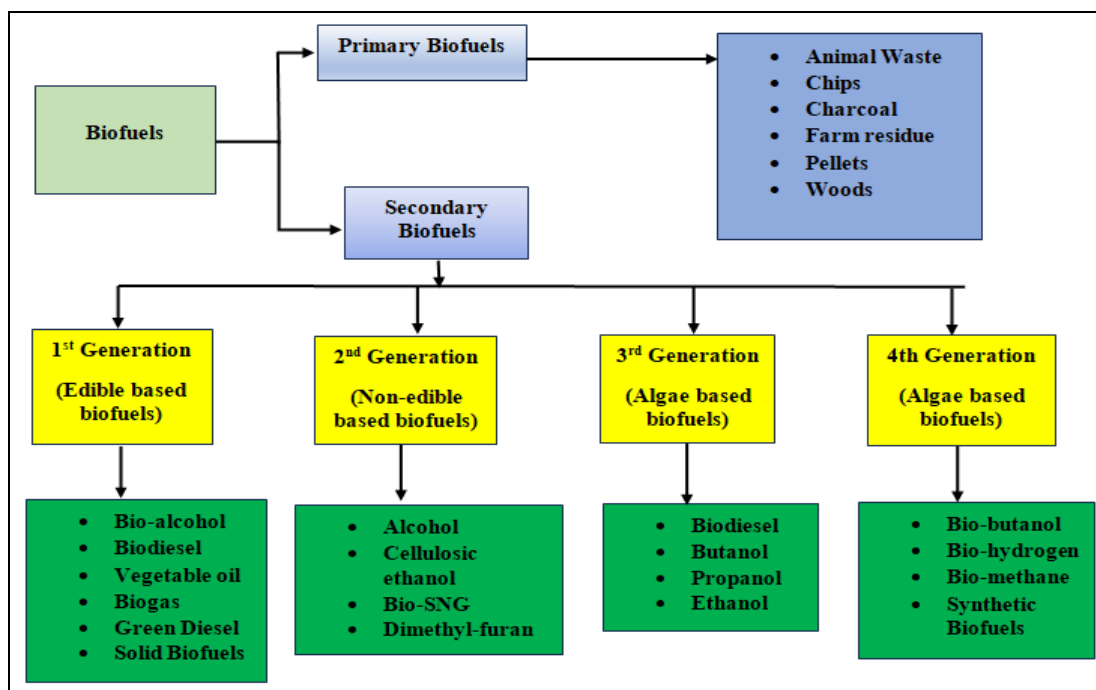


FIG. 2: TYPES AND GENERATIONS OF BIOFUELS¹²

The first-generation biofuels are generated from food-feedstocks, like bioethanol from sugarcane, maize, and biodiesel from oilseed crops (soybean oil, palm oil, rapeseed, and sunflower) with well-developed, economic, and technically proven technologies and processes like fermentation, distillation, and transesterification¹⁴. First-generation biofuels have a relatively small edge

over fossil fuels from a greenhouse gas point of view in that they consume a lot of energy to produce, harvest, and process¹⁵. They possess serious issues, such as competing with food cultivation, land utilization issues, moderate greenhouse gas savings when their life cycle is factored in, intensive water requirements, and potential soil erosion by extensive monoculture

agriculture¹⁶. The disadvantages have urged greater research towards second- and third-generation biofuels as alternatives to fix the issues,

but not lose sight of the advantage of renewable fuel production¹⁷.

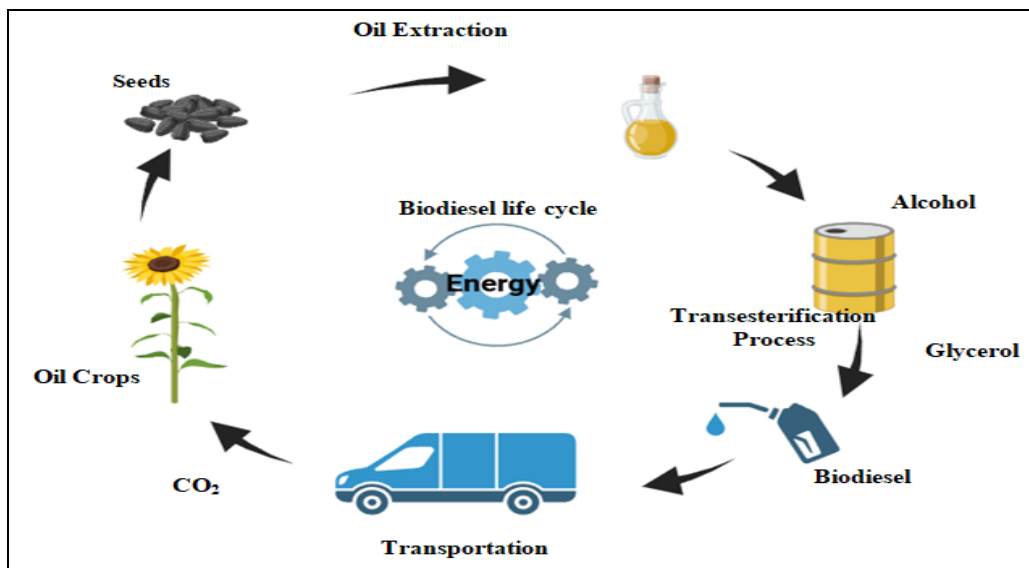


FIG. 3: THE BIODIESEL LIFE CYCLE

Jatropha Oil: *Jatropha (Jatropha curcas)* is a prospective biodiesel oilseed tree. *Jatropha* is cultivated in many tropical and subtropical areas in Asia, Africa, and Latin America, and the cultivation area was nearly 900,000 hectares in 2008 (FAO/IFAD, 2010). *Jatropha* can thrive under semi-arid conditions or marginal land with little input needed. Today, assured yields would result from greater investment in inputs on favourable soils (International Energy Agency (IEA))¹⁸. About 14% of crude *Jatropha* oil includes FFA, which is significantly more than the 1% threshold needed to encourage transesterification reactions

using an alkaline catalyst. According to some reports, if the oil contains more than 3% FFA, transesterification will not take place. Numerous pretreatment techniques, such as steam distillation, alcohol-based extraction, and esterification using acid catalysts, have been developed and put into practice. Nonetheless, the most often used technique is the esterification of FFA with methanol in the presence of acidic catalysts due to the ease of the procedure and the ability of the acid catalysts to employ the free fatty acids in the oil to produce biodiesel¹⁹.

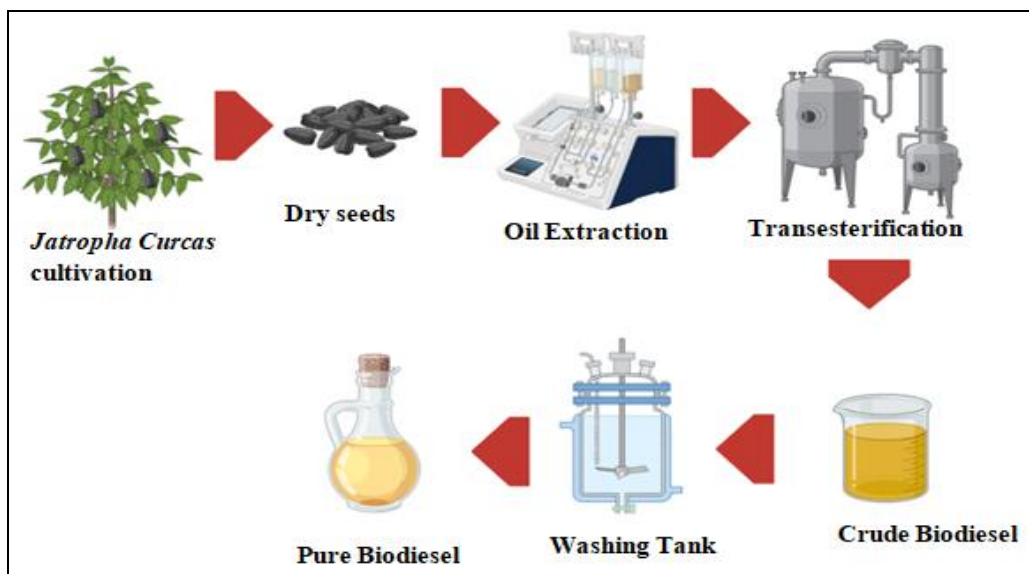


FIG. 4: TRANSESTERIFICATION FROM *JATROPHA CURCAS*

Most typically, though not exclusively, they are poisonous seeds for both humans and animals. Curcumin, a toxic protein that has been isolated from the seeds, has also been shown to inhibit protein synthesis *in-vitro* studies. Besides that, due to the high concentration of phorbol esters that it has in the seed, its toxicity has been identified²⁰. It is therefore unsuitable for cooking because of the presence of some anti-nutritional factors in oil. The fact that it cannot be used for consumption for nutrition without detoxification is certainly fine and makes it an attractive non-edible feedstock for the oleochemical industries: biodiesel, fatty acids, soap, surfactants, detergents, and so on. *J. curcas* currently produces 2000L/ha oil per annum. Jatropha oil has ~24.60% crude protein, 47.25% crude fat, and 5.54% moisture of 5.54%.

The fatty acid composition of Jatropha oil differs in various countries²¹. Mainly palmitic acid (16:0) at 14.1%, and stearic acid (18:0) at 6.7% constitute the saturated fatty acids of the Jatropha oil. The rest of the unsaturated fatty acids are oleic acid (18:1) at 47% and linoleic acid (18:2) at 31.6%²².

This oil, being rich in oleic and linoleic acid with high levels of monounsaturated and polyunsaturated content, is semi-drying and has been a very good diesel fuel substitute²³. The commercial exploitation is only possible with a complete elimination of the toxins from the oil. Mechanical pressing of seeds is the conventional method of oil extraction. The new ones are enzyme-assisted three-phase partitioning (TPP) and aqueous enzymatic oil extraction methods²⁴.

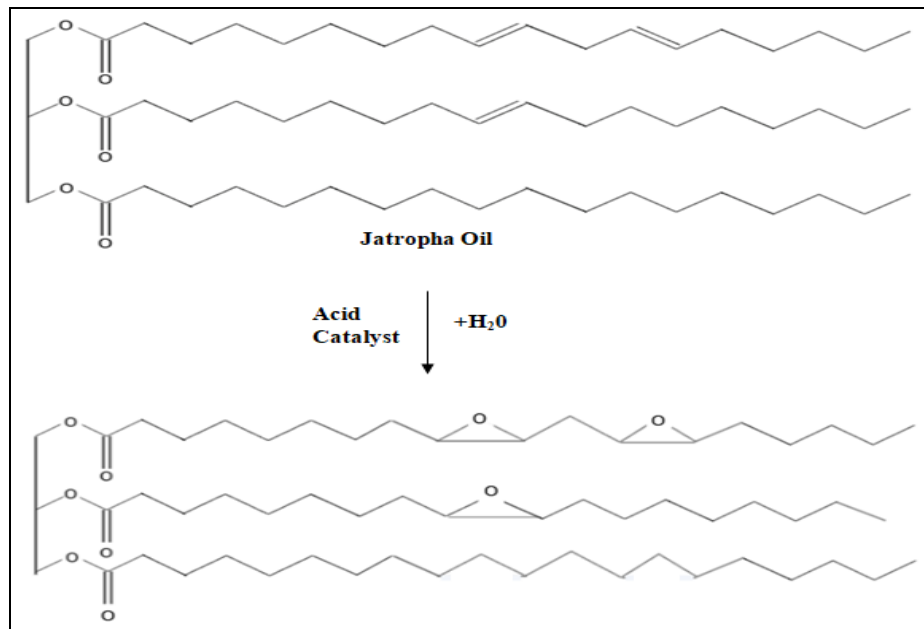


FIG. 5: EPOXIDIZED JATROPHA OIL

Jojoba Oil: The most significant location of diesel in the industrial economy of a nation is a key fuel for the transportation sector, with an increasingly rising demand for various alternatives to conventional fuels, which ought to be technically viable, financially competitive, environmentally friendly, and easily accessible alternatives²⁵. Biodiesel is produced through the transesterification of plant and animal oils and fats and is thus a more viable substitute for petroleum diesel fuel since it holds out the prospect of a renewable source of fuel with fewer greenhouse gas emissions than petroleum diesel²⁶. It is a biodegradable fuel that makes a negligible

contribution to greenhouse gases or sulfur in the air. The oil will respond to alcohol during the transesterification process, and the alcohol utilized during the transesterification is usually methanol. Methanol and vegetable oils are therefore the most prevalent forms of biodiesel and have been extensively researched in recent years²⁷. Very little research has been conducted, however, on the transesterification of jojoba oil-wax²⁸. Recently, researchers have studied the combustion of jojoba methyl esters in an indirect injection diesel engine. Jojoba is a desert-dwelling perennial shrub plant that has recently drawn interest as an industrial crop in various countries. Thousands of farmers are

currently growing this little-known desert shrub in the United States, Central and South America, South Africa, and numerous other nations. The weight of jojoba oil is approximately half the seed weight. The chemistry of jojoba oil is basically unlike that of the vegetable oils, which are generally available²⁹. Its chemistry is a long straight chain ester; the other common vegetable oils are triglycerides (branched esters derived from the glycerol molecule). Traditional oilseed crops yield glyceride oils in which fatty acids are attached to glycerol. Jojoba contains no glycerides³⁰.

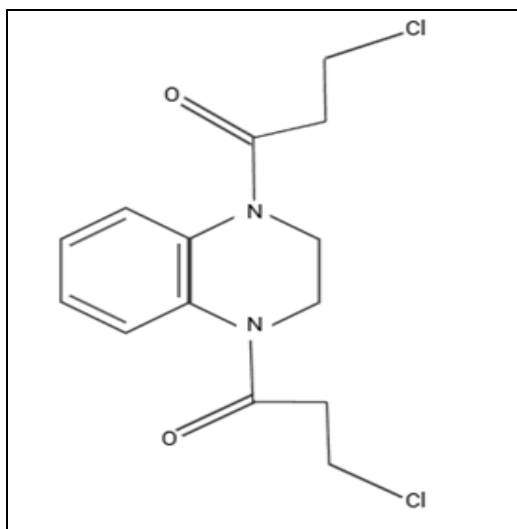


FIG. 6: JOJOBA OIL

Soybean Oil: Biodiesel, “a substitute for, or an additive to diesel fuel derived from the oils and fats of plants and animals,” is gaining popularity in Europe and the US markets. The European Union has a target to obtain a market share of 5% of the total motor fuel consumption by motor biofuels by 2005³¹. Much of this figure is anticipated to be biodiesel, and a council regulation laying down its specifications is pending discussion. In the same manner, the US Department of Energy estimated that biodiesel could potentially replace up to 50% of the overall diesel fuel use³². The primary benefits of utilization of this alternative fuel include renewability, high quality exhaust gas emissions (since it lacks sulphur, except in the case of biodiesel made from canola oil with a high sulfur content), its biodegradability, and, since all of the organic carbon used is photosynthetic in nature, it will not lead to an increase in the net amount of carbon dioxide in the atmosphere, and thus to the greenhouse effect (assuming that the

carbon dioxide released through the manufacture of fertilizers is excluded)³³. Vegetable oil fatty acid methyl esters (FAME) are potential biodiesel, as the outcome of better viscosity, volatility, and combustion behaviour compared to triglycerides, but with the same cetane number (approximately^{50, 34}.

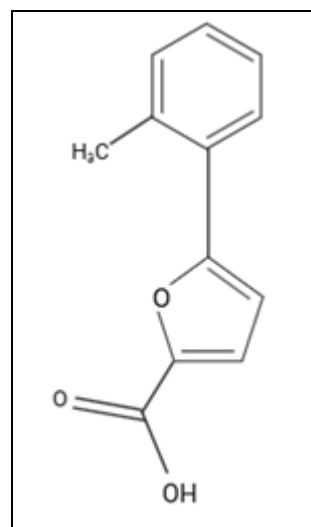


FIG. 7: CHEMICAL STRUCTURE OF SOYABEAN OIL (HYDROGENATED)

FAME biodiesel is also compatible with conventional diesel, and the two can be blended in any proportion, although the ignition quality of the blends remains essentially the same as that of the conventional diesel³⁵. Transesterification (also called alcoholysis) of triglycerides for soap manufacture has been studied intensively, and more than a dozen US patents and five European processes have been issued. The first objective of this paper is to describe the application of the current FAME biodiesel production technology to the transesterification of soybean oil and two residual fatty materials, frying oil and tallow³⁶. Soybean oil has been extensively studied as a raw material for FAME biodiesel production, and, in our study, it served as a test for the optimization of the production of biodiesel from the two fatty materials, the transformation of which would alleviate a disposal problem³⁷. In Spain, edible oils are used in frying pans or fryers (except the oil consumed in salads) and are discarded after a variable time of use. The used frying oil is mostly thrown through the home drains, leading to water pollution³⁸. Moreover, as more than 80% of the oil is consumed at home, controlling this disposal behaviour is very difficult.

The Council of Tres Cantos (population 28,000), a residential village on the outskirts of Madrid, has launched a pioneering program to recover all the used frying oil in waste oil containers (capacity 500 l). The containers are emptied and cleaned twice a week, and the used oil is transported to a factory for processing³⁹. On the other hand, the consumption of animal fats such as tallow is in decline as a result of a change in the feeding habits of the population, and the soap industry cannot take up all the excess animal fats produced⁴⁰. This amidation reaction of soybean oil, used frying oil, and tallow was carried out with diethylamine to produce "amide biodiesel"⁴¹. To check its ignition quality, the blending cetane number of the amide biodiesel of used frying oil blended with petrochemical diesel was calculated⁴².

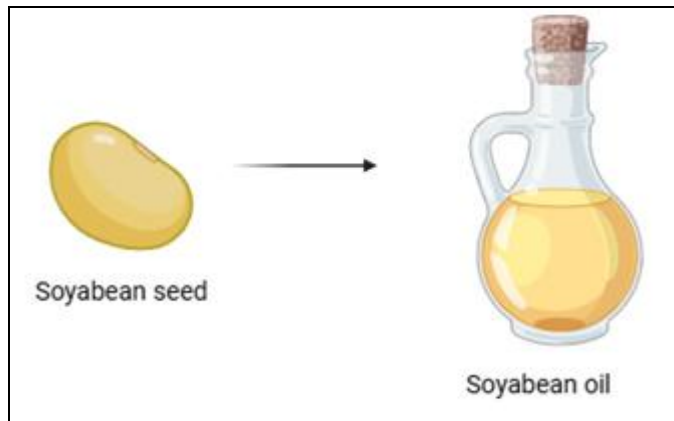


FIG. 8: SOYABEAN OIL

Second Generation Biofuels: Second-generation biofuels' sustainable approach for CO₂ concentration levels would be practically carbon neutral or even carbon negative⁴³. The term biomass plant refers to plant matter that mainly comprises lignocellulose- the most plentiful and cheap non-food materials available⁴⁴. Currently, there are technical barriers that need to be overcome before the production of such fuels can be rendered a viable and economically justifiable enterprise⁴⁵. Plant biomass is among the most abundant and least utilized biological resources on the planet, regarded as a potential feedstock to obtain fuels and raw materials⁴⁶. Simply put, any biomass may be burnt as a means of producing heat or electricity⁴⁷. Nonetheless, there is huge potential for biofuel production from plant biomass⁴⁸. The vast majority of constituent materials in plant biomass are wall cell components wherein polysaccharides are present, typically in an

abundance of 75% or more⁴⁹. Such polysaccharides are hence an excellent target pool for sugars. Even in traditional food crops such as the wheat (*Triticum aestivum*), just as much sugar is tied up in the stem as in the starch of the grains⁵⁰. Lignocellulosic materials represent a host of feedstocks for advanced biofuels and are obtainable either through hydrolysis. And fermentation (bioethanol) or gasification (Fischer-Tropsch biodiesel, bio-DME, and bio-SNG)⁵¹. The main sources for such fuels are short rotation forestry crops (popular ones being poplar, willow, and eucalyptus), perennial grasses (miscanthus, switchgrass, and reed canary grass), and various residuals from wood, forestry, and agricultural industries⁵². Advanced biofuels, or second-generation biofuels, are carbon-based fuels that are produced through new and innovative processes primarily utilizing lignocellulosic materials with commercial application yet to be developed. Embryonic bioethanol is an alternative to petrol. It can substitute petrol in so-called flexi-fuel vehicles⁵³.

Hydrolysis extracts the sugars from lignocellulosic feedstock, followed by the fermentation of sugars to ethanol. Fischer-Tropsch diesel (FT-diesel) or BTL (Biomass-to-Liquids) is a complete substitute for diesel⁵⁴. The gasification of lignocellulosic biomass converts generating syngas, followed by its transformation into liquid hydrocarbons, mostly diesel and kerosene⁵⁵. Bio-SNG (synthetic natural gas) can be used with a few modifications fitted into gasoline vehicles⁵⁶. Following a route similar to that of bio-SNG, methane is produced from the gasification of lignocellulosic biomass then turned to syngas⁵⁷. Bio-DME (dimethyl ether) may also be used with a few modifications to adapt the fuel system of diesel vehicles⁵⁸.

Dimethyl-furan: Global energy lacks and ecological pollutions have pushed researchers to develop a new generation of technologies for low-cost synthesis of biofuels from renewable biomass⁵⁹. The second-generation biofuels must be established in use of renewable chemical products and produced by innovative and mature chemical technologies such as pyrolysis, Fischer Tropsch synthesis, or a catalytic process, which are capable of synthesizing complicated molecules or materializing material into renewable biofuels.

More than 75% biomasses such as corns (maize), trees and grass, are composed of carbohydrates (e.g., starch and cellulose)⁶⁰. These carbohydrates generally exist as polymer chains of thousands of units (fructose or glucose)⁶¹. And every unit has six carbon atoms and a single oxygen atom, molecules of biomass contain more than 100 carbon atoms. In contrast, the conventional fuels for internal combustion engines generally have molecules consisting of five to 15 carbon atoms⁶².

Therefore, molecular miniaturization and oxygen atom removal are the primary challenges in converting biomass to biofuel. The initial approach is to pretreat the biomass and break it down to glucose or fructose and then remove three oxygen atoms from the glucose or fructose via selective dehydration to produce 5-hydroxymethylfurfural (HMF)⁶³. Finally, HMF can be hydrogenolysed to DMF. The second route is to convert biomass, such as cellulose or glucose, into 5-chloromethylfurfural (CMF) through dehydration first⁶⁴.

Then, hydrogenolysed CMF to DMF. Due to the ample availability of biomass and its inexpensive nature as a raw material, the progress of preparation and yield of DMF will have a direct influence on whether or not it can be employed as a substitute fuel for automobile engines on a large scale⁶⁵. Thus, in recent years, most researchers have aimed towards biomass like glucose, fructose, and starch as feedstocks to be converted to HMF or CMF through these two respective routes and have attempted to improve the conversion yield while being assisted by various catalysts and solutions⁶⁶.

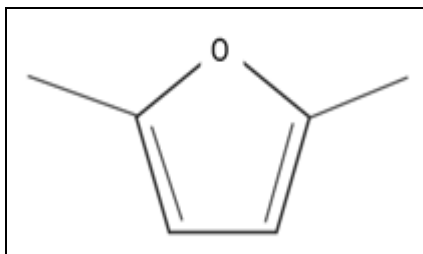


FIG. 9: 2,5- DIMETHYL FURAN

Alcohol: Alcohols are the most widely used in the manufacturing of biodiesel in a chemical reaction known as transesterification⁶⁷. During this reaction, alcohols, usually methanol or ethanol, are combined with triglycerides (oils or fats) to yield biodiesel (methyl or ethyl esters) and glycerol (glycerine) as a byproduct⁶⁸.

Major Alcohols Utilized in Biodiesel Manufacturing:

Methanol (CH₃OH): Methanol is the most common alcohol used in biodiesel production. It is a cheap, readily available alcohol and hence economically favourable for large-scale biodiesel manufacturing. In the process of transesterification, methanol reacts with the triglycerides to produce methyl esters (biodiesel) and glycerol. Methanol is used because it possesses a low molecular weight, which aids in increasing the reaction rate and efficiency⁶⁹.

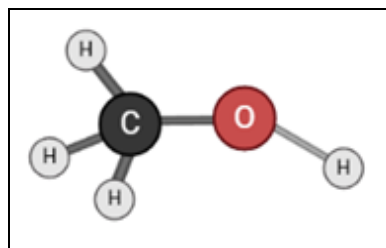


FIG. 10: METHANOL (CH₃OH)

Ethanol (C₂H₅OH): Ethanol is another alcohol that can also be utilized in the production of biodiesel, particularly in areas where ethanol is readily available, such as in areas that boast a large bioethanol industry (such as Brazil). The process of reaction between ethanol and triglycerides yields ethyl esters, which are biodiesel. Ethanol is a cleaner option than methanol since it comes from renewable sources of biomass, such as corn or sugarcane⁷⁰.

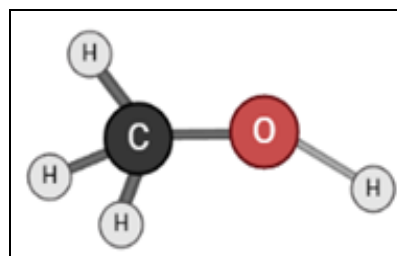
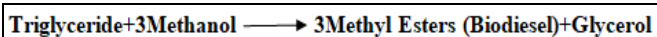


FIG. 11: ETHANOL (C₂H₅OH)

The Transesterification Process:

Reaction: Triglycerides (oils/fats) are combined with alcohol (methanol or ethanol) in the presence of a catalyst (sodium or potassium hydroxide). Alcohol molecules disintegrate triglyceride molecules into biodiesel (methyl or ethyl esters) and glycerol⁷¹.



Separation and Purification: After the transesterification reaction, the biodiesel and glycerol layers separate. The biodiesel is purified to

remove impurities, while glycerol is separated and can be used in other industrial processes⁷².

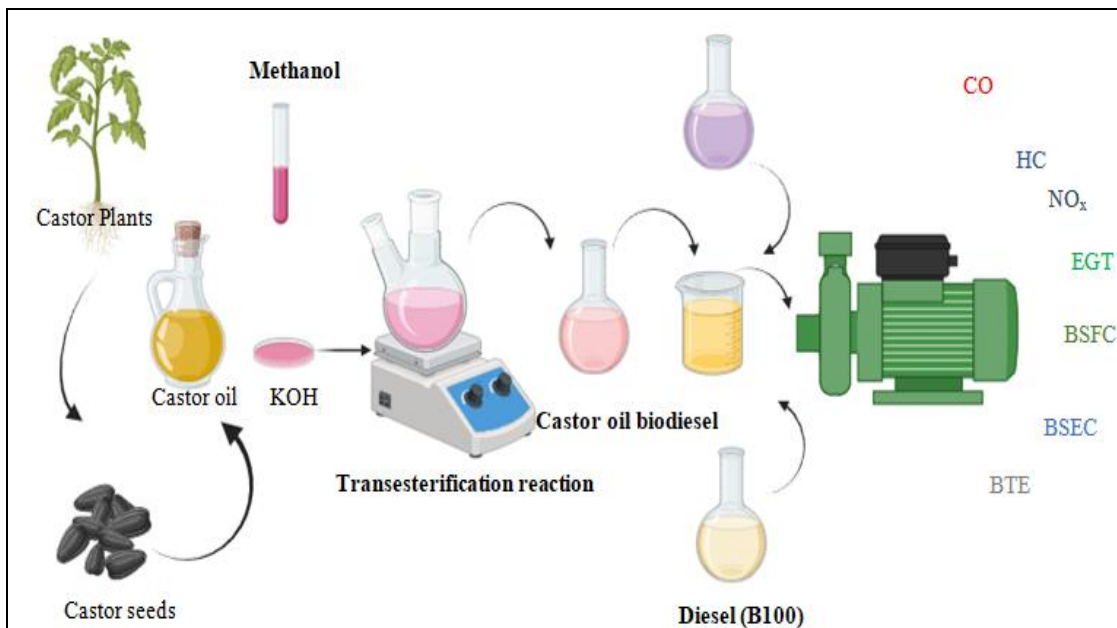


FIG. 12: PRODUCTION OF BIODIESEL FROM ALCOHOL BY THE PROCESS OF TRANSESTERIFICATION

Sources of Biodiesel from Natural Origin: In this part, various natural sources that have the potential as a biodiesel feedstock are discussed, especially related to previous studies about their engine performances and emission characteristics compared to diesel. The characteristic data were obtained by carrying out an engine test using biodiesel and blends as fuel. In this part, various natural sources containing biodiesel feedstock are

described, related to previous studies about engine performance and the characteristics differentiated as diesel. The characterized information obtained from that result was obtained by testing biodiesel on engines and blends as fuel. As if the procedure and process of the test vary. The engine diagram is shown in **Fig. 13**. Describes the working of the engine on biodiesel energy production.

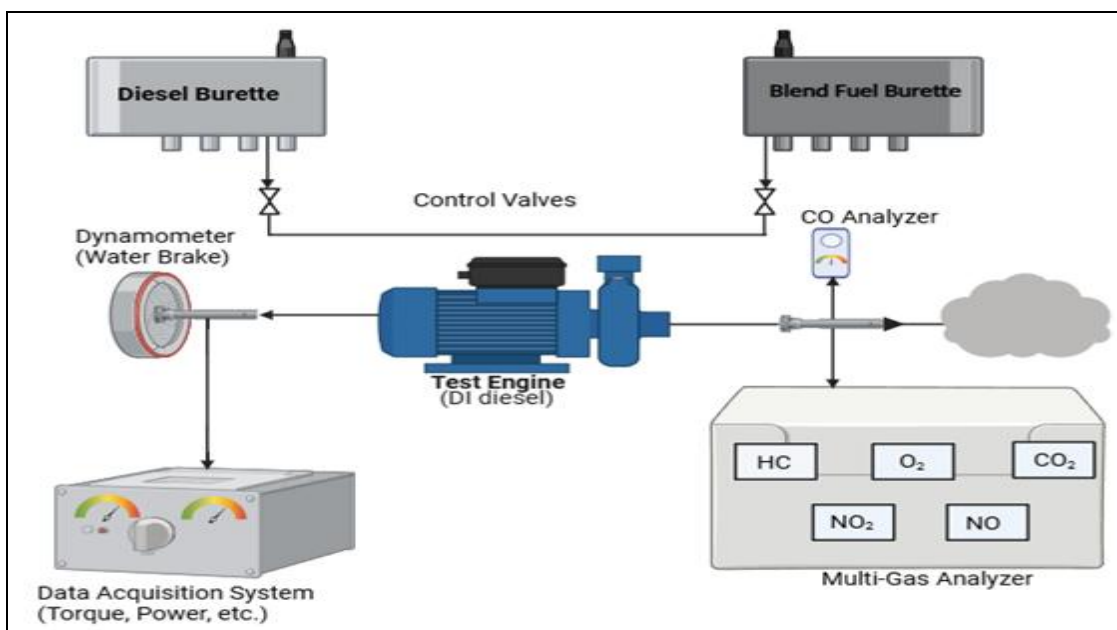


FIG. 13: THE ENGINE SHOWS THE WORKING OF THE TEST ENGINE FOR THE PRODUCTION OF BIOFUELS

TABLE 1: FUEL-RELATED PROPERTIES OF SELECTED VEGETABLE OILS

Entry	Oil	Iodine value	CN ^a	CP ^b (K)	PP ^c (K)	FP ^d (k)	Viscosity ^f (mm ² /s)	References
1.	Cotton Seed	90-119	41.8	274.7	258.0	507	33.5	73
2.	Rapeseed	94-120	37.6	269.1	241.3	519	37.0	
3.	Safflower	126-152	41.3	291.3	266.3	533	31.3	
4.	Soyabean	117-143	37.9	269.1	260.8	527	32.6	
5.	Sunflower	110-143	37.1	280.2	258.0	547	37.1	
6.	Karanja	-	29.9	-	278.0	488	43.67	
7.	Jatropha	101	23	-	267.0	459	35.4	
8.	Palm	35-61 ^g	42 ^g	-	-	577 ^h	42.66 ^h	
9.	Palm Kernel	14-33 ⁱ	-	-	295.0 ^j	545 ^j	115.55 ^j	
10.	WCO ^e	141.5	49	-	284.0	485.0	36.4	

a	CN	-	Cetane Number
b	CP	-	Cloud Point
c	PP	-	Pour Point
d	FP	-	Flash Point
e	WCO	-	Waste Cooking Oil
f		Measured at 311K (entries 1-5) and at 313K (entries 6-10).	
g		Iodine value and Cetane number combined from references 73	
h		Flash point and viscosity combined from references 73	
i		Iodine value combined from references 73	
j		Pour point, Flash point, and Viscosity combined from References 73	

Chemical Composition of Alternative Fuels (Oil and Biodiesel) and Diesel: From a chemical point of view, oils from different sources possess different fatty acids⁷⁴. The fatty acids vary in their carbon chain length and in their number of unsaturated bonds. Most plant and animal oils are water-insoluble hydrophobic substances, consisting of one mole of glycerol and three moles of fatty acids, commonly called triglycerides⁷⁵. Chemically, the oil/fats consist of 90-98% triglycerides and small amounts of mono and diglycerides⁷⁶.

Triglycerides are esters of three fatty acids and one glycerol. These contain a considerable amount of oxygen in their structures⁷⁷. If they all have the same fatty acid, then it is a simple triglyceride; if any one of them differs, then it is a mixed triglyceride fatty acid with the absence of a fully hydrogenated double bond⁷⁸. Monounsaturated has one double bond between carbon atoms, while having more than one double bond makes them polyunsaturated⁷⁹.

Fully saturated triglycerides lead to excessive carbon deposits in engines. The fatty acids are different about the chain length, degree of unsaturation, or presence of other chemical

functions⁸⁰. Chemically, biodiesel is referred to as monoalkyl esters of long-chain fatty acids derived from renewable lipid sources⁸¹. Biodiesel is a general term for different ester-based oxygenated fuels from renewable biological sources⁸².

In general, biodiesel can be used in compression ignition engines without or with very little modification⁸³. Biodiesel is produced by transesterification, in which organic-derived oils (vegetable oils, animal fats, and recycled restaurant greases) are reacted with alcohol (usually methanol) and transformed chemically into fatty esters. Advanced catalysis and reaction Engineering in biodiesel synthesis⁸⁴.

Biodiesel may be mixed with diesel fuel derived from petroleum in any ratio, for example, B20 (80% diesel, 20% biodiesel) or B100 (biodiesel 100%)⁸⁵.

Fatty Acid Esters: The major constituents of biodiesel, namely methyl or ethyl esters of long-chain fatty acids⁸⁶.

Glycerol (or Glycerine): A by product of transesterification, which can be removed and utilized for other purposes⁸⁷.

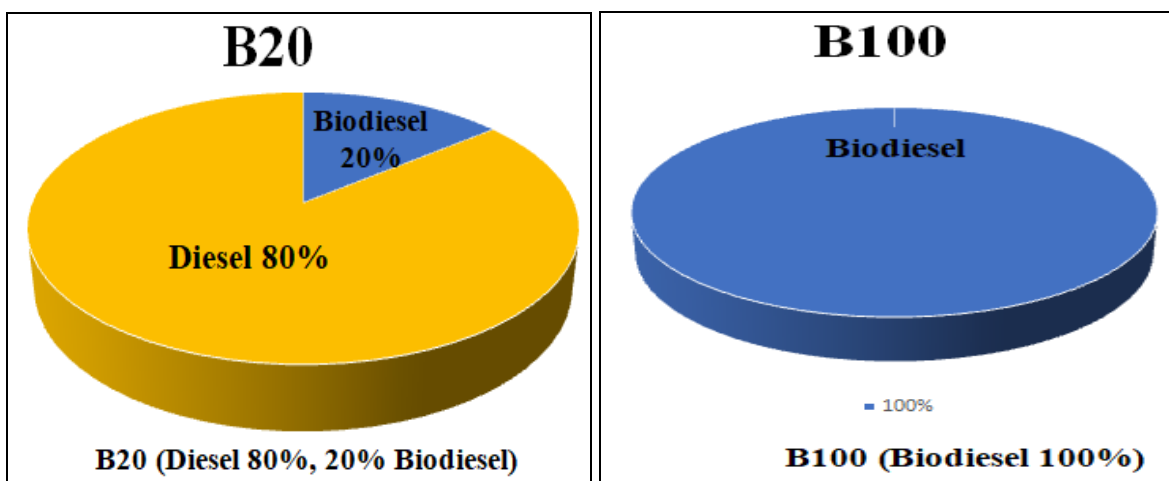


FIG. 14:

Hybrid Systems for Biodiesel and Other Renewable Energy Co-Production: Biodiesel emits lower emissions of CO₂, sulfur, and particulate matter, although it emits more NO₂ compared to fossil fuels¹⁰². In terms of fuel characteristics, it is more in the properties of lower heating value, greater cloud and pour points, reduced oxidative stability, but improved lubricity and cetane number than diesel, but due to the engine content restriction¹⁰³. However, hydrotreated vegetable oils (HVO) diesel, or sometimes referred to as green or renewable diesel, possesses pleasing properties¹⁰⁴. HVO diesel production yields an oxidation-stable, high cetane number, and energy-dense diesel fuel-like product having lower cloud and pour points¹⁰⁵. Additionally, by-products like propane, liquefied petroleum gas, and naphtha can be sold in the market, apart from the fact that low-quality oil can be utilized in hydrotreating¹⁰⁶.

Nevertheless, HVO diesel processing is costly, as the CAPEX (capital expenses) are greater than in the case of a normal biodiesel plant owing to costly hydrogenation equipment¹⁰⁷. Process synthesis and integration can make HVO and biodiesel processing more cost-effective¹⁰⁸. For example, mathematical modelling has been used to synthesize, integrate, and optimize the co-production of bioethanol and biodiesel, on a composition raw material and process level with positive outcomes; In addition, process synthesis and integration have also been used on HVO to combine in-situ oil production and hydrotreating¹⁰⁹. Presently, the majority of diesel-powered cars operate mixtures of diesel and biodiesel. If we take

into account the co-production of HVO diesel and biodiesel, there are some possibilities for the integration of the processes¹¹⁰.

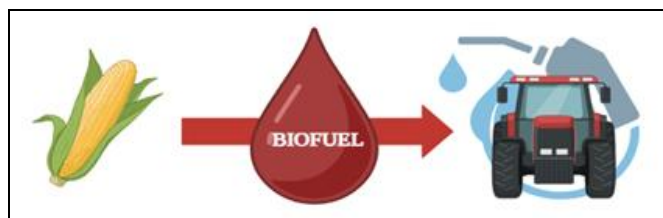


FIG. 15: DIAGRAM SHOWING PRODUCTION OF BIODIESEL FROM FEEDSTOCK

To our best knowledge, there are no clear proposals in the literature, but indications can be detected¹¹¹. For example, the use of glycerol to generate hydrogen and liquid fuels was proposed, but it was not considered at the same time as biodiesel production¹¹².

Then, we suggested the integration of biodiesel and HVO diesel as a low-cost co-processing option¹¹³. First, we formulated a synthesis network superstructure along with appropriate biodiesel and HVO diesel process technologies¹¹⁴. Subsequently, we applied a combined methodology combining rigorous simulation and MINLP (based on simplified models) to solve the synthesis and integration problem to optimality¹¹⁵. Lastly, we presented the optimal route and benefits of the proposed synthesis approach¹¹⁶.

CONCLUSION: The "Biodiesel from Natural Resources" review emphasizes the suitability of biodiesel as a future alternative energy supply, but emphasizes feedstock choice for its sustainability. Although conventional feedstocks such as soybean

oil, palm oil, and rapeseed oil are widely utilised, there are issues linked to food safety, land deforestation, and ecological footprint. The review highlights the necessity of alternative feedstocks, including waste oils, animal fats, and algae, which provide more sustainable options by minimizing competition with food crops and reducing environmental degradation. Technological advances, especially in transesterification processes, enzymatic routes, and supercritical fluid technologies, have greatly enhanced production efficiency, allowing a wider variety of feedstocks to be used. In addition, a circular economy to recycle waste oils and by-products into biodiesel is a prospective method of reducing the environmental impact. Nevertheless, the integration of biodiesel in the world energy system relies on improvement in production technology and policy support, market incentives, and investment. Finally, while natural resource biodiesel offers tremendous potential, its sustainability is contingent upon equilibrium among economic, environmental, and social considerations to make it a sustainable and green energy option. Although vegetable oils such as soybean oil have broad usage, food security and land use issues are still present. Exploitation of waste oils and feedstocks, including algae, provides alternative means that are more environmentally friendly.

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