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A Review on Comparison of Some Edible, Inedible and Waste Oil Sources with Algae for Biodiesel Production

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A B S T R A C T

The present biggest challenging task in front of the world is to search new energy source. Apart from the all energy sources, biodiesel was the only dominant alternate energy to accomplish the fossil-fuel demand in the transport sector which consist a diesel engine. Biodiesel production from edible, inedible feed stocks causes food versus fuel and greenhouse-gas emissions' problem. It is observed that yields of edible, inedible oils and animal fats are very less compared to third-generation feedstock like Algae: It is one of the fastest growing organisms. It is environmentally friendly because it captures Carbon dioxide (CO_2) from the environment to grow. According to the Indian scenario, this is the right time to fix attention on algae biodiesel, to meet the fossil-fuel demand. The higher heating value of biodiesel is slightly lesser than that of diesel, but higher than coal. Biodiesel combusts same like diesel fuel, concerns regulate emissions, and doubtlessly better efficiency than diesel fuel. Algae biodiesel has good physicochemical properties than others. This paper reviews the comparison of yield, fatty acid composition of oil, presently available methods to convert algae into biodiesel and its effect on Direct and Indirect injection diesel engines. Literature reveals that a reduction in exhaust emissions with slight compromise in performances are possible with the usage algae as a biodiesel

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Nomenclature

NIT	National Institute of Technology
RE	Renewable Energy
NOx	Nitrogen Oxides
SO	Sulfated Oxides
CO	Carbon monoxide
CO2	Carbon dioxide
LCOE	Levelized cost of energy
US	United States
ASTM	American Standard Testing Methods
EBB	European Biodiesel Board
NBB	National Biodiesel Board
FFA	Free Fatty Acid
FAME	Fatty Acid Methyl Esters
CI	Compression Ignition
DI	Direct Injection
IDI	Indirect Injection
GHG	Green House Gas
PM	Particulate Matter
H/C	Hydrozen to Carbon
CFPP	Cold filter plugging point
UBHC	Unburnt Hydro Carbons
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
bTDC	before Top Dead Center

INTRODUCTION

Based on World status of findings Renewable Energy (RE) is one of the new sources of energy and these sources have some disadvantages. Wind, solar and tidal energies are intermittent in nature, low potential and high

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cost. With the day to day increase of population, and energy demand's, RE source is not the sufficient substitution for Non Renewable Energy sources. Still, RE energy sources are inefficient in nature because lack of technology. Furthermore, earlier studies are revealed that green and sustainability are impossible with RE sources. It should compromise with society and the environment [1].

The objectives of clean alternative source of energy are reduction of green house effect, environmental concerns, and biomass conversions to energy. Emissions from biomass energy sources are much lower than fossil fuel energy sources. But, we should compromise with nitrogen oxides (NOx), particulate emissions, low input energy, time for crop production, availability of land and food vs. Fuel problems [2–5].

The first and second generation biofuel resources are incompetent to fulfil present biodiesel demand. Biomass production from algae was mostly for biofixation and waste water treatment. Even though the biofertilizers, biopolymers etc. are the co-products of biodiesel from algae, the price ($52-91) of biofuels from algae source are higher than that of plant based bioethanol & biodiesel fuels. However, it arises as most advantageous than wheat, sugar beet based European bioethanol [6].

Environmental point of view biodiesels are more attractive because it emits fewer GHG emissions than diesel fuel. The cost point of view it has a drawback of costlier feedstock. The coproduct like glycerol was the only one option to reduce the biodiesel input cost[7]. These drawbacks are also substantially eliminated from energy source of the waste which should yield higher biomass and elevated input energy. Alga is one of the options for CO_2 mitigation from the atmosphere. It is the biological waste, and produce more oil yield compared to other crops because, it has higher biomass production, food vs. fuel security and more co-products while bio-fuel's processing [8]. The microalgae have been opted for biodiesel production based on their capability to grow rapidly; these organisms can photo-synthetically convert carbon dioxide minerals into biomass [9]. Approximately 100 tons of Algae biomass can capture 183 tons of carbon dioxide from the environment [10]. Algae biomass is probably equivalent to low capacity RE technologies if implemented, many criteria can be met. These consists of the LCOE/kWh, land needed, water source, and practical manner of market opportunity and investment to pick up new technology [11]. The best suitable feedstock should have the chain length between C_{14} to C_{22} and low unsaturation level. The chain length is the most welcoming aspect but, the unsaturation level was the obstacle in some algal species for biodiesel production. The level of un-saturation negatively impacts oxidative stability, cetane number and heat of combustion [12]. As per the literature, more than 350 oil carrying crops were found in biodiesel production. The cheapest oil carrying crops will reduce 75% of the biodiesel production cost.

The World biodiesel production nearly more than 95% of edible oil sources like rapeseed (84%), sunflower (13%), palm oil (1%), and others (2%). The oil from above sources needs pesticides while cultivation and creating food vs. Fuel problems, even though cheaper [13]. Biodiesel from Algae can become a viable alternative to fossil fuels by 2020 [14]. The Indian biodiesel production was less compared to the U.S. and Germany, in-between the years 2000 to 2012 was mentioned in Table 1. This is the right time to fix attention on Algae biodiesel production, to fulfil the biodiesel demand in India [15].

Algae to biodiesel

The micro, macro organisms like algae require light, carbon dioxide, and some nutrients (nitrogen, phosphorus, and potassium) for its growth [16, 17]. The feedstock like algae can grow anywhere like salt and sewage water. It has a faster growth rate than

TABLE 1. Comparison of Indian biodiesel production & consumption (1000 Barrels/Day).

Year	Indian Biodiesel Production	Indian Biodiesel Consumption	US Biodiesel Production	US Biodiesel Consumption	Germany Biodiesel Production	Germany Biodiesel Consumption
2000	0	0	NA	NA	4.3	4.9
2001	0	0	0.6	0.7	5.4	6.8
2002	0	0	0.7	1.1	8.8	10.8
2003	0	0	0.9	0.9	14	15.7
2004	0	0	1.8	1.7	20	20.5
2005	0.2	0.2	5.9	5.9	33	35
2006	0.4	0.4	16	17	52	56
2007	0.2	0.2	32	23	57	64
2008	0.2	0.2	44	21	55	53
2009	1.3	1.0	34	21	45	49
2010	1.6	0.9	22	18	49	50.5
2011	1.8	1.0	63	57	57.235	47.4
2012	2.0	1.2	64	60	54.7	48.5

NA–Not applicable, Reference: [15].

other crops, and it never required any fertile land and food crops [18]. Algae biomass has been using as a feedstock for several bio-fuels production like biodiesel, bio-ethanol, bio-hydrogen, bio-oil and biogas [19–23]. To cultivate algae and convert to biodiesel, the Photo bio-reactor design, algae biomass harvesting, and its drying are the most important technological advancement areas. The large variety of by-products can produce from microalgae with wide applications in medicine, food, and cosmetic [24]. Solution for energy crisis was the most important aspect in the mid 1980s. German scientist started to extract lipids from algae (diatoms) for biodiesel conversion [25]. The algae biomass need not to dry after harvesting for liquefaction and bio-ethanol production methods. The liquefaction method can consume total algae biomass for liquefied fuel conversion, but not in the bio-ethanol, biodiesel conversion methods [26].The transesterification was the method to convert the biodiesel by utilizing alcohols (ethanol or methanol) and catalysts [27]. The drying of biomass is necessary to convert algae into biodiesel, drying can cause main energy input cost. The in-situ transesterification, solvent extraction or any wet algae transesterification method should adopt to reduce biodiesel production cost, and to eliminate algae biomass drying process [28–30].

Comparison of algal oil yields with other oil crops

The cost deciding, suitability of biodiesel mainly depends on crop oil yield. The Jatropa, Palms are to be oilier yielded crops. The Jatropa, Palm are found to be optimum mix for biodiesel blending [31]. The higher biodiesel yield possible with high oil yield crops. It reduces the 70-80% of total production cost, and also possible with type of catalyst, oil: alcohol molar ratio, temperature of reaction, and free fatty acid content [32, 33]. Algae have 7-31 times highest yield than next crop like palm oil 2404 liters; it has a higher lipid fatty acid composition than other crops. The estimated algae oil yields in-between 18,927 to 75,708 L/ha/year [18]

Algae to biodiesel conversion methods:

Before the invention of biodiesel, the diesel engines were run by straight neat vegetable oils. Those were created cold start, improper injection and NOx emission problems in diesel engines because, the oils are oxygenated and highly viscous than diesel fuel. To avoid all the aforesaid problems the scientists were found methods like pyrolysis, blending, micro emulsion and transesterification. Among all the aforementioned methods, transesterification was the best suitable method to produce fuel (biodiesel) for running diesel engines, with or without modification. Biodiesel was the long-chain alkaline ester produced from different feedstocks. Methanol was the mostly. used alcohol to produce fatty acid methyl esters (FAME) because cheapest and easily available [39]. The biodiesel from algae mainly depends on critical parameters like moisture present in the biomass and amounts of solvent and catalyst used for biodiesel production [40]. Algal oil yields very high compared to other oil sources and also the productivity of oil were a major factor to convert biodiesel. Quality of Algae oil, biodiesel and their yields can possibly only be based on growing strategies. It has been best suitable saturated and unsaturated fatty acid composition for biodiesel conversion [41]. Production of biodiesel from high FFA is feasible even it shows the bad effect on catalysts. The Low-quality feedstocks show negative effects on the crude biodiesel purification process in alkaline transesterification. Acid catalyzed transesterification requires higher reaction time, alcohol to oil molar ratios, and it shows high corrosion reaction on production installations. Enzymatic (heterogeneous)

TABLE 2. Algae oil yield comparisonwith some edible, inedible and waste sources

Oil source	Feedstock	Oil yield (wt. %)	Oil yield (L/ha)
Edible	Coconut	63-65	2689
	Palm	30–60	5950
	Groundnut	45-55	1059
	Rapeseed	38-46	1190
	Linseed	40-44	-
	Sunflower	25-35	952
Inedible	Pongamiapinnata	30-40	225-2250
	Jatropacarcus	35-40	1892
	Castor	53	1413
	Sea mango	54	-
	Neem	40-50	-
	Mahua	35-42	-
	Microalgae	30-70	58,700–36,900
Algal group	**Species**	**(Dry Wt. %)**	
Green algae	*Botryococcus braunii*	25–75	-
	Chlorella vulgaris	46	-
Heterotrophic	*Chlorella protothecoides*	55	-
Eustigmatophytes	*Nannochloropsis oculata*	31–68	-
Wild	Mixed culture microalgae	26.2±06	-

References: [13, 34–38].

transesterification was the most feasible process to produce biodiesel from low quality feed stocks. There is a need for in-depth research to make efficient and cost effective solid alkaline (heterogeneous) catalyst transesterification, and also similarity found in biodiesel yield with homogenous catalyzed transesterification [42]. In microalgae to biodiesel conversion process, FFA content (i.e. 70%) was the major issue. We know the base catalyzed transesterification causes the saponification problems. In this concept acid, two steps (acid, base) or in-situ transesterification were preferable processes to convert microalgae into biodiesel [43, 44]. Before extracting oil from algal biomass, drying was the major energy-consuming process. The in-situ transesterification was the synchronous process for extracting oil and biodiesel conversion in the presence of alcohol and a catalyst. Presence of moisture in the algal biomass showed a biodiesel yield deciding factor. The optimization of alcohol, catalyst quantity in the in-situ transesterification process can cause higher biodiesel yield even though algae biomass had more than 20% moisture [45]. Microalgae life cycle analysis stands point view; more amounts of co-products can ensure with fewer environmental impacts. The more income can be possible with higher biodiesel production, but it is impossible with more types of co-products [46].

Comparison of algal oil fatty acid, FAME composition with other sources:

In general, oils are composed of saturated, monounsaturated, and polyunsaturated fatty acids. The percentage of the Free Fatty Acid (FFA) contents present in the oils was the most deciding factor for type of catalyst should be used for biodiesel production. If the free fatty acid contented <2% Alkali catalysts are to be used, else the Acid catalysts for biodiesel conversion. The fatty acid composition of the oil shows the utmost effect on the biodiesel properties [47]. The majority fatty acids in the oils are Palmitic (C16:0), Stearic (C18:0), Palmitoleic (C16:1), Oleic (C18:1), Linoleic (C18:2), Linolenic (C18:3), etc [32]. The stability, cold flow properties, viscosity, and cetane number are most important to decide suitability of biodiesel for CI engine. The scientists are approached few methods to improve the biodiesel properties. In the first case, the emulsification of additives to biodiesel without changing their fatty acid composition. In the second case, the fatty ester composition was changed by using different alcohols while biodiesel production or by modifying profile. The more unsaturated fatty acids in the oil led to increase the iodine number, then it will increase viscosity but reduces the Cetane number, higher heating value and oxidative stability [48]. Algal group species are selected in Table 2 based on their total lipids (mg/g of dwt %) [49]. The increase of unsaturation in a biodiesel will cause 10% increase of NOx and 20% reduction in particulate (PM) emissions [50]. The algae oil fatty acid composition was high depends on the parameter like light intensity, temperature and doubling time (growth). It also depends on the wet or dry biomass used for transesterification process [51].

Effect of FAME composition on properties of biodiesel:

The saturation, unsaturation compositions of oils, fats are potential to produce biodiesel and satisfy ASTM D6751 standards. The more unsaturated composition of oil or biodiesel can cause worse oxidation stability, because it easily reacts with atmospheric oxygen. Similarly, the higher saturated composition of oils, fats and their biodiesel can create poor cold flow properties (cloud point, pour point and cold filter plugging point), because Saturated fats are solid at room temperature. In the edible and inedible oil sources, Castor oil has good oxidation stability, but additives are needed to improve cold flow properties [78]. The Sulfur content present in the oils is good for lubrication, but higher sulfur value may lead to SOx emissions. Sulfated ash also one problem while burning of biodiesel because it will cause gum formation and wear in between piston and cylinder. Though higher flash, fire points of biodiesel are good from the point of view of storage and transportation but, they require high temperatures for the combustion.The acid content presents in the oils are known by knowing their acid value. It may create the corrosion problems in the combustion chamber. Property like Iodine value will help to know the unsaturation composition present in the oil [79]. A fuel with higher iodine value may be able to produce high-heat release rates with the delayed start of ignition if the fuel having higher iodine value [50]. As per ASTM standards the kinematic viscosity must be in-between 1.9 to 6.0 mm^2/s at 40°C. If the fuel kinematic viscosity <1.9 causes leak in the fuel system, and >6 will show the effect on improper fuel atomization in the combustion chamber. The fuel atomization also depends on a carbon atom number (i.e., Chain length). The chain length ≤14 will give good fuel atomization than ≥16. The increase in saturated composition of biodiesel can increase thekinematic viscosity. The kinematic bonds higher forcis configuration [80, 81]. The property like density shows the great effect on engine performance, emissions. The density of FAME decreases with an increase in chain length, temperature and increases with its double bond increase. The level of saturation will be better for reducing NOx emissions [82–84]. The property like Cetane number shows the great effect on diesel engine combustion characteristics. It is the time between injection of fuel into the combustion chamber and its auto ignition. The cetane number increase mainly depends on the level of saturation

TABLE 3. Comparison of algal oil fatty acid compositions (weight %) with others

Group		Oil	14:0	16:0	18:0	20:0	16:1	18:1	18:2	18:3	Others
Edible		**Coconut** [52]	18	9	3	-	-	6	2	-	**A**
		Palm [52]	1	45	4	-	-	39	11	-	-
		Peanut [53]	0.04	11.2	4.75	1.6	0.07	43.5	35.9	0.04	**B**
		Canola [52]	-	4	2	-	-	61	22	10	**C**
		Linseed [54]	0.045	6.21	5.63	0.357	-	20.17	14.93	51.12	**D**
		Sunflower [52]	-	6	5	1	-	29	58	1	-
Inedible		**Jatropha** [55]	3	13.4	3.6	-	-	51.2	28.8	-	-
		Karanja [56]	-	13.8	6.1	-	-	65.3	11.6	3.2	-
		Castor [57]	-	1.1	3.1	-	-	4.9	1.3	-	**E**
		Neem [58]	-	17.8	16.5	2.4	-	51.2	11.7	-	-
		Mahua [59]	-	24.5	22.7	1.5	-	37.0	14.3	-	-
		Sea mango [32]	-	20.2	6.9	-	-	54.2	-	16.3	-
Waste fats & Oil		**Chicken fat** [52]	1	25	6	-	8	41	18	1	-
		Beef tallow [52]	4	26	20	-	4	28	3	0	**F**
		Lard [60]	1	21.1	11.5	-	1.5	40.1	21.7	1.5	**G**
		Yellow grease [34]	1.3	17.4	12.4	0.3	-	54.7	8	0.7	-
		Waste cooking oil [56]	1	39	4.5	-	-	44.6	10.9	-	-
Algal group	Species I	***Botryococcus braunii*** [61]	-	-	4.3	-	4.8	55.7	34.2	0.2	**H**
		Chlorella vulgaris [62]	2.3	18.9	0.6	0.1	9.5	19.6	11.2	22.2	**I**
	II	***Nannochloropsis oculata*** [63]	5.8	32.2	1	-	29.6	20.1	1.3	-	**J**
	III	***Chlorella protothecoides*** [57]	-	51	2	-	-	39	7	-	**K**
Mixed culture microalgae [62]			1.4	19.3	1.2	0.18	15.0	14.8	15.6	18.1	**L**

I. Green algae, II. Diatom, III. Heterotrophic, xx. Carbon chain length, y. Number of double bonds, NF. Not found
Others:A - (6:0 = 1, 8:0 = 7, 10:0 = 7, 12:0 = 47), **B** - (22:0 = 2.32, 20:1 = 0.57), **C -** (20:1 = 1),
D - (22:0 = 0.222, 24:0 = 0.5), **E** - ($18:1_{OH}$ = 89.6), **F** - (12:0 = 1, NF = 14) **G** = 2.3, **H** - (17:0 = 0.8),
I - (16:2 = 0.04, 16:3 = 6.29, 16:4 = 7.62, 20:1 = 0.91, 20:2 = 0.79, 20:4 = 0.01),
J - (8:0 = 0.2, 12:0 = 0.4, 15:0 = 0.5, 17:0 = 0.4, 20:5 = 8.3), **K=** 1.
L - (16:3 = 4.36, 16:4 = 8.94, 18:4 = 0.02, 20:1 = 0.57, 20:2 = 0.67),

and its chain length. The high unsaturation and their double bond position will decrease the Cetane number [81, 85]. The higher level of saturated fatty acid composition will increase the higher heating value of biodiesel [63]. The high unsaturation, shorter chain length of biodiesel will decrease their heating value due to more oxygen and lesser hydrogen, carbon content [86].The cetane number of fractionated fuel was less compared to non-fractionated. It will cause the peak heat release at the beginning of the combustion, and it increases ignition delay and NOx emissions. It can control by emulsifying tertiary fatty amines and amides as an additive in the fuel. The fractionation process shows the effect on reduction of saturates in the fuel. It causes the reduction in cold filter plugging point (CFPP) by 7°C. Based on reduced CFPP, the pour point (PP) and cloud point (CP) were stated as -26°C and -7°C, respectively. The 10% FAME loss also happened in the fractionation process. It can compensate by blending base diesel. The production of algae biodiesel more costly than other because drying of algal biomass causing more input cost. The emulsification of additives for improving CFPP also expensive, so it is not necessary to do fractionation. It can be possible by developing technology[87] **Application of biodiesel on Compression ignition (CI) engines:**

The level of unsaturation in biodiesel was not showing any effect on engine fuel consumption, brake thermal efficiency characteristics. It causes more retarted combustion, higher NO_x emissions, and high combustion velocity [50]. The blended biodiesel causing low fuel economy in old and new engines because of less calorific value than base fuel [96]. It is not showing the effect on better indicated mean effective pressure (IMEP). The better combustion noise at higher loads and lower engine speeds with blending [97]. Based on the evaluation of 3.5kW DI CI engine. The optimal parameters like CR, IP and advance IT are 18:1, 240 bar and 26°bTDC respectively [98]. The oxygenated additives like Dimethylcarbonate (DMC), diglyme (DG) have effect on engine performance, combustion and emission characteristics of biodiesel. The heat release rate of biodiesel+DMC will be high at full load compare to pure biodiesel but, gives less cylinder pressures than biodiesel.The heat release rate of biodiesel+DG blend will be less than pure biodiesel (B100). The ignition delays of biodiesel+DMC blend willbe less and biodiesel+DGwill be high at all loads. The 7 to 19%

TABLE 4. Comparison of algal biodiesel (FAME) compositions (weight %) with others

Group	Oil	14:0	16:0	18:0	20:0	16:1	18:1	18:2	18:3	Others
Edib	**Coconut** [55]	17.4	11.3	3.8	0.2	0.2	9.2	3	-	**a**

			Palm [55]	1	38.1	4.1	0.4	0.2	44.2	11	0.3	**b**
			Peanut [64]	-	17.2	2.7	0.9	-	40.5	36.6	0.5	**c**
			Canola [65]	-	4.16	2.048	0.666	-	64.65	18.60	8.258	**d**
			Linseed [66]	-	5.2	3.2	-	-	14.5	15.3	61.9	**-**
			Sunflower [64]	-	4.9	2.3	-	-	32.6	59.4	-	**e**
Inedible			**Jatropha** [56]	0.1	14.1	7.6	0.2	0.6	44.1	31.5	0.3	**f**
			Karanja [67]	-	13.8	6.1	-	-	65.3	11.6	3.2	**-**
			Castor [68]	-	1.25	1.31	0.05	-	3.81	5.27	0.81	**g**
			Neem [69]	-	10.82	9.15	-	0.06	18.17	61.28	0.51	**-**
			Mahua [70]	0.2	20.8	25.2	-	-	36.4	15.8	0.3	**h**
			Sea mango [71]	-	24.71	6.06	-	0.79	53.39	7.70	-	**-**
Waste fats & Oil			**Chicken fat** [72]	0.7	20.9	5.6	-	5.4	40.9	20.5	-	**i**
			Beef tallow [72]	3.2	23.8	12.7	-	4.7	47.2	2.6	0.8	**j**
			Lard [72]	1.3	23.5	13.5	-	2.6	41.7	10.7	-	**k**
			Yellow grease [73]	2.43	22.77	12.03	0.14	3.84	44.98	7.80	0.79	**l**
			Waste cooking oil [64]	1.5	27.3	4.9	-	-	36.1	25.7	1.9	**m**
Algal group	**Species**	I	***Botryococcus braunii*** [74]	-	28.76	-	-	3.76	47.99	11.71	7.78	**-**
			Chlorella vulgaris [75]	2.3	6	10.3	-	-	20.3	-	2.3	**n**
		II	***Nannochloropsis oculata*** [76]	7.69	35.43	2.50	-	27.54	8.62	5.22	-	**o**
		III	***Chlorella protothecoides*** [77]	-	4.7	2	1.9	-	65.2	15.5	6.9	**p**
	Mixed culture microalgae [35]			4.95	26.72	5.82	2.35	8.94	23.50	14.02	9.83	**q**

I. Green algae, II. Diatom, III. Heterotrophic, xx. Carbon chain length, y. Number of double bonds, NF. Not found

Others: **a** - (6:0 = 0.3, 8:0 = 6.5, 10:0 = 6, 12:0 = 42.1), **b** - (12:0 = 0.3, 20:1 = 0.2, 22:0 = 0.1), **c** - (22:0 = 1.5), **d** - (20:1 = 1.159, 22:1 = 0.297), **e** - (22:0 = 0.5), **f** - (12:0 = 0.1, 20:1=0.1, 22:0=0.1, 22:1=0.1, 24:0=0.5), **g** - (18:1 $_{OH}$=87.10, 20:1=0.38, 22:0=0.01, 22:1=0.01), **h =** 1.3**, i**- (14:1=0.13), **j** - (14:1=1.3, 15:0=0.5, 17:0=1.1),
k - (17:0=0.4), **l** - (15:0=0.36, 17:0=0.95), **m** - (12:0=1.6),
n - (14:1n9c=0.6, 16:1n9c=6.1, 16:1n9t=10.3, 18:1n9t=6.2, 18:3n6=18.6**),o** - (20:4=2.47, 20:5=8.29, 22:6=2.24).
p - (24:0=0.6). **q** - (12:0=1.27, 15:0=0.62, 17:0=1.98),

of Brake specific NO_x reduction was noticed at full load on Biodiesel+DMC blends (5 to 20) and 10 to 28% of Brake specific NO_x reduction was noticed at full load on Biodiesel+DG blends (5 to 20). Similarly the reduction in smoke of Biodiesel+DMC blends (5 to 20) was 7 to 45% and smoke reduction of biodiesel+DG blends (5 to 20) 13 to 58% at full load [99]. Any biodiesel can reduce soot emission because of oxygen content but fuel should have low H/C ratio and higher cetane number for NOx reduction [100].

Algae biodiesel on DI & IDI diesel engines:

Because of increasing fuel demand andcost. The researchers are trying to run the diesel engines in different ways. To minimize the total cost of biodiesel production from algae, the algal biomasswere directly emulsified with diesel or biodiesel fuel. The lower NOx and higher CO emissions were determined fromDI CI engine [101]. In the same manner, raw algal oil was used to run a diesel engine. The lower NOx, power output were obtained but with higher the brake specific fuel consumption, particulate matter (PM) and CO_2 [102]. The slightly lower Torque, power output was observed but emission values like NO_x, CO were improved with algal methyl ester [103]. During 10, 15, and 20% blends of algae oil methyl ester investigations of single cylinder water cooled diesel engine reductions in BSFC, UBHC, CO, and smoke detected but NO_x emission was increased [104]. However, the higher brake thermal efficiency and lower smoke level were observed with B20 blend in an unmodified diesel engine [105]. The 22˚ BTDC was found to be optimal injection timing for B20 algal oil methyl ester blend. At this injection timing BTE was increased and NO_x, CO and smoke emissions reduction was observed. The highest UBHC reduction atstandard injection 23˚ crank angle (CA) and NO_x reduction at 21˚ CA was observed [106]. The Microalgae biodiesel blends shown greater combustion characteristics than macroalgae blends. The cylinder pressure, heat release rates were increased in case of advanced injection and decreased in retarded injection timing. At full load condition micro, macro algae blends combustion characteristics are same. Finally B10, B20 macro and micro algae blends are found to be better alternative for diesel fuel [107]. The lower BSFC, higher BTE was observed with microalgae

Table: 5 Comparison of some algal biodiesel properties with others

Group	Fatty acid methyl esters (FAME)			Flash point (˚C)	Density at 15˚C (kg/m³)	Kinematic viscosity at 40˚C (mm²/s)	Calorific value (MJ/kg)	Cetane number
Edible	**Coconut** [55]			136.5	877.1	3.180	36.985	60
	Palm [55]			188.5	879.3	4.663	39.907	55
	Peanut [64]			193	886.4	5.252	39.7	54
	Canola [88]			146	882	3.6	40.1	52.9
	Linseed [54]			161	865	4.2	40.759	48
	Sunflower [64]			183	885.6	4.381	39.95	51.6
Inedible	**Jatropha** [55]			202.5	883.3	4.805	39.839	51
	Karanja [89]			196	898	5.46	39.15	57.9
	Castor [90]			140	886	4.38	39.048	51
	Neem [69]			110	900	5.5	39.89	55.31
	Mahua [91]			127	865	5.2	36.9	51
	Sea mango [71]			138	880	4.5	39.095	-
Waste Fats & Oil	**Chicken fat** [92]			176	876	4.35	39.934	54.8
	Beef tallow [93]			163	873.2	5.85	38.350	56
	Lard [94]			159.5	873.2	5.26	39.850	59
	Yellow grease [73]			-	872.8	5.1643	39.817	62.6
	Waste cooking oil [64]			167	884.2	4.869	39.68	55
Algal group	**Species**	I	***Botryococcus braunii*** [95]	140	853	5.52	40.4	55.4
			Chlorella vulgaris [62]	145	916	5.2	41.2	53
		II	***Nannochloropsis oculata*** [49]	-	880	4.2	39.8	55
		III	***Chlorella protothecoides*** [57]	115	864	5.2	41	-
	Mixed culture microalgae [62]			140	912	4.8	37.2	49

I. Green algae, II. Diatom, III. Heterotrophic,

biodiesel blends than Ricebran biodiesel blends. The lower carbon, smoke emissions of microalgae and ricebran biodiesels as compared to diesel fuel. In case of both the biodiesel blends NO_x emission was high but, better performance and combustion characteristics than diesel fuel. The microalgae, ricebran biodiesels are economic and environmental friendly [108]. The smooth combustion, lower the engine torque,and higher combustion noise was observed with algae oil methyl ester on the IDI diesel engine. It was controlled by controlling compression ratio and injection timing [109].

Summary:

Algae can grow all over the world like a biowaste. It is just one step right direction to fulfil biodiesel demand in the transportation sector. It captures more CO_2 from environment than other crops, so it is the best solution for GHG emissions. The oil yield from algae more than all other sources. Algae biodiesel chain length was the most welcoming aspect than another. Quality of biodiesel mainly depends on many aspects like growing strategies, yield, moisture content, catalyst and mostly on transesterification method. Among all aforementioned aspects growths, moisture content present in the biomass was the most cost increasing factors. The direct wet biomass to biodiesel conversion was the most adoptablemethod. Higher income can possible, because of higher oil and biodiesel yields. The more coproducts like bio fertilizers, polymers are also income increasing aspects. Compare to all other oils sources, algae has a more suitable saturated and unsaturated composition of biodiesel (FAME) production. The level of unsaturation in the algae caused by parameters like light intensity, temperature and doubling time (growth). It also depends on the wet or dry biomass used in the transesterification process. The higher level of unsaturation will reduce particulate emissions, but NO_x emission was increased. It can reduce by adopting in cylinderoraftertreatment methods. Physicochemical properties point of view algae had lower flash point (˚C) and higher density, viscosity than other sources. The calorific values of selected algae were ≥40 and cetane number also within the ASTM standard. In a DI CI engine, B20 blend and 22˚ BTDCwere founded optimal parameters for better BTE and for improved smoke, NO_x, and CO emissions. The microalgae biodiesel will give greater combustion characteristics than macroalgae biodiesel. In IDI CI engine smoother combustion, lower torque and higher combustion noise were observed with algae methyl ester. The microalgae biodiesel on DI CI engine will give better performance, combustion and emission characteristics than the IDI CI engine.

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Persian Abstract

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چکیده

مهمترین چالش کنونی در جهان جست و جو برای منابع جدید انرژی است. بیودیزل گسترده ترین سوخت جدید در کنار بقیه سوخت ها است که توانسته با سوخت¬های فسیلی رقابت نماید. تولید بیودیزل از منابع خوراکی و غیر خوراکی پدیده ای به نام غذا در برابر سوخت را به وجود آورده است. مشاهده شده است که بازده تولید بیودیزل از منابع خوراکی، غیر خوراکی و چربی¬های حیوانی به مراتب بازده کمتری از تولید نسل سوم بیودیزل مانند جلبک¬ها دارد. تولید این سوخت از این جنبه که رشد جلبک¬ها با مصرف کربن دی اکسید همراه است دوستدار با محیط زیست است. این مقاله به بررسی بازدهی، مقدار اسید چرب و روش¬های کنونی مورد استفاده جهت تبدیل جلبک به بیودیزل و همچنین تاثیر آن بر روی موتورهای تزریق مستقیم و غیر مستقیم دیزلی می¬پردازد.