

Challenges of Biofuel Applications in Industrial and Automotive: A Review

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Received 15 February 2021; Accepted 22 September 2021

Abstract

The increasing thirst for energy and the threat of global warming coupled with the diminishing production of fossil fuel has forced the implementation of substitute fuels from sustainable sources. As a sustainable fuel source, biofuel can be directly applied in various fields such as in automotive and industry. Moreover, biofuel also had a lower carbon footprint than traditional non-renewable fossil fuel. However, the effect of using biofuel on the industrial and transportation sector requires a more in-depth study to ensure its viability and effect on the existing infrastructure. Therefore, this study provides an overview of the application of the biofuel in two primary sectors, industrial and transportation. This study reviewed various peer-reviewed journals to provide an in-depth overview of the hurdles and opportunities in the biofuel's application. High NO_x emission and lower efficiency of the pure biofuel (B100) remains the main hurdles for the broader application of the biofuel in the industrial and transportation sector. Compared to the diesel fuel, pure biofuel combustion results in lower engine performance and efficiency. However, biofuel combustion emits lower hydrocarbons, sulfur, and carbon monoxide emission than diesel fuel. Moreover, biofuel emission also has better opacity and lower particulate emission (PM_{2.5}) than non-renewable fossil-fuel.

Keywords: Biodiesel, Biofuel, B100, Emission

1. Introduction

Ever-increasing thirst for energy is the critical challenges for all countries in the 21st century. This situation, combined with the growing concern of carbon emission that induced global warming and the diminishing availability of non-renewable fossil fuel sources, has sparked the race to find and implement sustainable energy generation sources. This condition is not without reason. In 2019, Indonesia alone produced 64,5 GWh of electricity, and around 50% of them have resulted from the burning of fossil fuel. Like Indonesia, other developing nations around the world is burning fossil fuel at astounding rates. However, fossil fuel availability is steadily decreasing, while the demand for fossil fuel increases as the demand for energy increases. Without a further effort to reduce and phase out fossil fuel application, the global climate will only

worsen, and the global energy supply will be heading into a crisis [1–6].

Almost 70 % of the world's total energy generation comes from fossil fuel. This condition is the key challenges to solve in the following decades [3]. However, merely phasing out all of the available fossil fuel engines and generators then replace it with renewable energy sources, like a solar cell, geothermal, wind turbine, nuclear and hydroelectric dams, would not be feasible [7,8]. These energy sources either have initial capital cost, greatly influenced by geography or need state of the art and expensive integrating system [2,3,9]. Also, the integrating system from renewables still needs improvement. The recent accident in South Australia power grids, where a wind turbine safety system was activated because of the integrating system's error, brought the entire state on hours of blackouts [10,11]. With these factors, the implementation of a green energy revolution in developing countries is halted. biofuel to reduce the carbon footprint and dependency on other countries [5,6,12–14]. This condition is also supported by rising production capacities and biofuel implementation worldwide, driven mainly by the United States, Indonesia, and Brazil [15,16]. Biofuel alone is defined as non-toxic, biodegradable and renewable fuel made from vegetable oils, animal fats, and wastes produced by different techniques [7,8]. Biofuel can be present in almost all form of fossil fuel like diesel, kerosene, and gasoline and easily implemented without a lot of improvement in the existing infrastructure. This is also supported by the fact that biofuel is a neutral carbon fuel that can reduce carbon-dioxide emissions by 78% compared to fossil fuel. Additionally, biodiesel has been proved to be versatile, ranged from 80.4% to 91.2% of biodegradability after 30 days while fossil diesel only has 24.5% of biodegradability. All this fact makes biofuel a more promising candidate to replace diminishing fossil fuel and reduce global warming's impact [5,7,8,17].

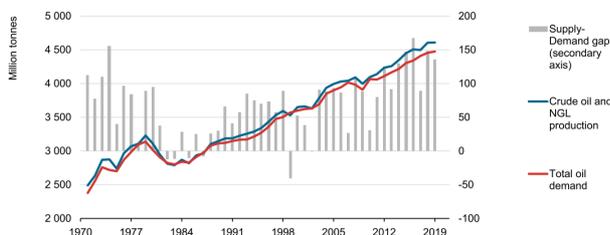


Fig. 1. World oil supply and demand [5]

However, another kind of fuel, biofuel, is on the rise to replace the limited fossil fuel sources. Some developing countries have started to use and ramp up the production of

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doi:10.25103/jestr.144.16

As promising as it sounds, the application of biofuel in various sectors was not going smoothly. Despite possible biofuel implementation advantages, biofuel present new and unknown risk to the general environment and the existing infrastructure. Moreover, a large scale application of the biofuel derived directly from edible organisms may present additional food security concern, especially in developing countries. This fact is aligned with the review study from Rodionova et al. [18] and Joshi et al. [19] that concluded the biofuel produced by using edible food, although simple, present a more significant impact on the larger society and the concern about the food security and availability. This condition can be further exacerbated by the rising cost of feedstock, which will eventually dampen the profitability of Biofuel production [20–24].

Nevertheless, the opportunity for biofuel as fossil fuel substitution still widely open in some sector. Research from Pourhoseini et al. [25] experimentally studied the characteristic of oil burner flame using palm oil biodiesel. The research measured the flame temperature, total luminous radiation of the flame, and the CO and NOx emission. This study concluded that the blended fuel produced more voluminous flame, enhancing the flame’s heat transfer. The research also observed the enhancement of the flame luminosity and the decline of the NOx emission. A similar result obtained by Bazooyar et al. [26], [27] studied biodiesel implementation in boiler and diesel engines.

Economically, biodiesel application in some sector could be more profitable than using traditional petrodiesel. A review study from Gebremariam et al. [26] presented a comprehensive review of biodiesel production’s profitability. The research showed very high potency for profitability by the usage of biodiesel. However, the biodiesel production cost can be further reduced by using a non-edible source and developing a better extraction method. Another research form Bazooyar et al. [27] provided another insight into the biofuel usage profitability. The research showed that biodiesel blend and boiler in the power plant could reduce their operating cost to some degree.

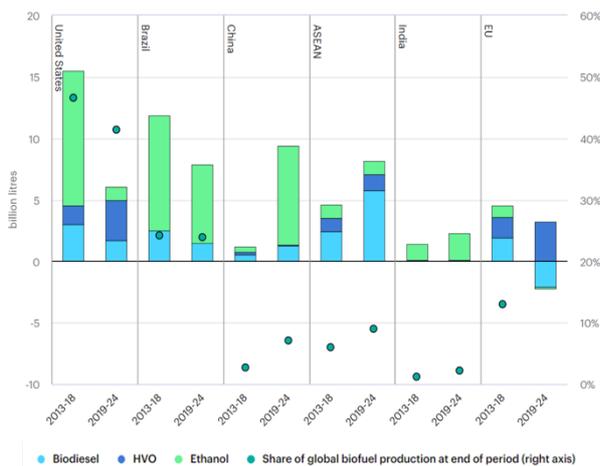


Fig. 2. Global Biofuel Production by Region [15].

These potentially conflicting facts on the opportunities and challenges of biofuel application led to confusion about biodiesel’s general potencies and drawbacks. Therefore, this study aims to assess and investigate the recent progress and experiments of biofuel use in various sectors, mainly industrial and automotive. This study is accomplished by reviewing various peer-reviewed study and reviews related to this topic.

2. Methods of Screening paper

We searched for literature in the Google Scholar, Scopus, Science Direct, MDPI, and Hindawi database in December of 2020 and January of 2021 using the following criteria and boundaries: (“biofuel challenges” OR “biofuel use in the industrial sector” OR “biofuel production” OR “biofuel use in a diesel engine” OR “biofuel in boiler” OR “power generation with biofuel” OR “future trend of biofuel” OR “Biofuel in tractors” OR “biofuel in agriculture” OR “future trend of biofuel” OR “biofuel and sustainability”) since the year of 2006. Subsequently, the articles obtained from the search were screened manually by reading the abstract. We excluded studies that (i) only focus on the political view of biofuel uses; (ii) biofuel application are not considered; (iii) solely focusing on manufacturing processes of biofuel. To include as more relevant paper and literature as possible, the literature was further expanded and explored by reading the selected papers’ references.

3. The Applications Challenge of Biofuel

As the world progresses to reduce the carbon footprint or at least become carbon neutral in the next several decades, the use of renewable energy has increased steadily [3]. As one of the latest renewable energy sources, modern biofuel energy provided 5.1% of the total global final energy demand in 2018 and still grew about 2 % per year in recent years [1–3]. Biofuels also provided around 9 % of industrial heat demand and is concentrated [1–3]. Worldwide, biodiesel production increases 13% with Indonesia overtaking the US as the world-largest biodiesel producer [1–3,13]. In the electricity sector, bioenergy’s contribution rose 9% in 2019. This strong growth is led by China, EU, Japan, and the Republic of Korea, as those countries plan an ambitious target for reducing greenhouse gas emissions [1–3].

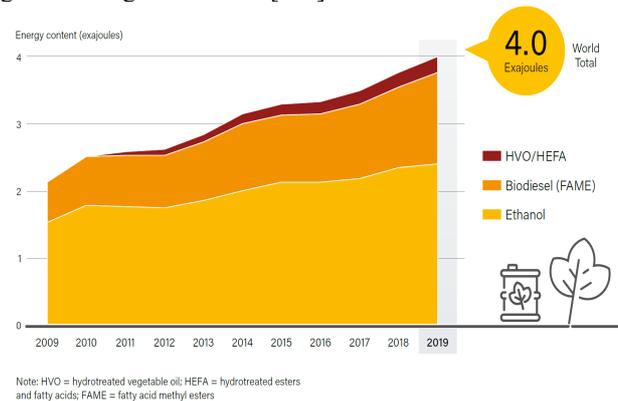


Fig. 3. Global Production of Ethanol, Biodiesel and HVO/HEFA Fuel, by Energy Content, 2009-2019 [3].

The main challenges of the biofuel implementation come from the fact that the use of biofuel will affect not just the environment but also the socio-economic conditions of particular countries. A review study from Mukherjee et al. and Syafiuddin et al. [14,17] reviewed the sustainability implication of palm oil biodiesel usage in Southeast Asia. The reviewed highlighted some of the most critical factors regarding the use of biodiesel. Two of the most important one was the biodiesel production processes and the ‘food vs fuel’ dilemma, which explained that the biofuel implementation

would likely impact the cost of the food, creating an active feedback loop that eventually raised the cost of the biofuel. Gaur et al. (25) also review the factors affecting biodiesel production from waste cooking oil in India. The study concluded that the most significant barrier towards biofuel production lay on biofuel manufacturing processes. More studies of new promising manufacturing techniques must be done to further develop the industry and reduce biofuel manufacturing costs. Another review study from other regions, Africa [24,28], Australia [20,29], South America [22], and EU [21,23], also concluded nearly the same challenges on the implementation of biofuel application; feedstock and food cost and higher cost of initial capital investment on the manufacturing processes.

The second most common barrier towards implementing biofuel in various sectors concerns the more significant environmental effect, mainly water scarcity, energy investment, NO_x emission, and biodiversity destruction. The study from Cremonese et al. [22] concerning challenges of biofuel application around South American countries, Puri et al. which analyzed various challenges of biofuel implementation around Australia [20], and Darda et al. that reviewed current challenges for biofuel in EU countries [21] have come to the same conclusion. Although biofuel is proved to reduce the CO₂ emission to some degree, researchers worldwide still did not have a clear picture of biofuel's sustainability.

Despite those general challenges, biofuel still has considerable opportunities to dampen the world's greenhouse gas emissions. However, biofuel's application and implementation still have other advantages and drawbacks in the industrial and automotive sectors. These challenges and opportunities will be explained in the following few sections.

4. Biofuel in the Industrial Sector (Pros and Cons)

The industrial sector, the industrial and power generation sector combined, provided little share and contribution to general application of biofuel, which accounts for 50% of global renewable energy application [1–3,32]. This small implementation sparked research worldwide regarding the possibilities of phasing out non-renewable energy sources for industrial uses. Overall, the use of biofuel in the industrial sector is still debatable from a variety of standpoint

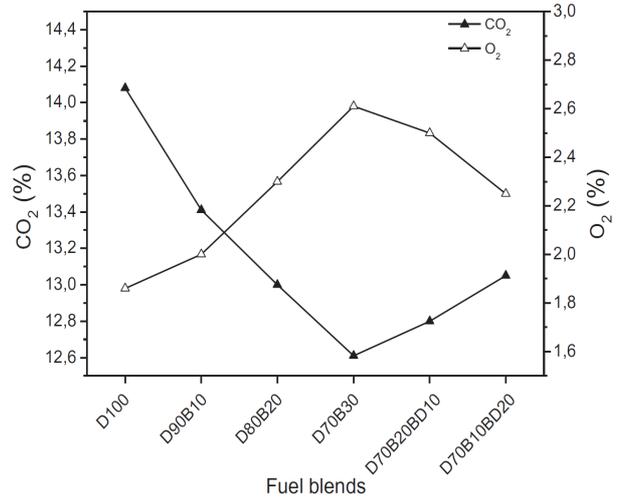


Fig. 4. CO₂ and O₂ emission compared to blend ratios [33].

Table 1. Summary of Biofuel Challenges in the different region around the world

| Region | Fuel Blends | Type of Application | Challenges | Opportunities | Ref. |
|---------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------|
| Asia | <ul style="list-style-type: none"> B30 (Indonesia) B10 (Thailand) B20 (Malaysia) B20 (India) All First and Second generation | All sectors | <ul style="list-style-type: none"> Feedstock Cost ↑ NO_x emission ↑ Complicated and high-cost manufacturing processes | <ul style="list-style-type: none"> CO₂ ↓ Low Flash Point Versatile Viscosity ↑ | [14,17,30] |
| Australia | E5, E10, E15, and E85 B5, B10, B20 B30, B50 All generation (1 st to 4 th) | All Sector | <ul style="list-style-type: none"> Feedstock Cost ↑ NO_x emission ↑ Complicated and high-cost manufacturing processes | <ul style="list-style-type: none"> CO₂ ↓ Prices ↓ SO_x ↓ | [20] |
| Africa | Mainly Ethanol and Biodiesel (Low percentile) | - | <ul style="list-style-type: none"> Feedstock Cost ↑ Lack of infrastructure | <ul style="list-style-type: none"> Low emission | [24,28] |
| South America | Mainly Ethanol | All sector | <ul style="list-style-type: none"> Feedstock Cost ↑ NO_x emission ↑ Water ↑ Biodiversity ↓ | <ul style="list-style-type: none"> Greener Fuel | [22] |
| Europe | All generation with all blends and bio-jet fuel (4 th generation) | All sectors | <ul style="list-style-type: none"> Feedstock Cost ↑ (1st generation) NO_x emission ↑ (1st generation) Water ↑ (2nd generation) Energy demanding (3rd generation) Complicated and high-cost manufacturing processes (4th generation) | <ul style="list-style-type: none"> CO₂ ↓ Low Flash Point Versatile Viscosity ↑ | [21,23,31] |

The study from Kilic et al. [33] presented an experimental analysis of combustion of diesel or butanol or biodiesel blended fuel in a flame tube boiler. This research is conducted by measuring miscibility of different fuel types (pure, blend of diesel and butanol, and blend of diesel, butanol, and biodiesel). The combustion chamber and tube's temperature distribution, the exhaust gas temperature, and exhaust gas emission were examined to investigate the combustion's characteristic. The study proved that the peak temperature zone's size reduces gradually from the use of Diesel 100% to Diesel 70% and Biofuel 30%, allowing for more uniform combustion. As a result, the CO emission and exhaust temperature decreased, and the efficiency improved. However, the NO_x emission remained unchanged. Yet other research by Yin et al. [34] about the characterization of physical and chemical properties of ash produced by combustion of palm oil biomass waste (OPA) on a boiler showed no evidence of toxicity. Particle size distribution, scanning electron microscopy, elemental dispersive X-ray, elemental analysis, toxicity characteristic leaching procedure (TCLP), and thermogravimetric, X-ray diffractometry and Fourier transform infrared analyses were used to determine OPA relative toxicity. The resulting analysis concluded that OPA did not pass the classification as heavy metal leachability since the following metal concentration is less than the standard. Moreover, the OPA is considered environmentally sustainable due to the high concentration of silica and potassium.

Another study from Park et al. [35] showed a similar pattern in heavy fuel oil operation in an oil-fired power plant. This research analyzed and studied 203 samples of bioliquid and demonstrated the test firing of them in 75, 90, and 100 MW oil-fired boilers. Compared to heavy fuel oil, the analysis result showed a decrease in heat absorption corresponding with the increase in exit gas temperature. However, this power plant's operation using biofuels can be done with little or no modification with the advantage of a remarkable decrease in NO_x and SO_x emissions. This fact is aligned with Kling et al. [36], which analyzed biofuel's co-combustion in PC boilers. The research analyzed the performance and emission of a PC boiler under co-combustion conditions. The experiment showed that significantly less emission is observed in the boiler's operation under co-combustion with biodiesel. Another research from Mediavilla et al. [37] also confirms the above statement. Mediavilla et al. analyzed the use of biofuel from broom clearing in commercial boilers. In this research, the biofuel is obtained from shrubland that frequently caught fire. This raw material is further processed into pellets and then used in MG40 boiler to be combusted. The research concluded that the commercial boiler's fuel substitution did not present any changes in the boiler's operational requirement. The fuel also produced less emission but had a higher tendency to produce ash. The research from Yang et al. [38] investigated the chemical characteristic of filterable and condensable PM_{2.5} emission from industrial boiler operated with biofuel also provide a similar conclusion. The research used USEPA 201A and 202 to do the sampling processes. The study concluded that the PM_{2.5} content for biodiesel was significantly less than ordinary diesel. Also, the amount of inorganic particulate was significantly less than ordinary diesel.

Biofuel application in power generation industry also presented drawback and challenges. As the study from Bazooyar et al. concluded, biofuel, mainly the 5% and 20%

blends (B5 and B20), could potentially reduce the CO₂ emission and the cost of operation of the power plant [27]. However, the concern still comes from higher NO_x emission [27,39]. This statement is clearly explained in the research by Bazooyar et al. [39] that evaluated the formation of NO in a utility power plant's combustion chamber.

Another research from Viornery-Portillo et al. [40] comprehensively studied the use waste cooking oil biodiesel blend and fossil diesel used in a power generator by using the lifecycle assessment and emission analysis. Environmental impact of the production and use of B25 biodiesel blend and ultra-low sulfur diesel (ULSD) in the power generator of 33 kW at maximum load using life cycle methodology was studied thoroughly. This research showed that the B25 had outperformed traditional ultra-low sulfur diesel in all categories. However, the CO emission from the B25 was still higher than ULSD, and more maintenance and assessment of the engine was needed to ensure optimal performance. Another research from Rigotte et al. [41] assessed the energy efficiency of engine-generator set using biofuels. Biodiesel from *Crambe* (*Crambe abyssinica Hochst*), soybean (Glycine (L.) Merrill) and waste frying oil were used in this study. The biodiesel was used in its pure form (B100) and in binary mixtures B10, B20 and B50. This research concluded that the performance and efficiency *Crambe* (*Crambe abyssinica Hochst*) biodiesel comparable to the diesel. Moreover, the efficiency of the *Crambe* biodiesel (B100) was observed to be slightly higher.

Economically, the use of biofuel in the electrical generation system was analyzed by Shemfe et al. [42]. The techno-economic performance analysis of biofuel production and miniature electric power generation from biomass fast pyrolysis and bio-oil upgrading were studied and simulated. This research found that the electrical generation from biodiesel could be sustained and profitable economically. Biofuel also had slight efficiency improvement than traditional fossil fuel. However, this research also concluded that the capital cost of this kind of substitution was still high. The slight increase in efficiency was also stated in the research from Sun et al. [43]. This research evaluated the Efficiency of Biomass Power Generation Industry in China. This research showed that the efficiency of the power plant was increasing slightly

Generally, biofuel use in the industrial sector have less environmental impact, but with higher operating cost than usual fossil fuel. The use of biofuel also contributed to the decrease in greenhouse gas emission. This truth will help the world meets the emission reduction target in the short run, possibly becoming the neutral-carbon society [3,4]. Nevertheless, a significant improvement in biodiesel production and variety is still needed. As stated in the study from Sandesh et al. [44] that the use and substitution of fossil fuel by biofuel clearly presented a decrease on performance. Usually, slight decrease of performance will not be a problem for small scale uses. However, industrial and power generation sector must maintain a high performance in order to make profit. Nonetheless, raising public awareness and opinions about climate change could potentially support the replacement of fossil fuel by slightly increasing price of energy, as stated in the study by Zhou et al. [45]. Furthermore, the increasing research and implementation of biofuel produced from waste on industrial sector will potentially accelerate the biofuel application [40].

Table 2. Advantages and disadvantages of biofuel use in industry

| Blend Composition | Engine Types | Test Condition | Advantages | Drawbacks | Ref. |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 100 % torrefied Empty fruit bunches (EFBs) | Palm Oil Mill Boilers | - | <ul style="list-style-type: none"> • High Heating Value ↑ (52,2 % to 93.3 %) • Revenue ↑ (~ 1 million MYR) • Emission ↓ | <ul style="list-style-type: none"> • Absence of Infrastructure | [46] |
| <ul style="list-style-type: none"> • D90B10 • D80B20 • D70B30 • D70B20BD10 • D70B10BD20 D stands for petrodiesel. B stands for Butanol. BD stands for biodiesel | Flame tube boiler | Using Residential water boiler with ALARKO ALM-5 diesel Burner. | <ul style="list-style-type: none"> • Significantly lower CO emission. • Efficient Combustion • Lower exhaust temperature • Higher Efficiency | <ul style="list-style-type: none"> • Diesel fuel only mixed homogenously with butanol at a 40% mixture ratio. • Higher NO_x emission • Need additional treatment for it to be used on the real machine | [33] |
| Petrodiesel and biodiesel of grape seed, corn, sunflower, soybean, olive, and rice bran oils (All 100%) | Semi Industrial Boiler | Examining the fuel combustion performance and gas emission while determining optimum combustion pressure | <ul style="list-style-type: none"> • Biodiesel combustion performance is comparable with petrodiesel, especially at higher energy rate. • Biodiesels emit much less emission than petrodiesel • Cheaper and higher availability | <ul style="list-style-type: none"> • Higher NO_x emission • Biodiesel performance is worse compared to diesel at low energy rate | [47] |
| Sunflower oil (B0, B10, B20, B30, B100) | Heating Boiler of 26.7 kW | Properties of the fuel and combustion and emission characteristic | <ul style="list-style-type: none"> • Lower CO₂ emission • Lower SO₂ emission • Nearly same combustion properties | <ul style="list-style-type: none"> • Lower heat yield • Higher CO and NO_x emission | [48] |
| Petroleum Biodiesel and B10, B20, B50, B80, and B100 | Experimental boiler | Using a boiler (with temperature less than 1100 °C) with a gas analyzer. | <ul style="list-style-type: none"> • Lower emission (CO, SO₂, and NO_x) than petrodiesel • More efficient (at low energy level usage) | <ul style="list-style-type: none"> • For B10 emitted higher SO₂ level than petrodiesel • Lower power and efficiency at a high energy level | [49] |
| Biodiesel absorbed pellets | Domestic Boiler | Analysis of combustion characteristic and gas emission | <ul style="list-style-type: none"> • Increase of thermal power output • Increase of thermal efficiency • Less NO_x emission | <ul style="list-style-type: none"> • Higher CO₂ emission | [50] |
| B100 | Boiler (400 kW) with a reversal flame combustion chamber and the RIELLO RL38 two-stage burner, with nozzles rated at 10–20 kg/h and 20–38 kg/h, respectively, with a solid cone spray | Analysis of combustion characteristic and gas emission | <ul style="list-style-type: none"> • Lower CO emission • Lower PM residuals • Lower PAH (Polycyclic Aromatic Hydrocarbons values) • Lower VOC (Volatile Organic Compound) | <ul style="list-style-type: none"> • Higher NO_x and SO₂ emission • Presence of formaldehyde | [51] |
| Tire pyrolysis liquid (TPL)/diesel fuel blend (50/50 vol.%) (B50) | ROCA NGO-50/25-GT with a nominal power of 29.1 kWh | Combustion characteristic test, emission characteristic test, and performance test | <ul style="list-style-type: none"> • Lower hydrocarbon emission • Lower CO emission • Slightly higher efficiency | <ul style="list-style-type: none"> • Higher PM emission and residual | [52] |

| | | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Using mixtures of animal fat biodiesel (AFBO) and vegetable oil biodiesel with (VOB) ultra-low-sulfur-diesel (ULSD) • AFB50 VOB50 | 4-stroke, water-cooled, direct-injection diesel generator engine (Fawde) and generator (NWR22) | The engine is operated at a constant speed at 1500 rpm | <ul style="list-style-type: none"> • Lower Specific Fuel Consumption • Lower Hydrocarbon and CO emission | <ul style="list-style-type: none"> • Higher NO_x emission | [53] |
| Animal Manure | - | Using a model of the animal manure cell with Fe and Cu electrodes | <ul style="list-style-type: none"> • Reducing the environmental impact of the manure • Reducing gas emission for the animal | <ul style="list-style-type: none"> • The NO₃ level in the manure is still high, possibly causing further NO_x emission. • Technological development is still needed | [54] |
| Ethanol and Biodiesel (B7) | MWM D229-4 Diesel-powered generator (55 kVA) operated using otto cycle with 17:1 compression ratio | Operating the engine at various power output (0 – 37.5 kWh) and measure the power output and emission characteristic | <ul style="list-style-type: none"> • Less efficient than traditional diesel • Higher emission for NO_x | <ul style="list-style-type: none"> • Higher availability of ethanol 1. Cheaper transport cost. | [55] |
| <ul style="list-style-type: none"> • N-butanol • coffee ground pyrolysis oil (CGO) diesel blended fuel | four-stroke indirect injection (IDI) diesel engine (D4BB-G; Hyundai, Korea) with an electrical generator attached | Measure engine and generator performance, emission characteristic and fuel efficiency | <ul style="list-style-type: none"> • - Lower PM emission • Lower CO and hydrocarbon emission • Lower NO_x emission (15 – 30% lower) • Higher fuel efficiency (20 % higher) | • | [56] |
| Petroleum diesel and three different types of biodiesel: crambe (<i>Crambe abyssinica Hochst</i>), soybean (<i>Glycine (L.) Merrill</i>) and waste frying oil, with the following mixture <ul style="list-style-type: none"> • B100 • B50 • B20 • B10 | Diesel engine-generator set made by White model BD 6500CF and single phase was used with 7.36 kW (10 hp) of power and 5.0 KVA. of nominal power. | Resistive loads of 1, 2, 3, 4, and 5 kW were used for each type of fuel, with a total of five replications. Specific consumption (SC) and energy efficiency (EE) were evaluated | <ul style="list-style-type: none"> • Lower specific fuel consumption for cramble oil than petrodiesel | <ul style="list-style-type: none"> • Lower calorific power than petrodiesel • Lower Energy efficiency than petrodiesel | [57] |

5. Biofuel in Automotive (Pros and Cons)

The use of biofuel in Automotive remains one of the fastest ways for transitioning this sector to more sustainable energy sources. Although the EV technology is slowly catching up with the internal combustion engine technology, the implementation of EV on the big transportation scale, which is larger than the household uses, is still developed [3,58]. However, biofuel in this sector can be the fastest solution to transition and temporarily reduced greenhouse gas emissions [3]. Research from Puricelli et al. [59] reviewed the use of biofuel on light-duty vehicles found that biofuel directly impacts the reduction of greenhouse gas emissions. However, further studies on the more considerable impact of biofuel must be done, especially in feedstock farming. This finding

also found in similar research from Azad et al. [60] in Australia.

Moreover, the research about the advantage and disadvantages of biofuel in an everyday vehicle is still debatable. The performance and emission parameters of a single cylindered diesel engine fueled by biodiesel fuel blends using Artificial Neural Network (AAN) was investigated by Aydın et al. The performance and emission of the corresponding diesel engine are then improved by using Response Surface Methodology (RSM) [61]. The researchers constructed the AAN for analyzing single-cylindered diesel engine parameters with data obtained from biodiesel/diesel fuel blends experiments at different engine loads and various injection pressures. The AAN is developed to predict

multitude of outputs such as thermal brake efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), and smoke regarding engine load, biodiesel ratio and injection pressure. The AAN used a feed-forward multi-layered perceptron network to investigate the correlation among different input and output factors. The RSM is then activated to identify the optimum engine operating parameter to ensure a simultaneous emission reduction, EGT, BSFC, and increase in BTE. The research showed that the AAN could adequately model the exhaust emission and the engine parameters with the regression coefficient (R²) between 0.8663 and 0.9858. The resulting correlation also showed the mean relative error (MRE) less than 10% compared with the experimental result. The RSM showed that the optimum engine operating temperature was with biodiesel ratio of 32%, 816-Watts engine load, and 470 bar of injection pressure. This research also concluded that the AAN with RSM could better predict optimal engine parameter with diesel/biodiesel mixtures. Another research from Aydın et al. [62] suggests that despite some of the advantages of using biodiesel blends, there is also some performance reduction in using them. This research used blended biodiesel of 10% of animal, vegetables, and microalgae oils and ultra-low sulfur diesel (ULSD). The result has shown better performance in brake specific fuel

consumption of all blended biodiesel, with the similar value of cylinder gas pressure, cumulative heat release, heat release rate, knock density, and average gas temperature. Moreover, all blends show decreased opacity, hydrocarbons, and CO emissions, but NO_x and CO emissions are slightly increased. More research on these topics also presents conflicting advantages and disadvantages of biofuel in automotive. Research from Kurczyński et al. [63] considered the effect of babassu butyl esters (BBuE) on the diesel engine parameters and exhaust composition concluded that the BBuE biodiesel produced higher NO_x emission, lower brake thermal efficiency but coupled with lower CO₂ emission. This fact is also found in the research conducted by Sharma et al. [64] that studied the effect of engine design on biodiesel fueled diesel engine performance. This study also concluded higher level of NO_x emission, slightly lower efficiency, and lower CO₂ emission. Another study from Islam et al. [65] that study emission and performance of the diesel engine using castor biodiesel. The study used castor biodiesel concentration by up to 40% (B40). This research also concluded the lower CO₂ emission with higher NO_x emission and lower fuel efficiency. Research from Aravind et al. [66] studied the Lawsonia inermis L. biodiesel in a diesel engine and supported this finding. This research also used pure biodiesel and B10, B20, and B30 mixture of biodiesel and found the lower efficiency obtained and higher NO_x emission level.

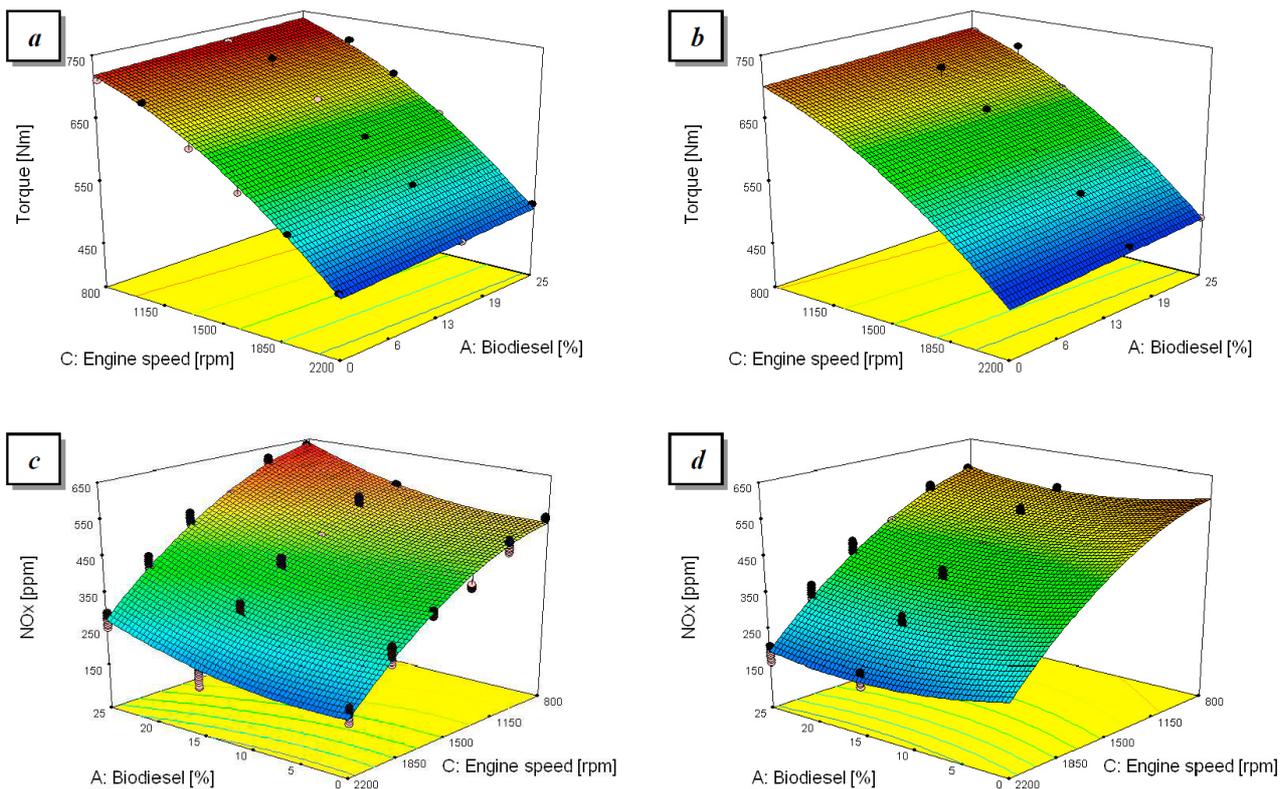


Fig. 5. Surface plot of the engine torque (a and b) and the NO_x concentration in the exhaust gases (c and d) as a function of the biodiesel [83].

Researches from the off-road automotive sector, mainly in the use for transportation, shipping, and agriculture, also presents conflicting advantages and disadvantages of biofuel application. Researches from Venkatesan et al. [67,68] presented the engine performance of tractor by using hybrid biofuel. This research was conducted using diesel fuel and biodiesel blends such as pine oil-soapnut oil methyl ester (P0SNB100, P25SNB75, P50SNB50, P75SNB25, P100SNB0) and diesel-soapnut oil methyl ester (SNB10,

SNB20, SNB30 and SNB100). The fuels were injected to the Simpson's S217 tractor engine while the engine performance, emission characteristics, and combustion characteristics were measured and analyzed. The result presented the decreased of the specific fuel consumption, exhaust gas temperature and HC emission of the hybrid biofuel blend P75SNB25 with 10% EGR rate decreased by 3.44%, 3.90% and 20% respectively than diesel operation without EGR at full load condition. Moreover, the increase of brake thermal efficiency and CO

emission of 4.44% and 8% was observed. For SNB20 with 10% EGR, the reduction in HC, NOx emission and EGT was about 20%, 10.55% and 3.12% respectively. This finding was also confirmed by Golimowski et al. [69] that study the rail diesel tractor engine performance running on pure plant oil. This research conducted using John Deere 6830 agricultural tractors equipped with six cylinders, 24 valve engine model 6068HL481, with a turbocharger generating power of 103 kW (140 km), a high-pressure fuel injection system “Common Rail”, 620 Nm torque at 1400 rpm, 6790 cm³ displacement, and an operating range of 1300–2100 rpm fueled with pure rapeseed oil (PPO). The study showed that there was a significant drop in torque and power output by using the PPO. However, the overall efficiency of the engine is still comparable to ordinary diesel fuel. The research from Karthikeyan et al. [70] also presented a similar finding with using *Stoechospermum marginatum* microalgae biodiesel. The research also observed a significant drop in power output without dropping the overall efficiency of the fuel. Another research about the use of biofuel in automotive is further explained in table 3.

To sum up, the application of biofuel in the automotive sector is still considered one of the most viable options to reduce the carbon emission of this sector significantly. Although biofuel’s use presented significant advantages on the lower CO₂ emission, biofuel presents more concern on the NOx emission, slightly lower efficiency, and higher PM and HC emission for some type of biofuel, especially for pure biofuel (B100). [60,71,72].

6. Environment effect by using biofuel.

As promising as it sounds, the use and application of biofuel are not without environmental effect. This growing demand

for biofuel has led to significantly higher feedstock demand. This growing demand for edible feedstock could potentially lead to land degradation and desertification. Moreover, biofuel produced by the farmland that once was forest or rainforest would not make a significant difference in the total emission compared to fossil fuel [84–87]. The assessment conducted by Escobar et al. [88] about the biofuel clearly explained the biofuel’s environmental impact and elaborated it with the developing technology and the raising awareness about food security. The study concluded that the environmental effect of biofuel production and use could not be easily forgotten. Land degradation, water scarcity, habitat destruction, and food scarcity are some of the impacts that could potentially emerge. Another research from Qin et al. [89] also presented similar concerns. This research that studied the potential and environmental effect biomass and biofuel in China presented the concern about land degradation, water quantity, and vanishing biodiversity. Research from Yang et al. [90] also supported this fact. This study clearly assessed and calculated the land and water requirement of biofuel and its implication for the food supply and China’s environment. The research found that the growing demand for biofuel is unsustainable. It would be consuming 32 – 72 km³ of water each year (approximately equivalent to the yellow river’s annual discharge) and using up to 10 % of all fertile land in China. This high environmental cost was also present in Malaysia, Indonesia, and India, where the biofuel crop competes with the existing rainforest. As the research from Mintz-Habib [91] from Malaysia, Nurlaila [92] from Indonesia, and Ravidranath [93] from India suggested that the biofuel crop could have a greater environmental effect than emitted the carbon from fossil fuel sources right away.

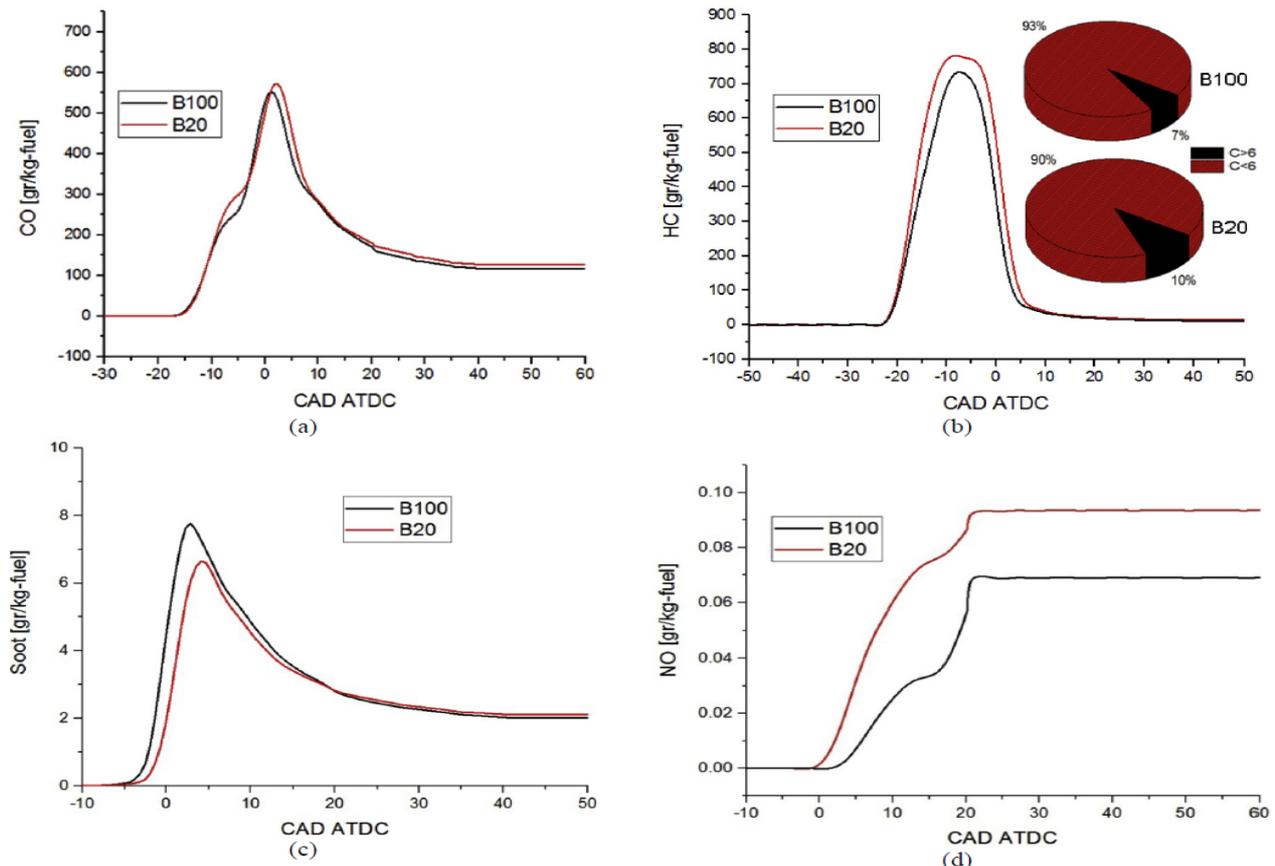


Fig. 6. Comparison of the various emissions for B100 and B20 cases [94].

Table 3. Advantages and Disadvantages of Biofuel use in Automotive and Machines.

| Blend Composition | Engine Types | Test Condition | Challenges | Opportunities | Ref. |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| <i>Spirulina platensis</i> biodiesel (B10, B20, B100) | 4-stroke diesel engine 947.3 ccs and 19.5 compression ratio | Combustion and emission of the biodiesel is analyzed and compared with the petrodiesel | <ul style="list-style-type: none"> • A decrease in ignition delay. • The lower heat release rate • Higher NO_x emission | <ul style="list-style-type: none"> • Comply with the EU and US standard on biofuel. • Significantly lower smoke emission • Lower pure hydrocarbon emission • Lower CO emission | [73] |
| B20, B20P5, B20P10, B20P15, and B20P20 | Single-cylinder, four-stroke, naturally aspirated, and direct-injection diesel engine | The engine operated at 4-engine load with a constant speed of 3000 rpm. | <ul style="list-style-type: none"> • Lower power than traditional diesel • High exhaust temperature • Lower ignition delay • Higher NO_x and hydrocarbon emission | <ul style="list-style-type: none"> • Lower CO, PM, and SF emission | [74] |
| Biodiesel with 10% ethanol, 20% ethanol and 10% pentanol by volume (B10, B10E10, B10E20, and B10P10) | 1-cylindere 4-valve, four strokes, water-cooled diesel engine with exhaust gas recirculation (EGR) | The constant engine speed of 1500rpm and fuel injection at 60 mg/cycle. Combustion and emission performance is analyzed | <ul style="list-style-type: none"> • Higher NO_x for BDP and THC for DBE. | <ul style="list-style-type: none"> • A decrease in ignition delay. • Cleaner soot emission • Hinger Indicated Thermal Efficiency | [75] |
| B2, B10, and B50 of safflower biodiesel. | 4-cylindere, 4-stroke, 5.81 CR, 1910 cc diesel engine | The engine is operated at a different speed (1000 – 4000 rpm) with performance and emission analyzed | <ul style="list-style-type: none"> • Lower power than traditional diesel • Higher NO_x emission • Higher CO₂ emission | <ul style="list-style-type: none"> • Lower Hydrocarbon and CO emission | [76] |
| <ul style="list-style-type: none"> • D92B3E5 (92% diesel, 3% biodiesel and 5% bioethanol), • D85B10E5 (85% diesel, 10% biodiesel and 5% bioethanol), • D80B15E5(80% diesel, 15% biodiesel and 5% bioethanol) • D75B20E5 (75% diesel, 20% biodiesel and 5% bioethanol) | single cylinder, water-cooled. diesel engine | Engine is operated between 1000 and 3000 rev/min. | <ul style="list-style-type: none"> • Lower power than traditional diesel • Lower thermal efficiency | - | [77] |
| B20D80, B5But15D80, B10But10D80, B15But5D80 and But20D80. | A single-cylinder, four-stroke, naturally aspirated and direct injection (Antor 4 LD 820) diesel engine | The engine is run at 3000 rpm initially then gradually decreased to 1500, 2000, 1500, and 1000 rpm while emission and performance of the engine is analyzed | <ul style="list-style-type: none"> • Lower power than traditional diesel (except at 1000 rpm) • Lower thermal efficiency (except at 1000 rpm) • Higher exhaust gas temperature (except at 1500 rpm) | <ul style="list-style-type: none"> • Lower Hydrocarbon and CO emission | [78] |

| | | | | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| | | | <ul style="list-style-type: none"> • Higher NO_x emission | | |
| Corn oil methyl ester (COME) blends (B0, B10, B20 and B50) | Four-stroke Direct injection diesel engine | A study was done by Taguchi method. The diesel-corn oil biodiesel blends (4 levels); , EGR , engine loads (4 levels) and engine speeds (2 levels; 1600 rpm torque and 2400 rpm. Emission and engine power is analyzed. | <ul style="list-style-type: none"> • Higher CO emission • Higher hydrocarbon emission | <ul style="list-style-type: none"> • Lower CO emission • Lower NO emission • Same effective power • Lower Specific Fuel Consumption • Similar Effective efficiency | [79] |
| <ul style="list-style-type: none"> • B10 • B20 • B30 • B40 From Karanja | Diesel engine | The effects of load, compression ratio and blend were investigated for the brake. thermal efficiency (BTE) and oxides of nitrogen (NO _x) statistically by Taguchi method | <ul style="list-style-type: none"> • Higher CO emission • Higher hydrocarbon emission | <ul style="list-style-type: none"> • Lower NO_x emission • Similar BTE | [80] |
| 0% (B0), 5% (B5), 10% (B10), 15% (B15) and 20% (B20) of dimethyl ether Biodiesel | The six-cylinder turbocharged common-rail DME engine | Fuel characteristic, engine performance, and emission characteristic are analyzed to understand the effect of EGR (Exhaust Gas Recirculation) | <ul style="list-style-type: none"> • Higher NO_x emission • Higher CO emission | <ul style="list-style-type: none"> • Higher engine performance | [81] |
| <ul style="list-style-type: none"> • B100 Jojoba Biodiesel (JBD) • D100 • D80JBD29 • D60JBD40 | A single cylinder four stroke direct injection internal combustion diesel engine | The compression ratio of the engine varied from 17:1 to 18:1 while fuel consumption, thermocouple, dyanometer, and gas analyzer was installed to obtain experimental data | <ul style="list-style-type: none"> • Higher NO_x emission • Higher CO emission • Higher smoke production • Higher Brake specific fuel consumption | <ul style="list-style-type: none"> • Higher Brake Thermal Efficiency. | [82] |
| blends of diesel oil (D), biodiesel (B) and bioethanol (E) have been used to fuel the tractor by using an external tank: <ul style="list-style-type: none"> • B15 (85% D, 15% B in volume), • B25 (75% D, 25% B), • B15E3 (82% D, 15% B, 3% E) • B25E3 (72% D, 25% B, 3% E) | New Holland T4020V” farm tractor is equipped with a 3200-cm3 diesel engine with direct injection at full load than diesel operation without EGR | the torque and the NO _x emission were observed and analyzed | <ul style="list-style-type: none"> • slight decrease of torque on the tractors due to the lower energy content • increase in NO_x emission in the lower concentration biodiesel blend | <ul style="list-style-type: none"> • decrease NO_x emission significantly on higher biodiesel blend | [83] |

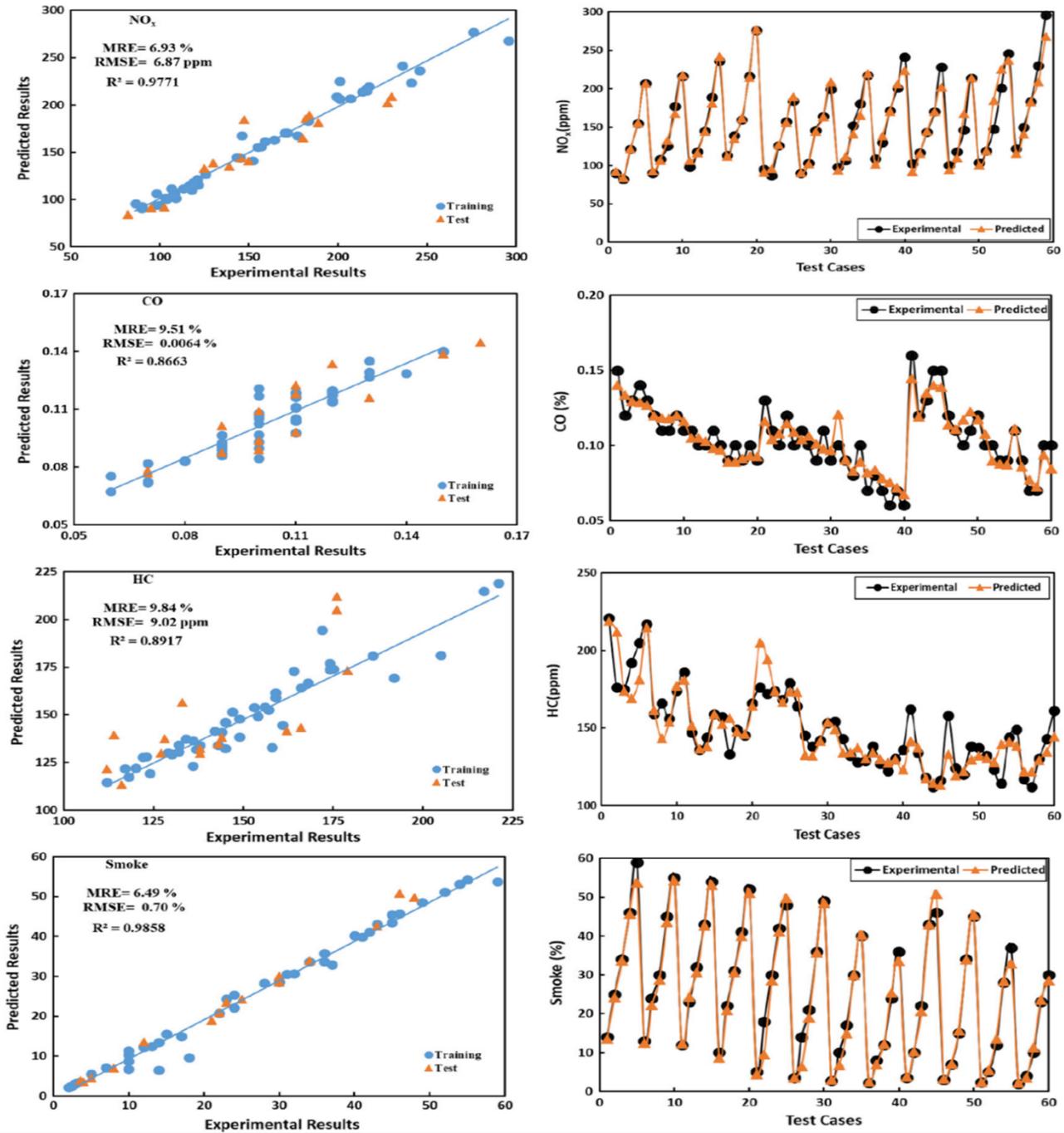


Fig. 7. Experimental results versus ANN results in terms of exhaust emissions [61].

Comparing the emission of pure biofuel and fossil fuel, the pure biofuel is clearly greener than diesel fuel. Pure biofuel presented lower CO₂ emission, 100% lower VOC (Volatile Organic Compound) emission, 0.1% lower smoke emission, nearly 50% drop of CO emission, and 30% drop on Hydrocarbon emission. However, pure biofuel contain significantly more NO_x emission (20 % more than regular fossil fuel). Pure biodiesel also have considerably lower formaldehyde (CH₂O) and hydroxyl (OH) radicals as well as O and H radicals emission than other biofuel blend and regular fossil fuel. Pure Biofuel also known to produce less SO_x emission and soot emission [38,51,61,73,94,95]. Moreover, pure biofuel is also proven to be less genotoxic than regular fossil fuel. Additionally, biofuel induced DNA lesions are repaired within 24 hours [96].

However, the biofuel must not always be environmentally destructive. The research from the Yan et al. [97] suggested a crop named agave that could reduce the water requirement and environmental impact while promoting green energy. This agave-based biodiesel had a low water-related impact including Freshwater Eutrophication (96% lower than corn and 88% lower than sugarcane), Marine Ecotoxicity (59% lower than corn and 53% lower than sugarcane) and Water Consumption (46% lower than corn and 69% lower than sugarcane). The crop also presents a lower global warming impact. Although the crop has higher land requirements to obtain the same energy output, this crop's land requirement was arid land that significantly reduced food scarcity. In terms of toxicity, the biofuel also presented an impressive record. As the research from Heger et al. [98], which investigated the toxicological from biofuels, concluded that biofuel is less

toxic to humans and the environment than traditional diesel fuel.

In conclusion, the biofuel's environmental impact could be reduced by the improvement of production method, regulation, and certification [99–101]. This statement is emphasized by Schmidt et al. (98) 's research that assessed and compared the greenhouse gas emission of certified and non-certified palm oil. The study modelled and studied palm oil production and processing to obtain a detailed tract of greenhouse gas emissions. The research showed that certified oil produced less GHG emission (35% lower). Moreover, the research from Lankoski et al. [102] also presented a similar point for regulation. The research that studied the biofuel impact on the EU and US. The study found that first-generation biofuel from rapeseed and ethanol contributed to negative environmental impact and must be further regulated. These statements clearly stated the importance of biofuel regulation to promote environmental safety and sustainability.

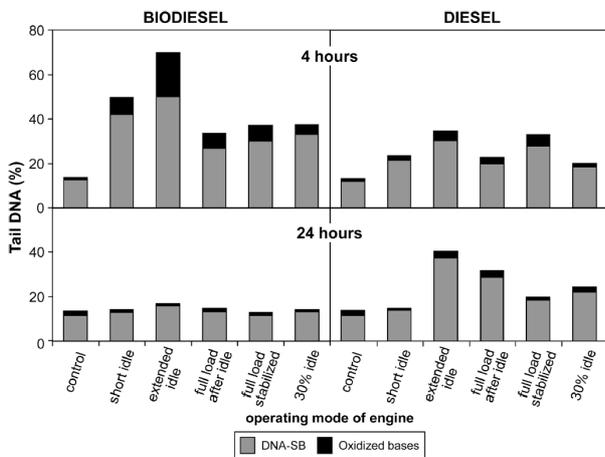


Fig. 8. DNA damage in A549 cells exposed for 4 or 24 h to organic extracts from truck emissions produced at various engine operating modes: comparison of diesel and biodiesel (B100) exhaust effects [96].

7. Future Trends

The changing climate and the rising oil price are some of the driving factors for the search and implementation of more sustainable energy sources [3,32]. In this race to reduce greenhouse gas emissions, bioenergy can significantly reduce carbon emission, mainly from difficult-to decarbonize sectors like aviation, heavy transport, and manufacturing. Reid et al. (100) explained that most of the bioenergy now come from land-intensive crops that emit substantial carbon emission and require a vast amount of fertile land. This land-intensive biofuel is predicted to be substituted by more sustainable biofuel.

In the future, most of the current biofuel production method by using land-intensive source will be considered unsustainable [44]. There are multiple ways to produce greener biofuel. The first way is to substitute current land-intensive biofuel, which usually made up from edible crop with non-edible more sustainable source or even agricultural and food waste. This substitution will eventually reduce the overall environmental burden of the biofuel. Nevertheless, the substitution will bring considerable advantages, as explained in the table 5.

Furthermore, the improvement of the biofuel's production processes and application will also shape much of the biofuel's future. The innovation of biofuel production processes can be seen by the Toit et al. (108) research that achieved continuous power generation from glucose with enzymatic biofuel cell. This technology could revolutionize energy needs for small sensor inside the body or organism. This technology could potentially get scaled up to be a general power plan. Another research from Güven et al. [114] also achieved a similar result using animal lymphocyte cell.

Nevertheless, ordinary biofuel production processes also will have significant improvement, especially in the catalysts sector. Nowadays, biofuel production mostly relies on a rare and dangerous catalyst. However, this will be changed with greener catalyst from waste biomass, as Hamza et al. (110) explained. The further improvement also possible by introducing new production agent as explained by Kongjan et al. [115] in the research of co-fermentation of 1,3-propanediol and 2,3-butanediol. This new agent presented considerable performance and result compared to a known production method.

Table 4. Future possibility of biofuel

| Source | Advantages | Challenges | Ref. |
|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Fat, oil, and grease (FOG) waste | <ul style="list-style-type: none"> Better oxidative stability Better performance (cetane number, flash point, and total emission) Lower prices More sustainable (the main ingredient come from waste) | <ul style="list-style-type: none"> High moisture content High free fatty acid (FFA) that require special processing technique | [103,104] |
| Microalgae biofuels | <ul style="list-style-type: none"> Less land-intensive Growth quickly Produce better biofuels. The produced biofuels are chemically similar to petrol and diesel fuel | <ul style="list-style-type: none"> High production cost High capital investment cost Require high energy to produce | [105–107] |
| Polystyrene | <ul style="list-style-type: none"> Remove non-degradable polystyrene waste from the environment. Environmentally friendly Similar performance compared to petrodiesel | <ul style="list-style-type: none"> Not stable in long term Potentially have higher carcinogen content | [108] |

| | | | |
|--------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Waste Plastics | <ul style="list-style-type: none"> • Remove non-degradable plastic from the environment. • Improved engine performance (BTE and BSFC) • Less NO_x and CO emission | <ul style="list-style-type: none"> • Still developing processing processes • PM emission • Increase viscosity | [109] |
| Agricultural by-product fermentation with <i>Clostridium</i> | <ul style="list-style-type: none"> • Environmentally friendly • Similar performance compared to diesel and petrol | <ul style="list-style-type: none"> • The production process must be improved. • Development of high concentrated biomass hydrolysis to produce high sugar concentration. • Development of fermentation technology | [110–113] |

Eventually, biofuel application and production will still be a viable choice to become a carbon negative society [44]. The development of biofuel application, especially on the aviation sector, will continue to happen [116,117]. Moreover, the improvement of emission and waste removal from the usage of the biofuel will also happen. As the research from Chong et al. [118] suggested removing boron waste from ceramic industries using palm oil moll boiler bottom ash and polymer and research from Kling et al. [119] that use alkali deactivation of high-dust SCR catalyst reduce NO_x emission of the biofuel boiler. In conclusion, the biofuel application will be developed and remain one solution for achieving carbon-neutral, possibly carbon negative, society.

8. Conclusions

A review on the challenge of biofuel applications in industrial and automotive has been presented in the preceding sections. The use of biofuel in industrial and automotive sectors can offer considerable advantages, mainly in CO₂ emission reduction and lower hydrocarbon emission. However, there are considerable challenges in the implementation of the biofuel in those sectors. The high cost of production, food vs fuel dilemma, less performance and concerning NO_x emission level are some of the challenges that dampen the application of the biofuel. The following section summarizes the finding from the exhaustive literature study of applying biofuel in various sectors.

1. In most regions worldwide, literature has shown that the most influential barrier through wider biofuel implementation is lack of production infrastructure, competing food and fuel dilemma, and more significant environmental impact from the plantation of the biofuel producing crop.
2. Most of the challenges for more comprehensive biofuel application on the industrial sector are higher NO_x

emissions and lower efficiency as a biofuel has lower energy density level. However, the recent development that suggested lower-cost operation and lower greenhouse gas emissions might spark a broader biofuel application in the industrial sector.

3. The automotive sector is the most promising sector to transition fully to biofuel as a biofuel is applying since there are no significant challenges in using biofuel in this sector.

4. The use of biofuel in the electrical generation sector is met with some challenges as the biofuel produces more NO_x emission and runs with lower performance and efficiency. Nevertheless, this challenge can be overcome as the government worldwide pledge to reduce greenhouse gas emissions, promoting greener electrical generation method.

5. Although biofuel is considered green fuel due to lower carbon emissions to the atmosphere, biofuel presented a severe environmental threat in water scarcity, soil degradation, and deforestation. However, with the development of newer and less land-intensive biofuel, this problem can be overcome shortly.

These are some of the probable facts through which the study on the challenges of applying biofuel in various industries can be accomplished by the researchers. Also, there is a necessity to investigate the specific challenges and the viable solution of the biofuel implementation in each of the sectors. Furthermore, a cost-effective method for producing and processing biofuel should be investigated.

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