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A Review of Challenges to Adoption of Biodiesel as a Biesel Substitute in India

S. Madhurjya[1*], S. Pranjal[2] and B. Partha Protima[2]

1. Dibrugarh University, Dibrugarh, India.
2. Mechanical Engineering Department, DUIET, Dibrugarh University, Dibrugarh, India.

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**Corresponding author: madhurjyasaikia3@gmail.com (S. Madhurjya)*

Abstract
Biodiesel, derived from biomass, offers significant environmental advantages by reducing CO_2 and CO emissions and promoting energy self-sufficiency. Currently, biodiesel remains limited to DG sets used by a small number of farmers in India, with minimal adoption in the transportation sector. Numerous challenges impede biodiesel's acceptance. This research work focuses on identifying challenges connected to India's biofuel policy, supply chain inefficiencies, and vehicle technology. In terms of cultivation, land management, and the delivery of high yielding varieties to farmers, biofuel policies have failed to encourage indigenous feedstock. Instead, the Biofuel Policy 2022 encourages the imported palm oil sterain. Inconsistencies in the supply chain caused by policies impair the cost effectiveness of biodiesel. Diesel engines in automobiles have compatibility concerns owing to corrosiveness and high fuel consumption due to the fuel's low calorific value. Furthermore, biodiesel causes substantial NOx emissions. This study offers policy-level solutions, such as encouraging the production of domestic feedstocks through efficient management of wastelands. In this approach, farmers may receive high yielding seeds at a reduced cost until the industry is self-sufficient. In addition, Policy Linked Incentive (PLI) scheme can be given to biodiesel producers. A policy like ethanol blending can also be implemented. The biodiesel supply chain, like that of Germany, the United States, Malaysia, and Indonesia, must be optimized. For the technological challenges in diesel engines, the government must use policy intervention, to incorporate engine components suitable for biodiesel, as well as upgrade diesel engines by calibrating electronic control units and with exhaust gas recirculation systems.

Keywords: *Biodiesel, Diesel, Sustainable, Renewable, Fuel, Biofuel.*

1. Introduction

Crude oil was first found in 1875 in Pennsylvania, USA. The British discovered it in India at Digboi, Assam, after 14 years. In 1893, Rudolf Diesel created the diesel engine. The original diesel engine could run on vegetable oils also, as crude oil was difficult to come by and never cheap. Thus people started using vegetable oils in various ways in diesel engines. A Belgian scientist named G. Chavane developed a chemical process called transesterification in 1937 to reduce the viscosity of vegetable oil to use in the diesel engine. This was the first step toward producing biodiesel. In this process, the vegetable oil is mixed with alcohol in the presence of a catalyst. The reaction is generally carried out below the boiling point of the alcohol. It results in mono-alkyl methyl esters and glycerol as the byproduct. In simple words, the mono-alkyl methyl esters can be used as biodiesel after separation from glycerol. The glycerol can be used to make a variety of cosmetics.

After the discovery of crude oil in Saudi Arabia in 1938, the development of biodiesel somehow stalled. Moreover, cheap crude oil was abundant all around. Thus the emphasis turned to crude oil development instead. Biodiesel reappeared in the 1970s due to the crude oil crisis. Scientists again worked on developing biodiesel as an alternate fuel instead of conventional diesel. In 1977, commercial production of biodiesel began in Expedito Parente of Brazil. Then the United States and Europe were interested in biodiesel. In 1989, Austria identified rapeseed for biodiesel production in Europe. In the USA, the commercial production of biodiesel started in 1994 with soya oil [1].

India's transportation sector, which includes personal and commercial vehicles, is mainly reliant on crude oil imports from Middle Eastern countries [1,2,3]. In 2020, liquid fuel consumption stood at 133,050 million liters [4]. As a result of economic activities, liquid fuel consumption increased, and imports skyrocketed. The Indian Government started thinking progressively about utilizing biofuels long back to cut down on crude oil imports. In 2001, India adopted an initiative to blend petrol with ethanol by 5%. The move was bolstered by launching the National Biodiesel mission in 2003. The mission's goal was to achieve a 20% blending of biodiesel in conventional diesel by 2011. In 2009, the Indian Government tabled National Policy on Biofuel (NPB 2009) [5]. It laid the foundation of the Indian Government's structured approach toward biofuels. Regarding the transport sector, the policy sets the aim of 20% blending ethanol and biodiesel in conventional fuels. Ethanol and biodiesel are renewable fuels that can be utilized in petrol & diesel engines, respectively, without much modification.

In 2018, the NPB 2009 was revised and re-launched as the NPB 2018 [6]. It was further amended in 2022 [7]. India is moving towards electric vehicles & flexible engines at a faster rate in personal car space. However, this does not imply that conventional petrol and diesel cars will cease to exist abruptly. They will continue to exist for some time as the transition cannot be overnight. There is positive news regarding the petrol cars sector as petrol is increasingly blended with ethanol and made available at petrol pumps. The Indian Government is endorsing the use of flexible engines which can run efficiently on higher petrol & ethanol blends with ease. Moreover, the commercial logistics sector will continue to operate conventional diesel vehicles as there is no option except to use them. As a result, the usage of biodiesel could be a good option.

Scientists have found 350 different varieties of plants that produce oil. There are both edible and non-edible oil crops in this category. Initially, biodiesel was made from edible oil crops such as rapeseed in Europe and soybean in the United States. They utilized extra crops to make biodiesel. According to the NMOOP (National Mission on Oilseeds and Oil Palm) study from 2018, Indian farmers predominantly plant nine oilseeds for vegetable oils [8]. Soybean, groundnut, rapeseed, mustard. Aside from main oil seeds, secondary oilseed crops include coconut, rice bran, palm, and cottonseed. However, India is only partially self-sufficient in edible oil. As per Directorate General of Foreign Trade, Government of India, in 2020-21, India imported 153.17 lakh tonnes of vegetable oils from various nations [9]. The tendency is expected to continue in 2022-23. Figure 1 displays the category-wise consumption of locally produced and imported vegetable oil in India from 2018 to 2021 according to Directorate General of Foreign Trade, Government of India [9]. As of April 2023, the prices of groundnut, mustard, soy, sunflower, and palm oil are around Rs217/ltr, Rs 205/ltr, Rs150/ltr, Rs190/ltr, and Rs140/ltr, respectively [10]. However, it is important to note that edible oils are very costly. Using vegetable oil for fuel usage will be even costlier. From an economic standpoint, edible oils are unsuitable for biodiesel. So, the emphasis has turned to non-edible oil resources. Indian scientists, including jatropha, Pongamia, yellow oleander, Karanja, rattan jot, lemon, rubber seed, tea seed, and others, have identified many non-edible vegetable oil resources. Table 1 shows the availability of non-edible feedstocks assessed by Keven *et al*. and Yeom *et al*. in India [11, 12].

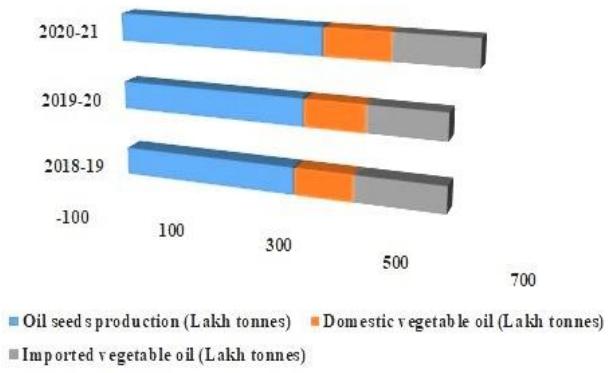

Figure 1. Status of vegetable oils in India vegetable oil in India [9].

Table 1. Various non–edible feedstocks available throughout India [11, 12].

Feedstock	Tonnes per Hectare
Jatropha	5
Pongamia	10
neem	4
Mahua	3
Orange	0.6
Rubber seed oil	0.15
Yellow Oleander	0.1575
Pongamia	10

Biodiesel can be produced from vegetable oil resources or animal fat. However, vegetable oils derived from non-edible sources are usually emphasized as biodiesel feedstock because of food security concerns. Currently, biodiesel is produced from non-edible resources, animal fat, and used cooking oil in India. Figure 2 shows the

category-wise contribution to biodiesel production. In India, biodiesel usage is growing steadily [13]. Figure 3 shows the category-wise biodiesel production for use as per demand [13]. Biodiesel has numerous advantages in terms of engine longevity and pollution reduction [14, 15, 16]. It has lubricating properties which is beneficial to the engine components.

Furthermore, because biodiesel is sulfur-free, its use in diesel engines does not create dangerous pollutants such as sulfur dioxide, which is prevalent in regular diesel fuel. Besides, neat biodiesel or blends produces less carbon monoxide and particulate emission than conventional diesel [17]. Although biodiesel offers several advantages, its usage is facing challenges in India.

Despite its numerous benefits, biodiesel has acquired slow growth in India since the first policy was introduced in 2003. The Government of India (GOI) has released four biofuel policies: the National Mission on Biodiesel (2003), the National Policy on Biofuel (2009), the Biofuel Policy (2018), and the Biofuel Policy (2022). Under the National Mission on Biodiesel (2003), jatropha was first pushed as a feedstock for biodiesel production. When the National Policy on Biofuel (2009) went into effect in 2009, it was evident that Jatropha cultivation faced a number of challenges, including seed shortages, low seed yields, land scarcity, and high plantation and maintenance costs. These issues were never addressed. People lost interest in cultivating jatropha when it was totally forgotten. Lack of consistent policy resulted in biodiesel uncertainty, and as a result, a biodiesel supply chain involving feedstock suppliers, biodiesel manufacturers, distributors, and retailers never developed. It remained fragmented. When the new Biofuel Policy came in 2018, it focused on the minimum support price (MSP) for oil seeds used in biodiesel production, which was already too little, too late. In addition, biofuel policy has shifted more towards ethanol. The Biofuel Policy 2018 was then amended in 2022 to enable imported palm oil and used cooking oil to be utilised in the manufacturing of biodiesel. However, the programme did not focus on diversifying India's indigenously produced feedstocks. Moreover, vehicle manufacturing industry must overcome the challenges of low energy content, oxidation, high NOx emission, and compatibility of engine fuel system for biodiesel's corrosiveness [18]. The present study has identified these challenges in adoption of biodiesel in terms of policy, supply chain inefficiencies, and technological barriers associated with biodiesel. Moreover, the study seeks to showcase probable solutions to the challenges.

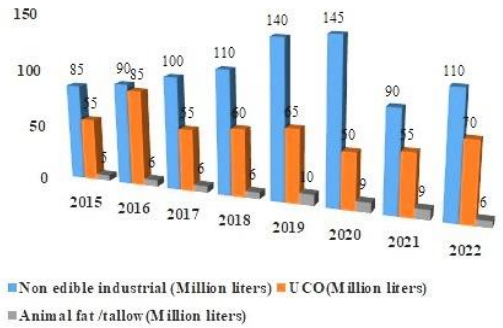

Figure 2. Category-wise feedstocks' contribution to biodiesel production [13].

Figure 3. Biodiesel production, consumption and import trend over the years [13].

2. Methodology

This study deals with the challenges of biodiesel as an alternative fuel in the Indian context. We began by reviewing research articles published in reputed Scopus and SCI indexed journals related to the subject matter in the last ten years. Moreover, we took the help of the reports from government organizations such as the Ministry of New and Renewable Energy (MNRE), Ministry of Petroleum and Natural Gas (MOPNG), and Ministry of Statistics and Programme Implementation (MOSPI) of the India Government and international think tanks such as REN21. After going through the articles and reports, we could identify the gaps or backlogs mainly in three major areas. These are in the fields of biofuel policies of India, supply chain inefficiencies, and technology for biodiesel utilization in IC engine.

3. Results and discussion

The present study discusses challenges in three major areas such as biofuel policy of India, supply chain inefficiencies and technological limitations. Moreover, the possible solutions have also been discussed while addressing the issues.

3.1. Biofuel policy of India

In 2003, the National Mission on Biodiesel was launched in India. A policy for biodiesel was introduced for the first time at that time. The Ministry of Rural Development was the nodal agency. The mission objective was to promote jatropha cultivation in India and derive biodiesel from its vegetable oil. However, jatropha cultivation did not pick up. As a result, the supply chain did not materialize. In 2009, National Policy on Biofuel came. It stressed using non-edible vegetable oils for biodiesel production and focused on using barren & degraded lands for crops. It also laid the guidelines for MSP for crop growers and biodiesel producers [5]. The biofuel policy failed to set the guideline for a mechanism for acquiring barren lands for cultivation. Even though MSP was provided, the farmers were unwilling to participate in cultivation as there are issues related to soil toxicity [12]. Moreover, many a time, there was the unavailability of a high-yielding variety of jatropha for cultivation. Therefore, the foundation block of biodiesel did not develop at all. The oil marketing companies (OMC) have been mandated to blend biodiesel from various biodiesel producers in the country [19]. Even though the Government had kept a provision of MSP, the OMCs had their purchasing policy [20]. They are continuing with it. Sometimes, they offered a price lower than production costs. This has been demoralizing the producers to a great extent. Though Government of India does not levy taxes on biodiesel, the state-level policies are not uniform regarding procuring, processing, and blending biodiesel.

In order to address the problems, the Indian Government updated the Biofuel Policy 2018 in 2022. Since there is no local alternative, imported palm oil was permitted for use in the manufacturing of biodiesel [7]. Palm oil stearin is imported from Indonesia and Malaysia, according to the Ministry of Petroleum and Natural Gas. However, domestically produced used cooking oil will soon take the place of the palm oil stearin (UCO). Numerous reputable businesses including Emami, are involved in the manufacturing of biodiesel from UCO.

Acting as per the National Policy on Biofuels-2018 Amendment in 2022, the public sector OMCs of India such as HPCL, IOCL, and BPCL, had issued expressions of interest for the purchase of biodiesel in 2022 in a coordinated way [21]. It emphasizes the need to buy biodiesel in accordance with the IS 15607:2022 standard [21].

To encourage biodiesel acceptance in India, the government must push biodiesel blending with diesel in aggressive manner, similar to ethanol mixing with petrol. In this regard, India can learn from like Germany, Malaysia, United States, and Indonesia. In these countries, incentives and tax breaks are provided for extensive use of biodiesel in transportation and industrial sectors alike. Moreover, Indonesia provides export incentives to producers for biodiesel promotion.

Popularization of biodiesel among the masses is very important as it will open up new avenues of employment. Farmers, producers, and consumers might be offered financial incentives to help popularize and promote awareness. Above all, India's biodiesel policy lag in terms of research and development. There must be research and development initiatives to produce high-yielding crops and to promote non-edible feedstocks such as algae. The Indian biodiesel industry is still locked in old extraction and conversion techniques that must be upgraded. Additionally, incentives must be granted to build efficient engines. Recently, automobile manufacturers have been hesitant to invest in diesel engines since they have been gradually phased out in all big cities due to pollution norms. In this regard, the government and automakers must reach an agreement and common working ground on diesel engine regulation in the future years. To resolve the policy stalemate at the state level, the central government must lead the discussions with the states.

3.2. Supply chain inefficiencies

Developing biodiesel as a commercial fuel like diesel requires a solid supply chain from crop cultivation to end product at oil depots. According to Bharat Petroleum Corporation Limited's 2020-21 annual report, biodiesel is facing a feedstock scarcity problem [21] due to a need for more attention on feedstock development. To address the issue, the Government of India issued NPB2018, which emphasized using indigenous non-edible oil resources such as palm stearin, UCOs, and acid oils [6]. The strategy did not assist in popularizing biodiesel production since India is not self-sufficient in any of the feedstocks. Every year, India buys millions of liters of palm oil from Indonesia and Malaysia for cooking purposes. Furthermore, used cooking oils (UCO) are not available, despite the fact that India consumes a lot of vegetable oil each year. In India, cooking is done in such a way that there is little or no leftovers. Leftover oils are frequently reused. Furthermore, the gathering of UCOs and acid oils is still in its early stages. There have been no substantial initiatives in this regard. As a

result, the biodiesel supply chain in India is insufficient to sustain the full commercialization of biodiesel as a diesel alternative. Lately, many NGOs and reputed companies such as Emami have started collecting UCOs for biodiesel production.

To make biodiesel competitive or on par with diesel, the supply chain must be optimized like Germany, United states, Indonesia, and Malaysia. In fact, all stakeholders, including farmers, producers, distributors, and government agencies, can be brought in for dialogue and the development of a complete framework in this respect. For biodiesel to be cost viable, the framework must include optimization of transportation routes, logistics, and storage facilities. Otherwise, it will stay fragmented, and cost savings will not be passed on to end users. Furthermore, standardization of quality as per IS 15607:2022 mandated by the OMCs is to be ensured.

3.3. Vehicle technology for biodiesel utilization

Biodiesel is produced to run on ordinary diesel engines. According to studies, neat biodiesel and biodiesel blends can be used in diesel engines. However, it has been noticed that the engine efficiency decreases with its use. The engine efficiency is measured in terms of brake-specific fuel consumption, brake power, and brake thermal efficiency. Brake-specific fuel consumption (BSFC) means the fuel consumed by the engine in kg for each unit of brake power in kW-hr. The power available at the output shaft is referred to as brake power (BP). Many factors influence BSFC, such as calorific value and viscosity. Biodiesel has a lower calorific value compared to diesel. Hence, more biodiesel or blends is required for the same brake power output as diesel.

Moreover, the high viscosity of biodiesel causes improper atomization of blends during combustion. The air-fuel mixture does not burn properly, causing higher BSFC. As a result, biodiesel blend run engines have greater fuel consumption. It makes them unappealing to consumers. Besides, it affects the power production at the cylinder, generating lower power availability at the output shaft. Therefore, the engine produces less brake power compared to diesel-fueled ones. Many researchers like Carrareto et al., Aydin et al. & Murillo et al. have confirmed that the usage of biodiesel has resulted in a loss in brake power during operation [22, 23, 24]. As BSFCs are high due to the lower calorific value of biodiesel blends, the brake thermal efficiency (BTE), the ratio of brake power & thermal energy at the input, is also impacted because thermal energy at the input is the product of the fuel's mass flow rate and calorific value. Many researchers, like Karabetkas *et al*., using turbocharging; Hasimoglu *et al*. by using low heat rejection engine; Carraretto *et al*. by changing injection timing; Amarnath *et al*. by changing injection pressure and compression ratio; Kalam *et al*. by adding NPAA to biodiesel tried to reduce BSFCs and increase BPs of the neat biodiesel or biodiesel blends fed diesel [25, 26, 27].

There are several techniques to address the problems such as biodiesel's low energy content, oxidation of the fuel in storage tanks, high NOx emissions, and fuel system compatibility problems caused by corrosivity. By recalibrating the electronic control unit (ECU) in accordance with the requirements of the fuel, it is possible to address the low calorific value of biodiesel. Complex adjustments like injection timing and compression ratio adjustments can also help diesel engines run as efficiently as possible. Biodiesel is susceptible to oxidation because, unlike diesel, it is made from biomass. Butylated hydroxytoluene (BHT), Tertiary Butyl Hydro Quinone (TBHQ), and other synthetic antioxidants can significantly extend storage times [28]. Utilizing exhaust gas recirculation (EGR) technology in the emission system can reduce NOx emissions on the emission front. Due to its solvent qualities, biodiesel cannot be used in the fuel system of diesel engines that are currently in use. As a result, engine manufacturers have to create fuel systems using materials that are resistant to the corrosiveness of biodiesel. By incorporating these measures, customers' concerns about the fuel's low energy content, stability, and NOx emission may be allayed, and the fuel will be more widely accepted. Long-term, it will support the development of regionally focused small businesses and the rural economy. Success of biodiesel means less reliance on foreign crude oil. In 2022, ethanol blending had resulted in savings of 40,000 crores in India. Similar results can be expected with biodiesel if it is aggressively pushed. Additionally, it will guarantee that India's energy sources are diversified.

4. Conclusions

Biodiesel holds immense potential as a substitute for diesel in diesel engines. Although it cannot entirely replace fossil fuels, it can play a vital role in the transportation industry, offering significant benefits. By increasing the utilization of biodiesel, we can substantially reduce our dependence on imported oil and alleviate the economic burden

associated with imports. However, our research has focused on identifying the challenges involved in adopting biodiesel as a diesel replacement, which encompass various obstacles, ranging from policy issues to inefficiencies within the supply chain. In our study, we have tried to address the challenges through the following probable approaches.

- To foster the growth of biodiesel, it is crucial for the Indian biofuel policy to support biodiesel crop cultivators by providing competitively priced seeds and facilitating the utilization of cultivable wastelands through policy intervention. Additionally, manufacturers should be offered financial assistance through Product Linked Incentive (PLI) schemes, enabling the development of an integral component in the biodiesel supply chain.
- A national strategy is required to promote the use of biodiesel in conventional diesel engines, either through blending with fossil diesel or in its pure form, similar to how ethanol is utilized in petrol. For that matter, India can learn from strategies implemented by Germany, Malaysia, United States, and Indonesia.
- The concerns regarding engine application necessitate further investigation. Studies have indicated that biodiesel exhibits higher brake-specific fuel consumption and poorer brake thermal efficiency compared to diesel fuel, despite delivering the same braking power output. Nevertheless, blending biodiesel up to a 20% ratio has minimal impact on performance measures, which is deemed acceptable considering the environmental benefits. Therefore, car manufactures and research communities can be encouraged to do research on developing biodiesel compatible optimized diesel engines through grants and financial assistance. Moreover, the policy towards diesel engines should be consistent without ambiguity or the car manufacturers would not deem fit to invest their resources in the direction of bringing out diesel engines with electronic control unit (ECU), injection timing and compression ratio recalibration for better performance.
- To address the issue of excessive nitrogen oxide (NOx) emissions resulting from biodiesel usage, the exhaust gas recirculation systems should be incorporated with the engines running on biodiesel.
- The storage stability of biodiesel is a concern. The storage stability should be enhanced by using synthetic antioxidants like Butylated hydroxytoluene (BHT), Tertiary Butyl Hydro Quinone (TBHQ etc.
- The adoption of biodiesel hinges on creating widespread awareness among the general public about this fuel. It is essential to educate people about biodiesel and its benefits in order to foster acceptance and encourage its use.

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