DISCUSSION PAPER

National Transport Decarbonization Council

BIODIESEL AS FUEL

teri
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About National Transport Decarbonization Council

The Intergovernmental Panel on Climate Change (IPCC) reports a serious need to implement transport decarbonization policies in India. The responsibilities to draft and implement the decarbonization policy fall under the various ministries of the central government, such as the Ministry of Environment, Forest and Climate Change/ Transportation/ New and Renewable Energy. An effective decarbonization policy requires collaboration between various central ministries, civil societies, activists, industry, technology providers, and research organizations. The need of the National Transport Decarbonization Council (NTDC) is to bring all the stakeholders to a single platform.

Role of the Council

To develop a common understanding of the transport decarbonization measures and build consensus among all policymakers at various levels. Under the guidance of the council, three theme-based workshops on key issues in the transport sector were organized to discuss the pivot issues and challenges in achieving the decarbonization and formulating the various control strategies. The deliverables also include the preparation of a policy brief on each of the themes.

The themes identified for the study are:

1. Vehicle Scrappage Policy
2. Emission Reduction and Efficiency Improvement

   Part A: CO_2 emission reduction through fuel efficiency improvement

   Part B: Future road map for tightening emission standards
3. Biodiesel as Fuel

This discussion paper is on the third topic – 'Biodiesel as Fuel'.

To know more about NTDC: https://www.teriin.org/project/national-transport-decarbonization-council

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List of Abbreviations

BAU	Business As Usual
BDAI	Biodiesel Association of India
BMAI	Biodiesel Manufacturers Association of India
DI engines	Direct Injection Engines
EBP	Ethanol Blending Programme
EU	European Union
FAME	Fatty Acid Methyl Ester
GHG	Greenhouse Gas
GoI	Government of India
ha	Hectare
HDRD	Hydrogenation-Derived Renewable Diesel
HDV	Heavy-Duty Vehicles
HSD	High-Speed Diesel
LDV	Light-Duty Vehicles
MDV	Medium-Duty Vehicles
MTPA	Million Tonnes Per Annum
MoP&NG	Ministry of Petroleum and Natural Gas
OMCs	Oil Marketing Companies
PME	Palm Oil Methyl Ester
PPAC	Petroleum Planning and Analysis Cell
PSO	Palm Stearin Oil
PSO	Public Sector Obligation
RUCO	Repurpose Used Cooking Oil
STEPS	Stated Policies Scenarios
UCO	Used Cooking Oil
US	United States
WCO	Waste Cooking Oil

1. Background

With the continuous growth in the world's population, rapid industrialization, urbanization, and economic growth, fossil fuel consumption is escalating to meet the global energy demand. The most crucial resource in today's world is energy, as day-to-day activities such as transportation, industrial and agricultural sectors rely on it. Using liquid fuels provides high energy density, high combustion efficiency, and easy storage and transportation.

According to the STEPS[1], India's Energy Demand for road transport is projected to increase by two folds by 2040, in which half of the growth is fuelled by diesel-based freight transport. As the road freight activity triples, it is predicted that around 25 million extra trucks will be travelling on Indian roads by the year 2040. Thus, it predicts adding about 300 million vehicles of all kinds and types to the Indian fleet (IEA, 2021).

According to TERI's estimates (TERI, 2021), the overall energy demand from the transport sector may increase more than four-folds; between 2016 and 2050. The carbon emission from the transport sector is estimated to grow by four folds by 2050 to 1164 million tonnes and the share of emissions from transport in total emissions would increase to 19%.

Since the 1990s, a major shift has occurred from rail towards road transport as it accounts for around 70% and 95% of the total land transport activity for freight and passengers, respectively.[2] In recent years, India has been the fastest-growing sector in terms of end-use and is already set for a huge expansion of transport infrastructure in every mode. India's oil demand, as per STEPS, rises by almost 4 million barrels per day (mb/d) to reach 8.7 mb/d[3] by the year 2040. The domestic oil resources in India are limited; hence, to meet the energy demands, it imports large quantities of crude oil (the second largest importer). The country's dependence on imported oil is around 75% (IEA, 2021) and costs a massive foreign exchange investment.

The contribution of the fossil fuel to global energy is around 80% (Ritchie, Roser, & Rosado, 2020). According to the Bureau of Energy Efficiency,[4] India's dependency on imported fossil fuels is mounting incessantly. India is the fourth-largest petroleum consumer in the world after China, the United States, and Russia. Due to modernization and its dynamic economic growth, India's energy demand will continue to have a robust growth. The petroleum products consumption in the country has increased by about 38.2% from the past one decade, resulting in a substantial expenditure on oil imports. Considering the growing demand for fossil fuel and the rapidly growing motor vehicle fleet in India, the Government of India has set a target to reduce the 10% oil imports by the year 2022.[5]

2. History of Biodiesel

Biomass feedstock used to make fuel in the 1800s is fundamentally the same as today's process. In contrast to its technological development, biodiesel has more of a political and economic history. In 1890, Rudolph Diesel developed biodiesel and used pure vegetable oils in diesel engines for agricultural purposes. In Belgium (the 1930s), researchers produced modern-day biodiesel by converting vegetable oils into fatty acid methyl esters (FAME) compounds.

Due to the vast amount of crude oil refined to provide gasoline, for gasoline-automobiles oil companies ended up with a surplus of distillate, a much less expensive and ideal fuel for diesel engines. On the other hand, there has always been a concern about resource depletion, price inflation, and energy security with imported petroleum. So, considering all factors, efforts are made to find and utilize locally available vegetable oils as fuel (Biodiesel, 2008).

A transesterification process converted vegetable oils into fatty acid alkyl esters to lower the viscosity and resemble the physiochemical properties of diesel. Apprehensions over energy security, agro-products use, and the environment took this picture of using vegetable oils to the forefront. The world needs to produce renewable feedstock so that biodiesel stays competitive with petroleum in terms of cost.[6]

Commonly used feedstocks are shown in Table 1.

Table 1: Feedstocks used for biodiesel manufacturing

<table>
<tr><th>Vegetable Oils and Derivatives</th><th>Animal Fats</th><th>Other Sources</th></tr>
<tr><td>Soybeans</td><td>Lard</td><td rowspan="12">Recycled Restaurant Cooking Oil (a.k.a. Yellow Grease)</td></tr>
<tr><td>Rapeseed</td><td>Tallow</td></tr>
<tr><td>Canola Oil (a modified version of rapeseed)</td><td rowspan="10">Poultry Fat</td></tr>
<tr><td>Safflower Oil</td></tr>
<tr><td>Sunflower Seeds</td></tr>
<tr><td>Yellow Mustard Seed</td></tr>
<tr><td>Palm Oil</td></tr>
<tr><td>Palm Olein</td></tr>
<tr><td>RBD Palm Stearin</td></tr>
<tr><td>Fatty Acids</td></tr>
<tr><td>Acid Oils</td></tr>
<tr><td>Tree Borne Oilseeds</td></tr>
</table>

Source: (Strong, Erickson, & Shukla, 2004), and BMAI

3. Introduction to Biodiesel

The number of vehicles on the road is increasing daily, leading to an increase in petroleum product consumption. Hydrocarbon fuel combustion contributes to the generation of carbon-based species in the exhaust and pollutes the environment. Compared to renewable biofuels, non-renewable fuels emit more hydrocarbons, nitrogen oxides, sulphur oxides, and carbon monoxide. Various alternative fuels are considered substitutes for petroleum products, and efforts were made to analyze their suitability. Increasing attention has been paid to renewable fuels to reduce pollution (by completing the carbon cycle) and reduce petroleum imports. Consequently, scientists worldwide have focused on developing biodiesel and optimizing its production processes to meet the standards and specifications.

According to a recent report by Petroleum Planning and Analysis Cell (PPAC) on all India study for sectorial demand of petrol and diesel (PPAC, 2021), the retail diesel sales constitute 68% share of the petrol-diesel basket. India's transport sector accounts for 87% and the remaining 13% with non-transport sector. The heavy-duty vehicle (HDV), and the light-duty vehicle (LDV) together consume more than 64% of the total diesel consumption (PPAC, 2021). As freight activity is expected to grow[7], the commercial vehicle segment will likely continue to dominate the demand for diesel and impact oil import dependency.

Currently, India has a limited variety of alternative fuel options for diesel vehicles and is in the initial stages of electrification. The use of hydrogen fuel cells, battery-operated vehicles, etc., especially in medium and heavy-duty bus segments, is in the commercialization phase. At the same time, the issue remains with the availability and reliability of the prime energy source. In this regard, biodiesel is the most prominent source and one of the relatively cleaner options in medium/heavy-duty vehicles, SUVs, taxis, buses, etc. The use of biodiesel in transportation has been proven to be a good replacement for oil because they are renewable liquid resource derived from biologically derived raw materials. Hence, biofuels- (ethanol and biodiesel) are gaining global acceptance for

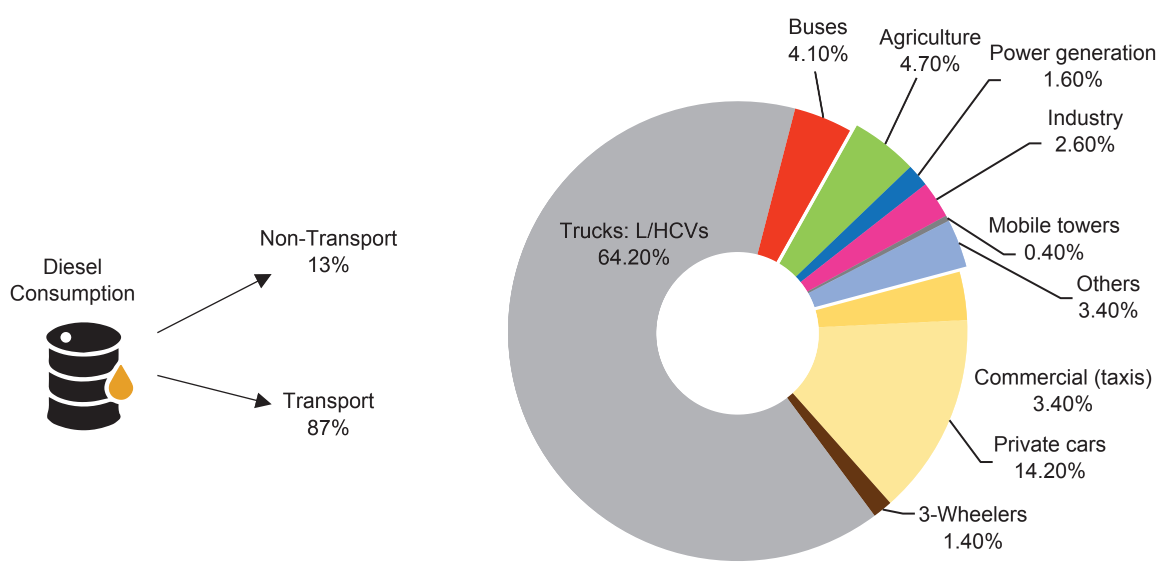


Figure 1: Diesel retail sales by sector and segment in India

Source: PPAC, 2021

many reasons, i.e., including environmental problems, energy security, reducing imports, rural employment, and improving agricultural economies (Planning Commission, 2003).

Biodiesel is one of the alternative fuels and can be produced from renewable sources like vegetable oil, soybean oil, canola oil, non-edible sources, and animal fats. India's government is emphasizing energy security with a target of reducing the usage of fossil fuels and import burdens. In tandem with emission problems, this has driven the requirement for alternative fuels that benefit the environment and are economically competitive.

In India, biodiesel is produced primarily from non-edible vegetable oil, acid oils, animal tallow, and palm stearin oil. Domestically available used cooking oil (UCO) has been identified as a potential raw material for biodiesel production in National Policy on Biofuels-2018. The waste cooking oil can be collected in bulk from consumers such as restaurants, hotels, etc., for conversion into biodiesel. Biodiesel in its pure form is termed B100 or neat biodiesel and can also be blended with conventional diesel as B5[8] (5% biodiesel and 95% diesel by volume) and B20[9] (20% biodiesel and 80% diesel by volume) (Konishi, 2010).

3.1 Biodiesel as a potential energy source

There is a need for sustainable and appropriate replacement of fossil fuels to reduce import duty on oil and lower exhaust emissions. In addition to being renewable, non-toxic, and eco-friendly, biodiesel is an ideal alternative to diesel engines. Various other potentials related to biodiesel are:

- It can reduce our dependence on petroleum imports
- It can control limited supplies of fossil fuels
- It can support reducing GHG emissions
- It can support boosting our domestic economy
- It maintains the payload capacity and range of petroleum-derived diesel

> **"Biodiesel industry can create millions of jobs and assist in achieving Net Zero before the deadline"**
>
> *-Biodiesel Manufacturers Association of India*

3.2 Emission reduction from biodiesel

Biodiesel significantly reduces the tailpipe emissions of carbon monoxide, unburned hydrocarbons, and other particulate matter compared to conventional diesel and supports the environment. A major component of acid rain sulphur dioxide and sulphates are virtually eliminated with biodiesel.

Nitrogen oxide emissions are either reduced or increased depending on the engine duty cycle and testing methods. The overall ozone-forming potential of emissions from biodiesel is less than half of that measured for the diesel counterpart. Hence, it can be used as a replacement for conventional petroleum-based diesel and could be named a 'clean energy source'.

Table 2: Biodiesel emissions compared to conventional diesel

Emission Type	B5	B7	B10	B20	B50	B100
Particulate Matter	-3%	-4%	-6%	-12%	-27%	-47%
Hydrocarbons	-5%	-8%	-11%	-20%	-43%	-67%
Carbon Monoxide	-3%	-4%	-6%	-12%	-28%	-48%
SO_x	-5%	-7%	-10%	-20%	-50%	-100%
CO_2	-4%	-5%	-8%	-15%	-38%	-76%

****Note on emission reductions:** The above analysis is based on research and studies conducted by the University of Idaho and the USDA, including the complete direct and indirect GHG emissions of biodiesel production. This latest study is a further update to the previous methods used by USEPA in 2010. Global warming potentials of various greenhouse gases are weighted to present results in CO_2 equivalents.*

Source: BMAI

4. Production of Biodiesel

The chain of biodiesel production can be represented in the following main steps:

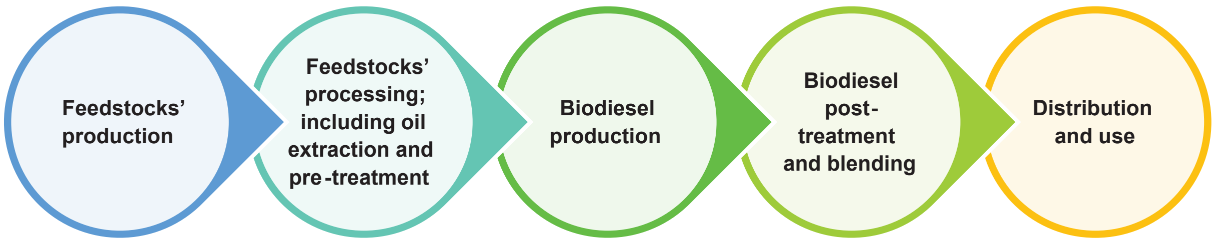


Figure 2: Stages of biodiesel production

Source: Mata & Martins, 2010

Various methods are widely used for the production of biodiesel (Rajalingam, Jani, Senthil Kumar, & Khan, 2016), namely:

1. **Direct use and blending:** Animal fat or vegetable oil are used as fuel in DI engines. It possesses a decent heating value and provides sufficient power. But it cannot be used directly without any modification (due to high viscosity, poor atomization, and injector coking issues); hence it is blended with conventional fossil fuels.

2. **Transesterification process:** It is the most widely used method in which the reaction between triglycerides in vegetable oil and alcohol replaces the triglycerides within alcohol and produces esters (biodiesel) and glycerol, as shown in the Figure 3 below:

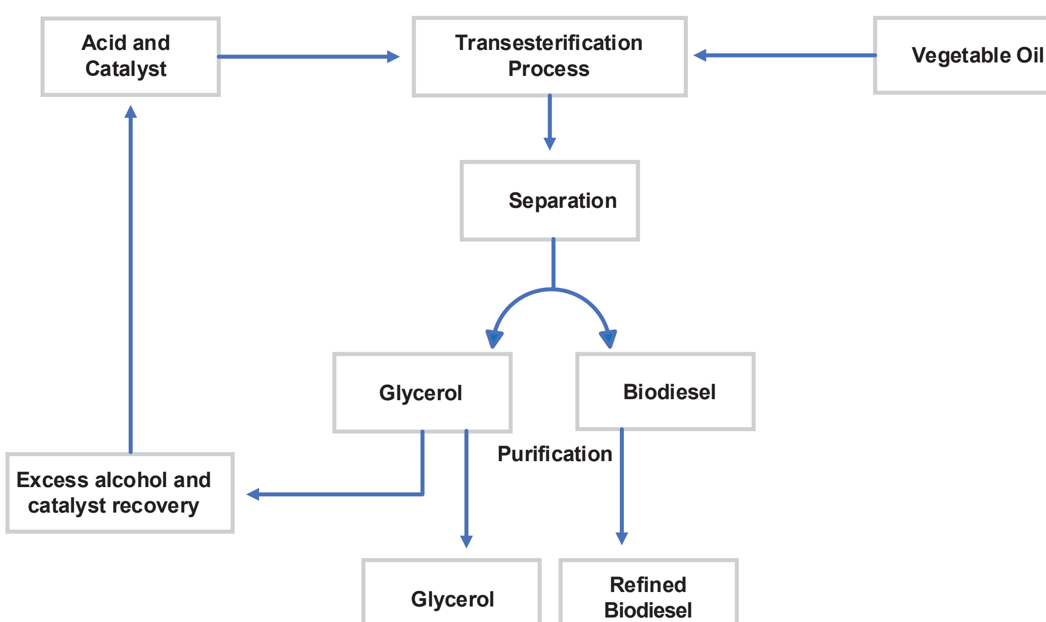


Figure 3: Transesterification process

Source: Rajalingam, Jani, Senthil Kumar, & Khan, 2016

3. **Thermal cracking:** This process converts the complex structure of hydrocarbons into their simplest structure with or without a catalyst, which thereby helps to reduce the density and viscosity of oil, allowing the treated oil/fuel to be used directly in diesel engines without any modifications as shown in Figure 4.

4. **Microemulsion:** This process can be defined as thermodynamically stable, isotropic liquid mixtures of oil, water, and surfactant that assists in solving viscosity and atomization properties of oil and helps to provide good spray properties when injected by a nozzle in the engine. However, this process is still not commonly used as it might result in nozzle failure, incomplete combustion, and carbon deposit.

4.1 Generations of biodiesel

An edible, non-edible, or waste oil converted into biodiesel using methanol and catalysts for transesterifying triglycerides into monoalkyl esters composed of long-chain fatty acids, commonly known as biodiesel. As a byproduct of transesterification, glycerol (glycerin) is formed. Methanol's low cost and easy availability make it a popular choice for producing biodiesel.

As part of the development of biodiesel, specific steps have been taken to cover the development of feedstock, optimum production methods, and quality and quantity improvements for biodiesel and carbon-neutral economies. There are three generations of biodiesel: the first, second, and third. The fourth generation is derived from man-made biological tools and is in the early stages of research (Singh, et al., 2019).

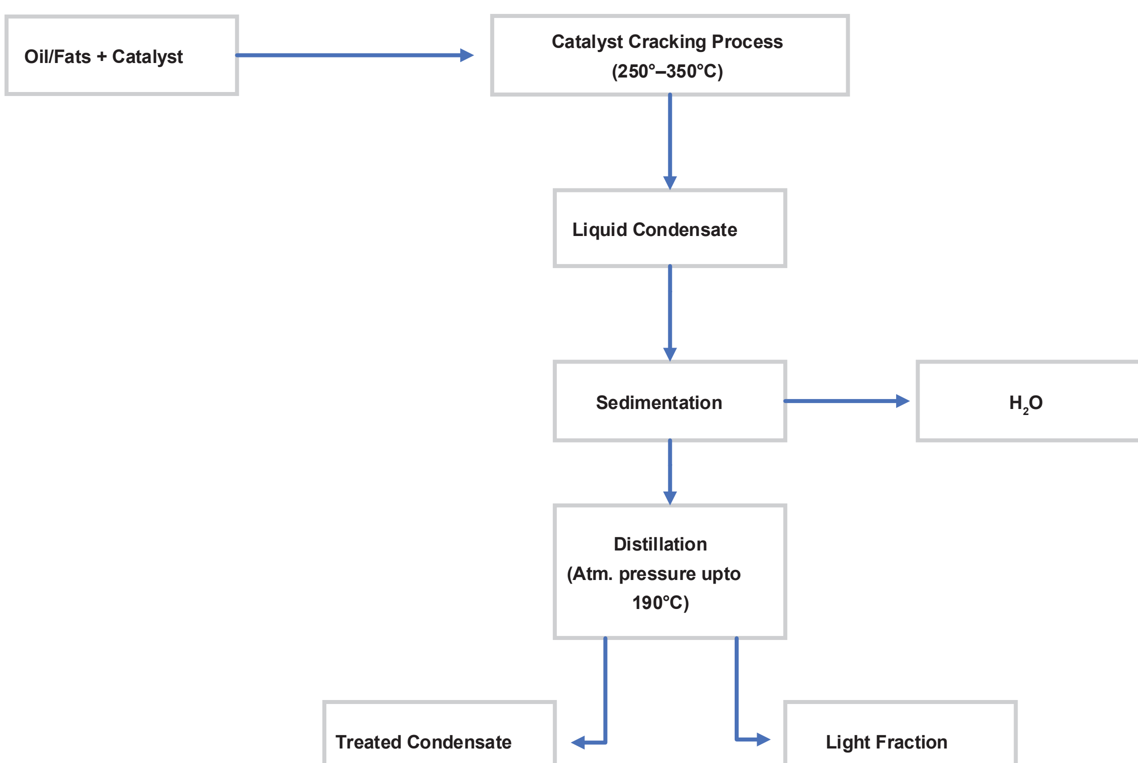


Figure 4: Thermal cracking process

Source: Rajalingam, Jani, Senthil Kumar, & Khan, 2016

Various generations of biodiesel used are as follows:

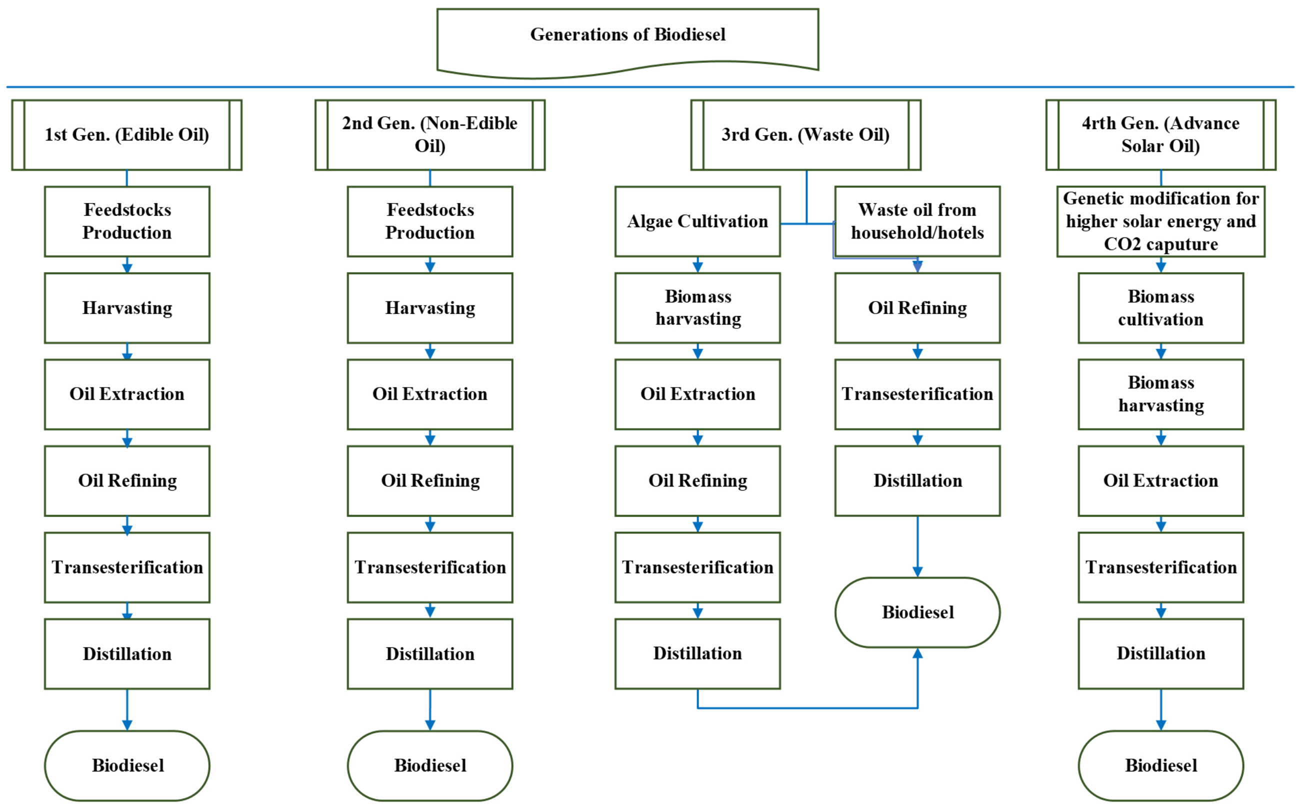


Figure 5: Biodiesel production process for different generations

Source: Singh, et al., 2019

4.1.1 First-generation biodiesel

First-generation biodiesels are produced from the edible feedstock. An example of edible feedstock is the oil of palm, soybean, rapeseed, coconut, etc. Using edible oils as feedstock for biodiesel production is a very popular and oldest practice. A primary advantage of first-generation feedstock is its availability and ease of conversion. Cons include the risk of limitation in the food supply that increase the cost of food products, limited cultivation area, and adaptability to environmental conditions that drive users to explore further alternative sources for biodiesel production (Singh, et al., 2019).

4.1.2 Second-generation biodiesel

The biodiesel is produced from the non-edible feedstock. Examples of non-edible feedstock are jatropha, karanja, neem, mahua indica, etc., and second-generation biodiesels. Gaps, limitations, and concerns over food-fuel from first-generation feedstock enabled scientists to explore non-edible feedstock. These eradicate food inequality, have minimal production costs, and require less land for farming. Disadvantages include majorly yielding capabilities and farming non-edible crops at farming lands, directly impacting food production and the economy (Singh, et al., 2019).

4.1.3 Third-generation biodiesel

Third-generation biodiesels are produced from used cooking oil, microalgae and fish oils, etc. Major pros include elevated growth rate and productivity, low GHG impacts, high oil contents and conversions, and minimal influence on the food chain. Major drawbacks involve high capital investments, larger scale collection and production, etc. (Singh, et al., 2019).

4.1.4 Fourth-generation biodiesel

The fourth-generation biodiesels include photo-biological solar fuels and electro-fuels. It is a new field of research that converts solar energy into biodiesel using raw materials. Sources for raw materials are extensively available, limitless, and cheap. Developing new-to-nature solutions is essential for sustainable development, such as making synthetic living firms and stylish microorganisms to transmit solar energy to fuel efficiently and directly (Singh, et al., 2019). Various feedstocks for different generations of biodiesel are shown in Table 3 below.

The fore-mentioned different generations of biodiesel have various benefits and limitations linked with them, which are illustrated in Table 4.

4.2 Different feedstock for biodiesel production

Since its invention, there are multiple feedstocks that have been tested and used for the production of a few widely used feedstocks, and their nature and given below:

1. ***Jatropha curcas:*** Jatropha is a plant of the tropical region. Since the beginning of the biodiesel era,

Table 3: Various feedstock for different generations of biodiesel

Edible oil (1st generation)	Non-edible oil (2nd generation)	Waste oils (3rd generation)	Synthetic biodiesel (4th generation)
Cashew nut	*Aleurites fordii*	Animal tallow	Photobiological solar biodiesel
Coconut	Babassu tree	Biomass pyrolysis	Electro biofuels
Corn	*Calophyllum inophyllum*	*Botryococcus braunii*	Synthetic cells
Cotton seeds	Castor	Chicken fat	
Hazelnut	*Cerbera odollam*	*Chlorella vulgaris* algae	
Mustard	*Crambe abyssinica*	*Dunaliella salina* algae	
Olives	*Jatropha curcas*	Poultry fat	
Palm	*Jatropha curcas*	Fish	
Pistachio	Karanja	Waste Cooking Oil	
Rapeseed	*Mahua indica*		
Radish	Milk bush		
Rice bran	Nagchampa		
Soybean	Neem		
Sunflower	*Nicotiana tabacum*		
Tigernut	*Nicotiana tabacum*		
Walnut	Rubber seed		
	Sapindus mukorossi		
	Silk cotton tree		
	Thevettia peruviana		
	Tall		

Source: (Singh, et al., 2019)

Table 4: Benefits and limitations of different generations

	First generation	Second generation	Third generation	Fourth generation
Benefits	• Easy biodiesel conversion process • Easy availability of crops	• No effect on food supply • Feedstocks can be grown on non-arable land • Less production cost	• Waste food oil can be used for biodiesel production • The growth rate of algae is high • No effect on food supply • Can use seawater or waste water for algae growth	• More lipid contents • More CO_2 absorbing ability • High energy content and rapid growth rate
Limitations	• Affect food supply • Low crop yield • Limited area of cultivation • Less adaptability of the crop to environmental conditions	• Less cost-effective conversion technology • Low crop yield for some feedstock	• High energy consumption for algae cultivation • Low lipid content in open pond system • Expensive oil extraction process from algae	• High initial investment • Research on infancy level

Source: Singh, et al., 2019

Jatropha has been assumed to be of great significance and potential as a non-edible oil seed-producing plant, especially around the world. Amongst the 137 different species of Jatropha, only 12 types could be found in different parts of South East Asia. The most commercially viable and significant is *Jatropha curcas* because of its high oil content in the seeds, which ranges from 38%-46% during different maturing stages. The plant was initially grown as a hedge because cattle do not graze it.

Considering its potential for cultivation in the country because of its tropical nature and attracting potential buyers from round the globe, the Government of India launched a mission on biofuels to make India self-reliant in fuel oils with a view of mass-scale plantation of Jatropha for biodiesel production. However, a number of factors made biodiesel projects unviable, including very low Jatropha seed yields, limited availability of wasteland and high plantation and maintenance costs. The top four states with high capacity in the field of Jatropha plantations are Chhattisgarh, Uttaranchal, Mizoram, Rajasthan, followed by others.[10]

2. **Palm oil:** Palm fruit is the source of palm oil (extracted from palm fruit) and palm kernel oil (extracted from fruit seeds). Both are high in saturated fatty acids, about 50% and 80%, respectively. Biodiesel production is driving the growth in demand for palm oil, especially for biodiesel production.

   Palm oil biodiesel is also called Palm Oil Methyl Ester (PME) and differs from other types of biodiesel in terms of molecule unsaturation. PME is more saturated, which specifies excellent ignition properties recommended for diesel engine applications. However, they also harden at higher temperatures, making them tough to use in cold weather. As it is generated from renewable sources, the production and use of biodiesel are promoted on a large scale. Increasing the use of biodiesel reduces oil dependence and greenhouse gas emissions to a large extent.

   Palm stearin oil is the non-consumable portion of palm oil (PSO). A strong and important advantage of using palm stearin biodiesel is that it does not create a conflict between food and fuel. The raw material for making palm stearin methyl ester is widely available in Southeast Asia and India.[11]

3. **Rape seed oil:** Rapeseed is one of the most important and widely used oils for biodiesel production. Rapeseed, also known as rapeseed, rapa, oilseed rape, rape, and canola, is a bright yellow flowering member of the Brassicaceae (mustard or cabbage family). The European Union, Canada, the United States, Australia,

China, and India are among the most prominent countries that cultivate rapeseed for animal feed, oil for humans, and biodiesel.[12]

It was once more costly to produce rapeseed-derived biodiesel than standard diesel fuel due to the high cost of growing, crushing, and refining rapeseed biodiesel. The most commonly used oil source in Europe for biodiesel production is rapeseed oil, which produces more oil per unit of land area than soybeans.

4. **Used cooking oil/used vegetable oil:** Biodiesel from used cooking oil (UCO) produces liquid fuels from biomass that can be used for various purposes. In addition to excellent economic and environmental benefits, biodiesel production by recycling UCO and methanol in the presence of a catalyst also offers a waste management benefit.

   Collecting UCO is growing globally, especially in India, UAE, Qatar, Kuwait, and many other countries. Restaurants can use the system to remove waste products from the water system that would otherwise cause a high treatment load for wastewater treatment plants. Several collectors collect UCO from households, small restaurants and other places and convert it into biodiesel or sell it to biodiesel manufacturers. Biodiesel manufacturing is like purifying UCO and using it as a resource. Due to its nature as a fuel, biodiesel does not fall under food production regulations and is governed by the rules for petroleum products.

5. **Animal tallows:** Animal tallow is yet another important feedstock obtained by rendering animal fat in slaughter houses. There is a big global market for animal tallows, but using it still a debatable topic in some parts of the world.

   Animal tallows have a higher cetane number than plant-derived oils; biodiesel produced from animal tallows is much more cleaner and offers better and more efficient burning in diesel engines. Tallow has a high cloud point[13], and a high level of saturation in animal tallow tends to cause rapid crystallization of biodiesel produced from it than biodiesel produced from vegetable oils.[14]

4.3 Challenges of biodiesel

There are few challenges associated with using biodiesel as fuel:

- Due to its lower calorific value, the fuel consumption becomes higher
- NOx emissions are slightly higher than the conventional diesel
- Biodiesel, as discussed, has a higher freezing point in comparison with diesel
- Biodiesel used in its pure form for a longer period of time can cause corrosion; especially if used without any coating, etc.

5. Specifications and Supply-chain

Biodiesel's (B100) quality and stability depends upon the specifications as mentioned in IS 15607:2016. Any changes other than mentioned in the code can have quality and performance degradation. The specifications are given in Table 5.

The supply chain includes activities such as cultivation, production, blending, transportation, storing, and distribution to consumers. This becomes very complex in case of biodiesel because of the associated challenges. Supply-chain management becomes crucial when adaptation is required on a larger scale.

When purified, plant/vegetable oils are completely harmless to the environment, especially the groundwater, but when they are esterified, they become more hazardous

Table 5: Biodiesel specifications as per IS 15607: 2016

Characteristics	Unit	Requirement	Test method ISO, ASTM, EN/IS 1448
Density at 15°C	kg/m^3	860-900	ISO 3675 /P 32
Kinematic viscosity at 40°C	cSt	3.5-5.0	ISO 3104 / P25
Flash point (closed cup), min	°C	101	P21
Sulphur, max	mg/kg	10.0	D5443/P83
Carbon residue (Ramsbottom), max	%m	0.05	D4530
Sulphated ash, max	%m	0.02	ISO 6245/P4
Water content, max	mg/kg	500	D2709/P40
Total contamination, max	mg/kg	24	EN12662
Copper corrosion 3 hr. @50°C, max	-	1	ISO 2160 / P15
Cetane number, min	-	51	ISO 5156/ P9
Acid value, max	mg KOH/g	0.5	P1
Methanol, max	%m	0.2	EN 14110
Ester content, min	%m	96.5	EN 14103
Monoglycerides content, max	%m	0.7	D6584/EN14105
Diglyceride content, max	%m	0.2	D6584/EN14105
Triglyceride content, max	%m	0.2	D6584/EN14105
Free glycerol, max	%m	0.02	D6584/EN14105/EN14106
Total glycerol, max	%m	0.25	D6584/EN14105
Phosphorous, max	mg/kg	4.0	D 4951/EN14107
Sodium + potassium, max	mg/kg	5	EN 14108/EN 14109
Calcium + magnesium, max	mg/kg	5	EN14538
Iodine value, max	g iodine/100 gm	120	EN 14111/EN16300
Oxidation stability at 110°C, min	Hr	8	EN 14112
CFPP, summer, max	°C	18	EN16329/D6371
CFPP, winter, max	°C	6	EN16329/D6371
Linolenic acid methyl ester, max	%m/m	12	EN 14103
Polyunsaturated (>=4 double bonds) methyl ester, max	%m/m	1	EN 15779

Source: *IS 15607: 2016, Bureau of Indian Standards* to water. It is always recommended to store biodiesel in approved tanks that are clean and dry and to treat blends of biodiesel and petroleum diesel as petroleum diesel. Despite the high flash point of biodiesel, conservation precautions should be taken, much like those for diesel fuel.

It is possible to store biodiesel for an extended period in closed containers with little headroom. However, the container must be protected from direct sunlight, low temperatures, and weather. Proper insulation, heating, and other equipment should be installed at low temperatures with preferred underground storage when stored in an open container.

Biodiesel can become jelly in nature on exposure to low temperatures. It is always recommended to use good additives for storage and pumping in that kind of situation. The biodiesel should be stored at least 15 degrees above the fuel's pour point, and when splash blending the biodiesel, care should be taken to avoid very low fuel temperatures because submerged compounds can crystallize and clog the fuel line and filter. Intense care should also be taken in case of water condensation inside the tank, as bacteria can grow and use biodiesel as food (Planning Commission, 2003).

Storage of biodiesel for the long term (longer than 5-6 months) without any further additives significantly impacts composition. Biodiesel blends show more stability than neat B100 and are highly influenced by temperature variations (Christensen & McCormick, 2014). In the presence of sediments, biodiesel tends to dissolve sediments found in tanks and cause filter blockages, injector failures, and fuel clogging. The colour of the fuel and fitting will appear to be changed with time as the sediments are formed. Hence, it is always preferable to use a storage tank made of aluminium, steel, etc.

It is generally recommended that biodiesel and petroleum diesel blends are treated as petroleum diesel. It is essential to take some storage precautions similar to those for storing diesel fuel, even though the flash point of biodiesel is high and its handling and storage do not require separate infrastructure. Neat biodiesel contains no aromatic hydrocarbon or chlorinated hydrocarbons and releases no harmful or corrosive gases. However, biodiesel blends significantly release some fumes.

When small amounts of biodiesel are accidentally discharged or spilled, they should have little environmental impact compared to petroleum diesel. Biodiesel spills are less likely to affect the environment than oil spills (Planning Commission, 2003). Separating animal fats from vegetable and petroleum oils and applying separate standards depending on their physical differences is necessary.

6. Biodiesel Policy Initiatives in India

As an initiative to limit oil import and support its energy needs, back in the early 2000s, India took several policy steps to encourage biodiesel production and use in the country. Some of these policies are listed below, which played a significant role and contributed to the adoption of biodiesel in the country:

1. As part of a commitment to promote biodiesel production, the MoP&NG announced in October 2005 a Biodiesel Purchase Policy[15], which became effective on January 1, 2006. As per this policy, OMCs were required to purchase biodiesel for blending with High-Speed Diesel (HSD) at 5% while meeting Bureau of Indian Standards (BIS).

2. At its meeting on January 16, 2015, the Cabinet determined that private biodiesel manufacturers, their authorized dealers, and joint ventures of oil marketing companies (OMCs) authorized by the MoP&NG would be allowed to sell biodiesel directly to consumers.

3. On August 10, 2015, the government amended the motor spirit and High-Speed Diesel (Regulation of Supply, Distribution, and Prevention of Malpractices) Order, 2005, to allow the direct sale of biodiesel to large bulk consumers such as railways, state road transport corporations, and others. From August 10, 2015, oil marketing companies also started selling blended biodiesel from selected retail outlets throughout the country.

4. As per MoP&NG's **Gazette Notification: GSR 728 (E)** issued on June 29, 2017[16], the Reserve State Government may permit the direct sale of biodiesel (B100) to blend with high-speed diesel to all consumers under the conditions outlined in the notification.

5. The latest amendments to IS: 1460 (Automotive Diesel Fuel Specification) issued in December 2017 allow biodiesel to be blended up to 7% with automotive diesel fuel.

Table 6: Phases of biodiesel in India

Policy/Guidelines	Year	Summary/Objective
Biodiesel Purchase Policy	2005	The policy sets out measures to support activities for blending biodiesel in diesel and marketing such blended fuel.
National Mission on Biodiesel	2009	The objectives were to bring unutilized wasteland into productive use by promoting Jatropha and Pongamia plantation for 20% blending with HSD.
Amendment no.-GSR 352(E) of Motor spirit and high-speed diesel (Regulation of supply and distribution & prevention of malpractices) order, 2005	2015	The government allowed the direct sale of Biodiesel (B100) for blending with diesel to Bulk Consumers.
Amendment no.-GSR 782(E) of Motor spirit and high-speed diesel (Regulation of supply and distribution & prevention of malpractices) order, 2005	2017	The government allowed the sale of biodiesel to all consumers for blending with diesel.
National Policy on Biofuels	2018	India aims to achieve 5% blending (B5) of biodiesel with conventional diesel by 2030.
Guidelines for sale of biodiesel for blending with high-speed diesel for transportation purposes-2019	2019	The government notified guidelines for the sale of biodiesel for blending with HSD for transportation purposes and has granted permission exclusively for the sale of biodiesel (B-100) only and not for any mixture thereof of whatever percentage.

Source: TERI's compilation

6. The MoP&NG has issued the National Policy on Biofuel -2018[17], in which an indicative target of 5% blending of biodiesel in diesel is proposed by 2030.

7. According to the policy, UCO and WCO produced in-house are potential sources of biodiesel. Nevertheless, UCO is diverted into the edible stream by various small eateries/vendors and traders, and attention will be focused on defining strict norms for preventing UCO from entering food channels and developing a suitable collection mechanism to augment its availability for biodiesel production.

8. The government has notified the Guidelines for the sale of biodiesel for blending with high-speed diesel for transportation purposes in the extraordinary gazette of India in 2019.[18]

6.1 Biodiesel Policy: Current status and gaps

In recent years, the global biodiesel market has grown rapidly. The use of biodiesel has been encouraged in many countries through pro-active policies. The blending of petrol with ethanol obtained from sugar mills has picked up in India, but the Biodiesel Policy has been on the back foot. Even though diesel is the most common fuel used for commercial vehicles and public transit, biodiesel does not receive the attention it deserves. Table 7 shows the year-wise procurement of biodiesel in India by OMCs.

In 2021, the national average blend rate of biodiesel was estimated at 0.02%. Biodiesel is manufactured from imported palm stearin, domestically sourced animal fats, UCO, and small volumes of non-edible oils.

Usage of biodiesel remains negligible due to the:

- Limited availability of feedstock
- High feedstock prices
- Lack of an integrated and dedicated supply chain
- Dependence upon the imported feedstock
- Import restrictions
- Blended diesel consumers are limited to only a few OMC retail outlets

To meet its blending goal of biodiesel by 2030, India would need to invest in new plants substantially to enhance the production capacity from its current effective capacity of 520 million litres (as of 2021) and form a supply chain infrastructure for UCO while imposing some essential collection mechanisms. In India, the entrepreneurs, who are typically fuel traders with comparatively better access to the domestic fuels market, dominate biodiesel manufacturing and operate micro, small and medium enterprises compared to other countries that mostly rely

Table 7: Year-wise procurement of biodiesel by OMCs

Year	Quantity Procured (in million litres)
2015-16 (Aug 15'-March 16')	11.9
2016-17	35.9
2017-18	43.7
2018-19	82.2
2019-20	105.5
Aug-Sept 2022 (Expected procurement)	256.4

***Note:** *As per latest data shared by PPAC, Actual blending details for Apr-Sept'22 was 14443 KL (B-100) procured & OMCs sold 71680 KL (B7) Blended diesel during Apr-Sept'22.*

***Source:** *MoPN&G[19] and EOI no OMC/EOI/NUCO/BD/JUL22 dated July 23, 2022* on manufacturing units set up by vegetable oil refineries or large oil companies. The GoI has not yet demonstrated a determination to encourage or induce noticeably greater biodiesel production (Chandra, 2021).

With proactive and immediate policy measures and government intervention India has a capability of producing and offering 16.5 MTPA[20] in a short span of time to replace India's import dependency.

Various policy measures to achieve these goals have been suggested in a White Paper titled ***'Achieving Goals of The National Policy on Biofuels by Sustainable Growth of The Biodiesel Industry in India',*** which has been prepared and presented to relevant ministries by the Biodiesel Manufacturers Association of India (BMAI). A swift and proactive approach will ensure higher blends, encourage entrepreneurship, job creation and transform rural India.

Key Highlights from the White Paper prepared by BMAI

Potential of the Indian Biodiesel Industry:

Biodiesel is an economic weapon to fight global warming. It is capable of bringing 10 million hectares of wastelands under cultivations, which can:

- Produce **20,000 million litres** of biodiesel every year, at about INR 43 per litre hence reducing imports
- Create rural employment of **2320 million man-days**
- Reduce emissions by **250 million tonnes** of CO_2 every year
- Generate green power from biogas
- Increase green cover, leading to additional carbon sequestration
- Achieve India's 2070 Net Zero Target well in advance, allowing further industrial development
- Promote rural economies

7. International Experience

Overview of biodiesel blending targets for various countries and their current blending rates are presented in Table 8.

Based upon the production criteria, we have identified few countries from which India can learn some experiences in biodiesel production.

7.1 Indonesia

Indonesia's biodiesel mandate programme aims to reduce fuel imports, increase the demand for palm oil at home, and reduce emissions by blending palm-derived Fatty Acid Methyl Ester (FAME) with diesel. As a result of eased pandemic-related restrictions, Indonesia's biodiesel allocation volume will increase to 10.1 billion litres in 2022. Following the launch of B20 in the Public Sector Obligation (PSO) in 2016 and nationwide expansion in September 2018, the Government of Indonesia officially launched B30 in January 2020.

Indonesia began adopting a biofuels policy at the national level in 2006 by issuing a Government Regulation concerning the procurement and usage of biofuels. In support of that regulation, a **National Biofuels Development Team** was established so that modern biofuel programmes could be monitored and a blueprint for biofuel development growth (USDA, 2022). According to the blueprint, biofuels development aims to:

- Alleviate poverty and unemployment,
- Drive economic activities through biofuel procurement and
- Reduce domestic fossil fuel consumption.

Table 9 shows GoI's plans to increase biodiesel blending through/by/in 2025.

Table 8: Biodiesel blending targets of various countries

Country	Blending Target	Current Blend Rate
Indonesia	B20 by mid-2022	28.6%
Malaysia	B30 by 2025	10%
Colombia	B12	11%
Philippines	B5 by 2022	3%
US	B12	6%
European Union	-	7-8%
Australia	No mandate	0.1%

Source: TERI's compilation

Table 9: Indonesia Biodiesel Mandatory Targets

Sector	2016	2020	2025
Transportation	20%	30%	30%
Non-PSO Transportation, Public Service Obligation (PSO)	20%	30%	30%
Industry	20%	30%	30%
Electricity	30%	30%	30%

Source: Ministry of Energy Mineral Resource, Indonesia

Table 10: Indonesia: Production, Supply and Demand Stats

Biodiesel (Million Litres)									
Calendar Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beginning Stocks	27	11	97	94	110	152	258	294	329
Production	2,950	3,500	1,200	3,500	2,800	5,600	7,700	8,500	9,550
Imports	24	0	0	0	0	28	0	0	0
Exports	1,942	1,569	343	476	187	1,772	1,271	39	193
Consumption	1,048	1,845	860	3,008	2,572	3,750	6,393	8,426	9,296
Feedstock Use for Fuel (1,000 MT)									
Crude Palm Oil (CPO)	2,714	3,220	1,104	3,220	2,576	5,152	7,084	7,820	8,786
Market Penetration (Million Litres)									
Biodiesel, on-road use	734	1,292	583	2,263	1,963	2,982	5,238	7,341	7,945
Diesel, on-road use	24,508	23,257	21,931	21,567	23,877	24,984	26,753	25,255	27,752
Blend Rate (%)	3.0%	5.6%	2.7%	10.5%	8.2%	11.9%	19.6%	29.1%	28.6%

Source: USDA, 2022

It is expected that Indonesia will reach 10.6 billion litres of biodiesel production in 2022, from 9.55 billion litres last year. Indonesia exports biodiesel and expects 200 million litres of biodiesel exports in 2022 (refer to Table 10).

7.2 Malaysia

For reducing fossil fuels dependence and stabilizing the palm oil industry by using environmentally friendly and sustainable energy sources, the Malaysian government launched the National Biofuel Policy in 2006 to reduce dependency on fossil fuels. As part of its National Biofuel Policy, the Malaysian Parliament adopted the Biofuel Industry Act in 2007, which mandated using blended biodiesel fuels. Initial plans for implementing a 5% blend (B5) by 2008 failed to materialize until 2014. It was again revised to B7 and was accomplished in 2016. Released "Eleventh Malaysia Plan 2016-2020" in 2016, according to which there will be an increase in the blend rate gradually to 20% by 2020 as part of its efforts to promote domestic consumption of biodiesel in the transportation sector; unfortunately, due to unusual circumstances of Covid-19 pandemic, this was again revised to mid of 2022 (USDA, 2021).

Malaysia uses Crude Palm Oil for biodiesel production and is one of the biggest exporters of biodiesel around the globe. The European Union is among the largest importer of Malaysian biodiesel, with more than 60% of total biodiesel export, followed by Peru, China, and Japan (USDA, 2021). Basic stats of biodiesel in Malaysia are given in Table 11.

7.3 Colombia

Colombia's government controls the Colombian fuel market with The Ministry of Mines and Energy's (MME) responsibility of establishing biofuel blend mandates, regulating prices, and fixing technical regulations on biofuel standards. Multiple changes have been implemented since 2005, when Colombia's implementation of biofuel blend mandates started, but the biodiesel blend mandate remained at B10.

Import and export of biodiesel in Colombia are allowed, but the country does not import or export biodiesel. The feedstock used for biodiesel is historically palm oil, but now, UCO is also contributing its part in the process (USDA, 2022). Basic stats of biodiesel in Colombia are given in Table 12.

Table 11: Malaysia: Production, Supply and Demand Stats

Biodiesel (Million Litres)									
Calendar Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Beginning Stocks	18	27	62	42	76	70	150	155	405
Production	235	510	475	743	595	854	1,100	1,778	1,249
Imports	0	0	0	0	0	0	0	0	0
Exports	31	190	95	194	91	256	560	663	412
Consumption	195	285	400	515	510	518	535	865	798
Feedstock Use for Fuel (1,000 MT)									
Crude Palm Oil (CPO)	216	469	437	684	535	786	1,012	1,636	1,149
Market Penetration (Million Litres)									
Biodiesel, on-road use	195	285	400	515	510	518	535	745	665
Diesel, on-road use	7,368	7,492	7,957	7,342	7,246	7,351	7,639	7,447	6,637
Blend Rate (%)	2.6%	3.8%	5.0%	7.0%	7.0%	7.0%	7.0%	10.0%	10.0%

Source: USDA, 2021

Table 12: Colombia: Production, Supply and Demand Stats

Biodiesel (Million Litres)									
Calendar Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beginning Stocks	11	14	15	13	11	13	15	20	20
Production	573	590	583	530	545	627	610	570	720
Imports	0	0	0	0	0	0	0	0	0
Exports	0	0	0	0	0	0	0	0	0
Consumption	570	589	585	532	543	625	605	570	715
Feedstock used for Fuel (1,000 MT)									
Crude Palm Oil (CPO)	527	543	536	468	479	554	535	498	632
Used Cooking Oil	0	0	0	22	25	26	30	30	35
Market Penetration (Million Litres)									
Biodiesel, on-road use	570	589	585	532	543	625	605	570	715
Diesel, on-road use	5,883	6,071	6,296	6,315	6,183	6,282	6,422	5,686	6,596
Blend Rate (%)	9.7%	9.7%	9.3%	8.4%	8.8%	9.9%	9.4%	10.0%	10.8%

Source: USDA, 2022

7.4 Philippines

The Philippine government implemented a biofuel law in 2006 to reduce dependence on fossil fuels and carbon emissions. The government began producing biodiesel from coconut oil converted into coconut methyl ester blended with petrol diesel. Three months after the Act came into effect, diesel engine fuels sold in the country had a minimum of 1% (B1), which was increased to 2% blend (B2) two years after, which now has a target of B30 by 2030.

The consumption of biodiesel is expected to increase in the Philippines in the year 2022 with the rise in diesel prices, and the government wants to reduce its dependence on imports. Biodiesel blends are produced locally with the

Table 13: Biofuels blend targets of the Philippines

Year	Biodiesel Target Blend (%)
2007	1
2008	1
2009	2
2010	2
2011	2
2015	5
2020	10
2025	20
2030	20

Source: USDA, 2022

use of coconut oil currently, which can mostly fulfil the demand for a short period with no imports or exports of biodiesel and has around 13 biorefineries with an overall capacity of around 708 million litres with about 35% of capacity use (USDA, 2022). Table 14 shows the stats related to the production, use and blending of biodiesel in the Philippines during the last few years.

7.5 European Union

Combining the markets of all 27 countries in the EU makes it the world's largest producer of fatty acid methyl ester (FAME)/hydrogenation-derived renewable diesel (HDRD). The EU has pioneered the modern commercialization of HDRD since 2010-14, making it a drop-in, fully replaceable alternative to fossil fuels. Around three-quarters of the transportation biofuels market is composed of FAME and HDRD. Developed in the 1990s, FAME was the first biofuel used in the EU's transport sector.

Based on economic recovery after COVID-19, EU biodiesel consumption will increase by 3% in 2021. France, Germany, Spain, Sweden, Italy, and Poland were amongst the top six biodiesel consumers in the EU in 2021, accounting for 72% of the total EU FAME/HDRD consumption. EU is also one of the biggest importers and exporters of biodiesel in the word and uses almost every feedstock available in the market today. The use of rapeseed oil, UCO, and Palm oil is found to be the major feedstock in the EU. There are different mandates in different countries in the European Union, with about 170 biorefineries (FAME) and 16 bio refineries (HDRD) with usage capacity ranging from 62-67% (USDA, 2022). Various feedstocks and their utilization in European Union are shown in Table 15.

7.6 Brazil

There are aggressive policies in Brazil to promote the use of renewable fuels. Brazil is one of the largest producers and consumers of biodiesel. The Brazilian government

Table 14: Philippines: Production, Supply and Demand Stats

Biodiesel (Million Litres)									
Calendar Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Beginning Stocks	18	20	29	32	41	57	71	95	122
Production	172	204	227	220	220	220	242	188	198
Imports	0	0	0	0	0	0	0	0	0
Exports	0	0	0	0	0	0	0	0	0
Consumption	153	163	201	218	204	206	218	161	191
Feedstock Use for Fuel (1,000 MT)									
Crude Palm Oil (CPO)	142	158	187	208	202	202	222	172	182
Market Penetration (Million Litres)									
Biodiesel, on-road use	153	163	201	218	204	206	218	161	191
Diesel, on-road use	6,187	6,579	7,334	7,701	8,086	8,200	8,413	6,440	7,460
Blend Rate (%)	2.5%	2.5%	2.7%	2.8%	2.5%	2.6%	2.5%	2.6%	3.0%

Source: USDA, 2022

Table 15: Feedstocks used in European Union (1,000 MT)

Calendar Year	2014	2015	2016	2017	2018	2019	2020	2021
Rapeseed oil	6,300	6,300	5,850	6,300	6,000	6,200	5,600	5,900
UCO	1,570	1,950	2,200	2,400	2,600	2,980	3,330	3,230
Palm Oil	2,060	2,000	2,020	2,425	2,330	2,250	2,620	2,550
Soybean oil	860	500	550	700	1,200	1,290	1,160	930
Animal fats	950	1,200	1,000	940	1,050	1,130	1,060	1,150
Sunflower oil	320	210	250	240	240	260	240	210
Other (pine oil, tall oil, free fatty acids)	310	415	304	429	607	768	602	645

Source: USDA, 2022

regulates the production of biodiesel. The country has managed to keep their biodiesel production under their control and has shown a healthy growth in the production and blend rate over the last few years despite COVID-19 pandemic and Russia-Ukraine conflicts.

Brazil launched its Biofuel Policy recently in 2019 to support its climate goals which is called 'RenovaBio'. A B10 blend has been mandated by Brazil's National Energy Policy Council until March 2023, but the Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP) has been adjusting the blending in an attempt to control biodiesel production costs that have increased due to a shortage of biodiesel feedstock, mainly soybeans and tallow (USDA, 2022).

Brazil's majority of biodiesel production comes from soybean oil followed by animal tallow. Inputs such as methanol and additives are about 10% of the cost of producing biodiesel, whereas raw materials account for 70% to 80%. Soybean oil prices determine the prices of the feedstocks like animal tallow and other vegetable oils in the country. Basic stats of biodiesel in Malaysia are given in Table 16.

7.7 Other countries

Other countries like China, The United States, Argentina, and Peru are also in line with the production and blending percentages. The biodiesel consumption in 2021 in the US, Argentina, and China was 9.44, 0.92, and 0.81 billion

Table 16: Brazil: Production, Supply and Demand Stats

Biodiesel (Million Litres)									
Calendar Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beginning Stocks	137	105	85	89	90	99	111	112	113
Production	2935	3430	4020	3801	4310	5410	5925	6500	6870
Imports	0	0	0	0	0	0	0	1	2
Exports	39	40	12	0	0	0	0	4	8
Consumption	2928	3410	4004	3800	4301	5398	5924	6496	6928
Ending Stocks	105	85	89	90	99	111	112	113	49
Feedstock Use (1,000 MT)									
Soybean Oil	1937	2300	2760	2615	2714	3406	3609	4159	4445
Animal Tallow	590	704	775	612	699	834	792	718	695
Used Cooking Oil	30	25	17	27	57	86	89	77	111
Palm Oil	0	0	0	0	32	66	112	155	158
Market Penetration (Million Litres)									
Biodiesel, on-road use	2125	2458	2927	2759	3122	3918	4300	4715	5029
Diesel Pool, on-road use	42518	43283	41813	39402	39759	40381	41593	41719	45087
Blend Rate (%)	5%	6%	7%	7%	8%	10%	10%	11%	11%

Source: USDA, 2022

litres, respectively.[22] The production resources are locally available in the majority of the countries, thus making them viable for optimum production.

The European Union currently is one of the largest producers of biodiesel from feedstock like rapeseed oil, palm oil, and UCO in the world with 32.3% share, followed by the US with 18.1% share from soybean oil and UCO, Indonesia with 15% from palm oil, Brazil with 12.2% with soybean oil and Argentina with 5% from soybean and others (Table 17).

Table 17: Biodiesel production share and a major feedstock

Country	Biodiesel production share in 2021	Major Feedstock
European Union	32.30%	Rapeseed oil, Palm oil and Used cooking oil
United States	18.10%	Soybean, Used cooking oil
Indonesia	15%	Palm oil
Brazil	12.20%	Soybean oil
Argentina	5%	Soybean oil
Thailand	3.80%	Palm oil
China	2.30%	Used cooking oil
Colombia	1.30%	Palm oil
Canada	0.70%	Canola oil, Soybean, Used cooking oil
India	0.50%	Used cooking oil, Palm stearin oil
Paraguay	0.30%	Jatropha
Australia	0.1% (for 2020)	Animal tallow, Used cooking oil

Note: *Percentages refer to the production share of countries in the base period, i.e., 2021*

Source: OECD/FAO (2021), "OECD-FAO Agricultural Outlook", OECD Agriculture statistics (database), http://dx.doi.org/10.1787/agr-outl-data-en.

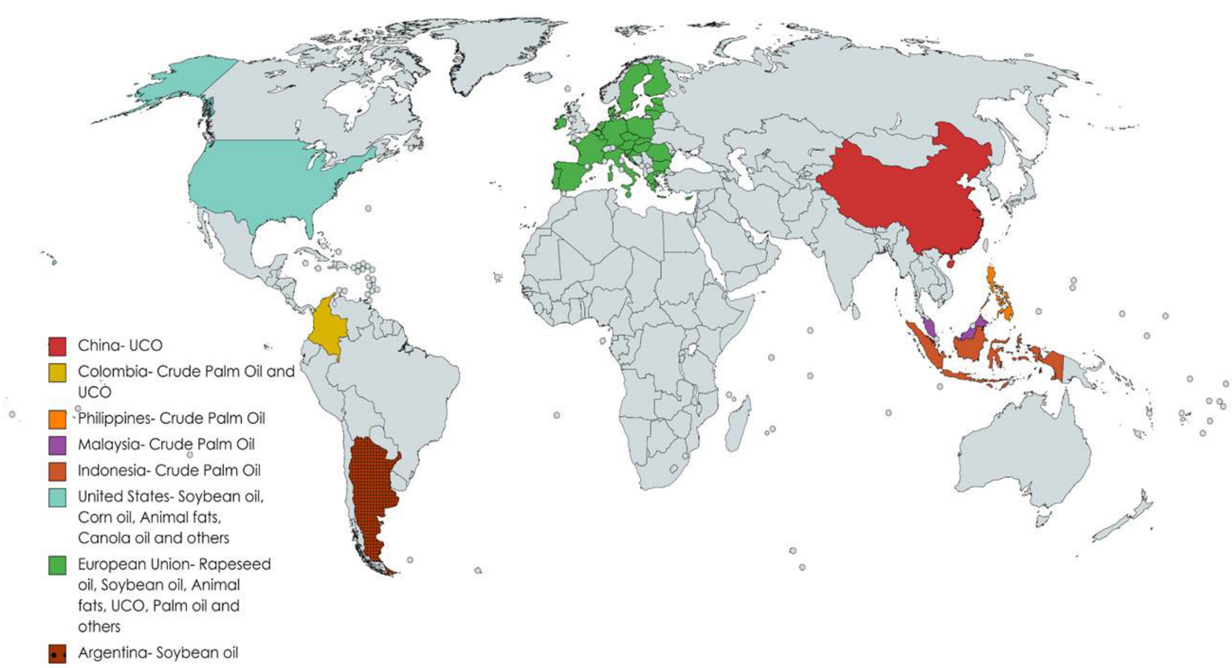


Figure 6: Countries with type-wise feedstock for biodiesel production

Map created with mapchart.net

Data Source: USDA Annual Biofuel Report

8. Biodiesel Market in India

After the US and China, India is the fastest-growing economy and the third-largest consumer of primary energy in the world. Until alternative fuels based on renewable feedstock are developed, India's fuel energy security will remain compromised. Under Nationally Determined Contribution (NDC), India aims to reduce its carbon footprint by 30-35% by 2030. To achieve these targets, five strategies will be implemented: increasing domestic production, utilizing biofuels and renewable energy, implementing energy efficiency norms, enhancing refinery processes, and substituting demand. As part of the Indian energy basket, biofuels are seen as having a strategic role to play. Several initiatives have been introduced to increase indigenous production of biofuels as part of the Indian government's aggressive plan of 20% ethanol in petrol by 2025-26 and 5% biodiesel in diesel by 2030.[23]

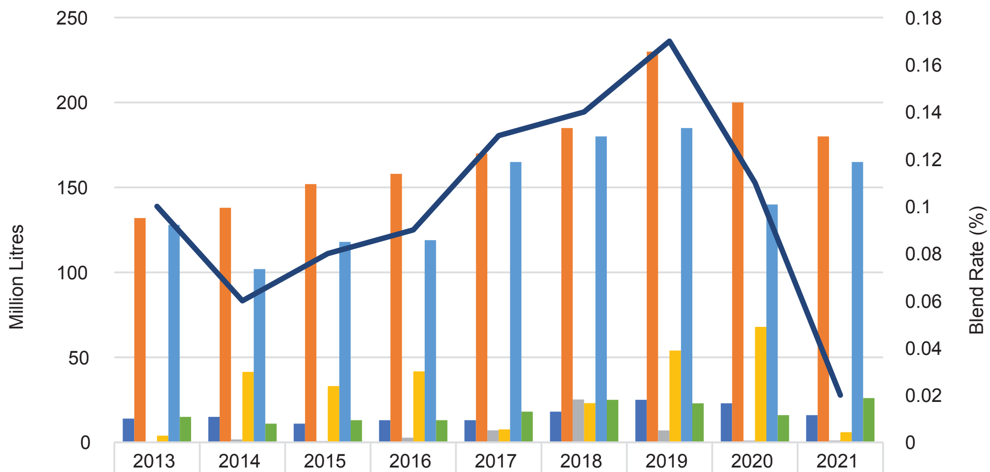
In India, the key drivers for sustainable and commercial production of biofuels are feedstock availability and production cost. The implementation of India's biofuel blending programme will be effective and fulfill if all stakeholders work together.

The country's national blending rate is estimated to be 0.071% in 2022.[24] Contributing factors include a surge in feedstock prices observed globally due to various supply restraints, the Russian-Ukraine conflicts, and energy prices. The COVID-19 pandemic and high operational costs have stressed the Indian biodiesel industry in the last couple of years. The country is still developing a consistent supply chain for UCO. The majority of biodiesel produced goes to informal sectors with limited support from India's oil marketing companies (OMCs) and demand continues to be inadequate. Furthermore, a lack of feedstock supplies has prohibited market development (USDA, 2022).

8.1 Production, supply, and consumption

India's annual biodiesel consumption experienced a healthy growth of 8% (CAGR) between 2013 to 2019. The biodiesel market in the country is still majorly informal and is dispersed and segregated, with limited domestic production. Due to high feedstock prices and anti-inflation measures, many countries operate at minimum B5 fuel level, and several run below B10 fuel level, like Brazil, Thailand, Argentina, and Malaysia, which leaves India's biodiesel market with considerable growth potential. Domestic suppliers produce biodiesel in very small numbers compared to the ethanol blending mandate. Most capacity is unused since there is a lack of suitable feedstock sources and government support mechanisms to create demand. The country's biodiesel stats from the past years are given in Figure 7.

India's biodiesel production lacks sufficient production and supply from OMCs to build commercial sales; hence, it is mostly consumed by locally dispersed groups to generate power. For decades in the country, field trials used jatropha, a few tree-borne oilseeds, and non-edible oilseeds grown on non-arable, rain-fed lands as multiple options for feedstock due to low yields have been of the concerning issues. However, the country experienced a surge in production due to various policy initiatives but lacks consistency. The blended rate is directly linked to the amount of production, which has been affected badly during the COVID-19 pandemic period. Figure 8 illustrates India's biodiesel production trend from different feedstock. Most of the share is through non-edible sources like jatropha, karanja, etc., backed by government policies. The share of edible oil has been limited due to food security reasons, but the share of UCO has been steady despite the RUCO initiative's launch by Food Safety and Standards Authority of India (FSSAI) in 2018. If the biodiesel sector is regularized and structured properly, animal tallow could also produce enough biodiesel to meet the demand.

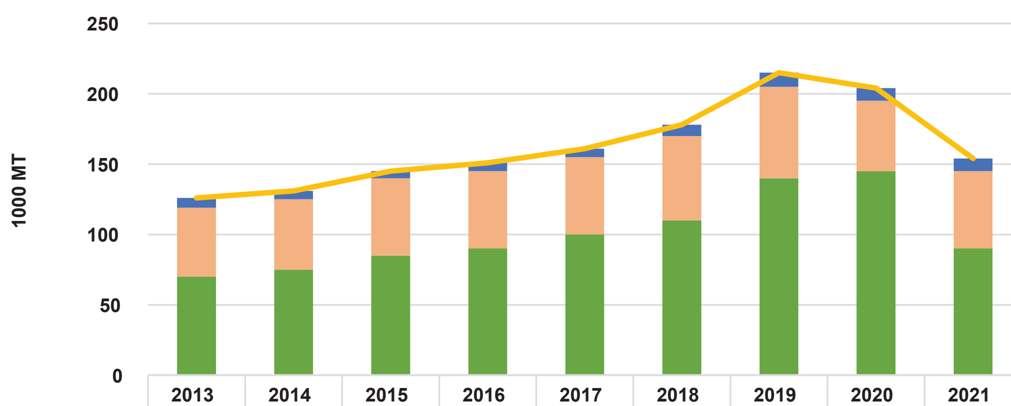


	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beginning Stocks	14	15	11	13	13	18	25	23	16
Production	132	138	152	158	170	185	230	200	180
Imports	0.3	1.7	0.8	2.7	7.1	25.2	7	1	1
Exports	3.9	41.5	33.1	41.7	7.6	23.1	54	68	6
Consumption	128	102	118	119	165	180	185	140	165
Ending Stocks	15	11	13	13	18	25	23	16	26
Blend Rate (%)	0.1	0.06	0.08	0.09	0.13	0.14	0.17	0.11	0.02

Beginning Stocks | Production | Imports | Exports | Consumption | Ending Stocks | Blend Rate (%)

Figure 7: India biodiesel stats

Source: USDA, 2022



	2013	2014	2015	2016	2017	2018	2019	2020	2021
Animal Fats & Tallow	7	6	5	6	6	8	10	9	9
Used Cooking Oil	49	50	55	55	55	60	65	50	55
Non-edible Industrial	70	75	85	90	100	110	140	145	90
Total	126	131	145	151	161	178	215	204	154

Non-edible Industrial | Used Cooking Oil | Animal Fats & Tallow | Total

Figure 8: India biodiesel production from multiple feedstock

Source: USDA, 2022

India has a huge on-road diesel consumption, which becomes crucial when its potential substitute is mentioned. The share and production of biodiesel are sparse when compared with conventional diesel. Table 18 illustrates the biodiesel market penetration in the country today, which clearly explains the need and urgency for proper and preplanned measures to achieve the B5 targets.

India has 1 billion litres of annual biodiesel production capacity. Still, due to the COVID-19 pandemic, most plants remained closed, and many ran out of production, limiting total operating capacity to 577 million litres. As a result of high feedstock prices, such as imported palm oil and palm stearin, as well as domestically available animal tallow, operating margins have declined. Current refineries have a production capacity between 11 million and 225 million

Table 18: India biodiesel market penetration (million litres)

Calendar Year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Biodiesel, on-road use	**49**	**32**	**41**	**48**	**72**	**83**	**100**	**50**	**10**
Diesel, on-road use	49,354	49,605	52,239	55,179	56,715	59,220	60,145	44,400	52,927
Blend Rate (%)	0.10	0.06	0.08	0.09	0.13	0.14	0.17	0.11	0.02
Diesel, total use	**82,256**	**82,674**	**87,064**	**91,965**	**94,524**	**98,700**	**100,241**	**74,000**	**76,270**

Source: USDA, 2022

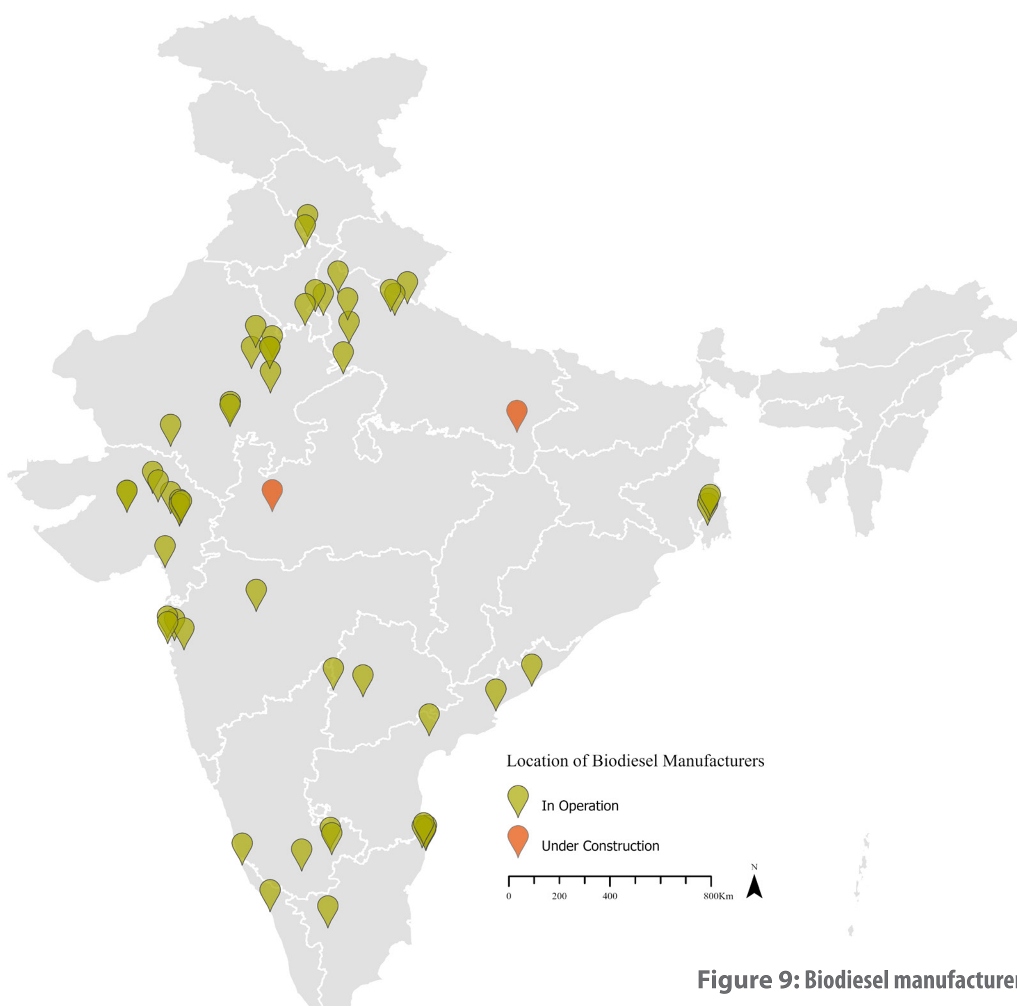


Figure 9: Biodiesel manufacturers in India

Source: BMAI

litres. There is no glycine refining, methanol recovery, or post-processing at smaller production facilities (USDA, 2022). There are 54 manufacturers, among which 52 are operational and 2 are under-construction biodiesel manufacturers in the country with locations, as shown in Figure 9. Most manufacturers are in the country's north, west and coastal region due to the availability of feedstock, land, and ease of transportation.

8.2 Import policies in India

It is necessary to obtain an import license to import biofuels into India. The license applies to pure biodiesel, biodiesel blends over 30%, petroleum oils containing up to 30% biodiesel, undenatured ethyl alcohol (strength by volume of 80% or more), and denatured ethyl alcohol (all strengths) (USDA, 2022).

Table 19: Biodiesel import duty (per cent ad valorem on CIF value)

Tariffs	Total Import duty
Biodiesel and mixtures thereof, not containing or containing less than 70% by weight of petroleum oils and oils obtained from bituminous minerals (greater than B30 to B100) [3826 0000]	24.32% (10% basic + 10% Social Welfare Surcharge (SWS) on basic customs duty plus 12% GST[25]
Petroleum oil and oils obtained from bituminous minerals (other than crude), containing by weight more than 70% or more of petroleum oils, contain biodiesel, other than waste oils (B1-B30), [2710 2000] *	30.98% (10% basic + 10%SWS on basic customs duty plus 18% GST

*Note: *For the sub-headings of 2710, the term "biodiesel" means mono-alkyl esters of fatty acids used as a fuel, derived from animal, vegetable or microbial fats and oils, whether or not used.*

Data source: www.cbic.gov.in (Updated as of May 2022), and (USDA, 2022).

9. Feedstock in India

9.1 Production and use

India is a very diverse country with immense potential for oil seeds and is one of the major oilseed-growing countries in the world. Oilseed production in India has steadily increased from 2016-17 onward and has shown a healthy surge of nearly 43% from 2015-16 to 2020-21 and produces around 36.5 million tonnes of total oilseeds in 2020-21 with a yield of 1.3 kg/ha.[26] Domestic oil production has, however, lagged behind its consumption necessitating the import of edible oils with the production of about 8 million tonnes and net imports of around 13.4 million tonnes during 2019-20.[27]

As per India's economic survey 2021-22[28], regarding vegetable oil consumption and imports, India is the world's second-largest consumer. There is a likelihood that dietary habits and traditional meal patterns will shift away from traditional foods that contain high levels of vegetable oil as urbanization increases in developing countries. Edible oil consumption is expected to remain high in the coming future. Indian vegetable oil consumption is projected to increase by 2.6% per year between 2021 and 2030, reaching 14 kg/capita by 2030, which will necessitate a 3.4% increase in imports. India imports nearly 60% of its total consumption of edible oils, and palm oils (Crude + Refined) constitute nearly 60% of the imports of edible oils.[29] Hence, to safeguard food security in the country, India should invest in other feedstock varieties like non-edible sources, etc.

There are over 350 oil-bearing plants available that can be used for producing biodiesel, among these are soybeans, palm, rapeseed, peanuts, and sunflowers (Chhetri & Islam, 2008) (Subramanian, Singhal, Saxena, & Singhal, 2005). There are, however, several non-edible oils that are more advantageous than edible oils, including Jatropha, Cottonseed, Mahua, Karanja, etc. (Altin, Cetinkay, & Yucesu, 2001) (Takase, et al., 2015).

Biodiesel production in the country is currently happening with non-edible oilseeds, UCO, animal tallow, acid oil, algal feedstock. etc. The majority share is through non-edible sources, followed by used cooking oils and animal tallows (refer to Figure 8).

However, palm stearin has been one of the country's most preferred sources for feedstock production for quite a long time due to its high yield, thus making it feasible for mass production without any upgradation needed in the production plants.[30] Currently, only 3.70 lakh hectares of palm oil is cultivated in the country. It produces 10 to 46 times more oil per hectare than other oilseed crops and yields around 4 tonnes per hectare. Given the fact that even today, nearly 98% of crude palm oil is being imported, which is a major problem.[31] India is one of the biggest importers of crude palm oil in the world, with an estimated import of about 6.3 million tonnes in the year 2021-22[32], which observed a reduction of 14.72% as compared to its previous year, 2020-21, due to various factors like COVID-19 pandemic and export constrains by Indonesia.

Table 20: Common feedstock and technology used for biodiesel production

Feedstock	Technology Used
Palm Stearin	Transesterification
Jatropha and Other Non-edible oils	Transesterification
Palm Fatty Acid Distillate (PFAD)	Multistage Acid Esterification/Enzymatic
Animal Oil/Waste Oil and Others (UCO)	Pre-treatment, Multistage Esterification-Transesterification-Glycerolysis
Animal Fat/Tallow	Pre-treatment, Multistage Esterification-Transesterification-Glycerolysis- finishing by Sulphur removal

Source: *BDAI and BMAI*

9.2 Potential and land availability

In India, National Policy on Biofuels, 2018 requires the growth of non-edible oil crops in wastelands, both in forests and non-forest areas (Agarwal, Prakash, & Bala, 2021). According to the Department of Land Resource, about 56 million hectares[33] of wasteland are available in India, which could be explored for feedstock cultivation in India depending upon their suitability. There are 23 categories listed in the Wasteland Atlas of India, 2019.[34] Oilseeds plantations can be set up on lands that meet certain criteria recommended by the Department of Land Resources under the Ministry of Rural Development are given below (Gunatilake, 2011):

- Annual rainfall should exceed 600 millimetres
- The pH of the soil should be less than 9
- The temperature should not fall below 0°C, and frost conditions should not prevail
- The slope of the land should not exceed 30°
- The land should not be waterlogged
- The land should not be barren or rocky

Based on these criteria, oilseed plantations could be established on four types of wastelands. According to this assessment, the total potential area available was estimated to be 26.46 million ha, and the distribution is shown in Figure 10. The term availability here only refers to physical availability. Still, there are many factors to consider when selecting land for biofuel plantations, such as climatic and soil conditions, access to infrastructure (such as roads and electricity), and ownership.

To meet the 5% blend target by 2030, the total land required for biodiesel production will depend on the amount of diesel consumed and its growth. The pandemic has hit the sector growth very hard, and diesel consumption during the year 2020-21 has fallen by almost 12% from the previous financial year, i.e., 2019-20[35]. According to the estimates based on previous trends, diesel consumption

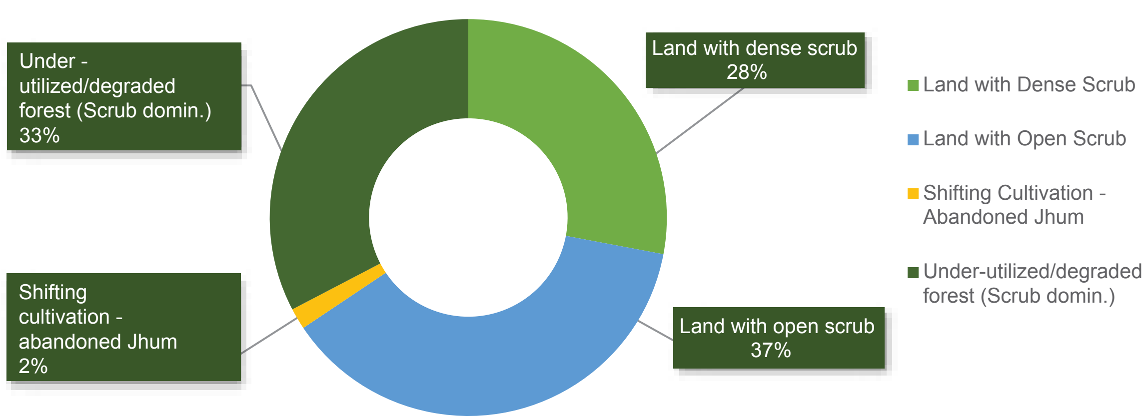


Figure 10: Categories of wasteland suitable for biodiesel plantation

**Note: The calculations exclude "Land affected by salinity/alkalinity", which constitutes about 1 hectare of suitable land, but has a pH over 9. However, this option could also be explored with some chemical or technological treatments.*

Source: Wasteland Atlas of India (2019), (Gunatilake, 2011) is expected to reach around 92.85 million tonnes by 2030[36] (Figure 11). The biodiesel requirement for the 5% blending target will be 4.64 million tonnes by 2030. Even though these estimates differ, we have used 4.64 million tonnes by 2030 as the most appropriate estimate for assessing the land requirements for feedstock production.

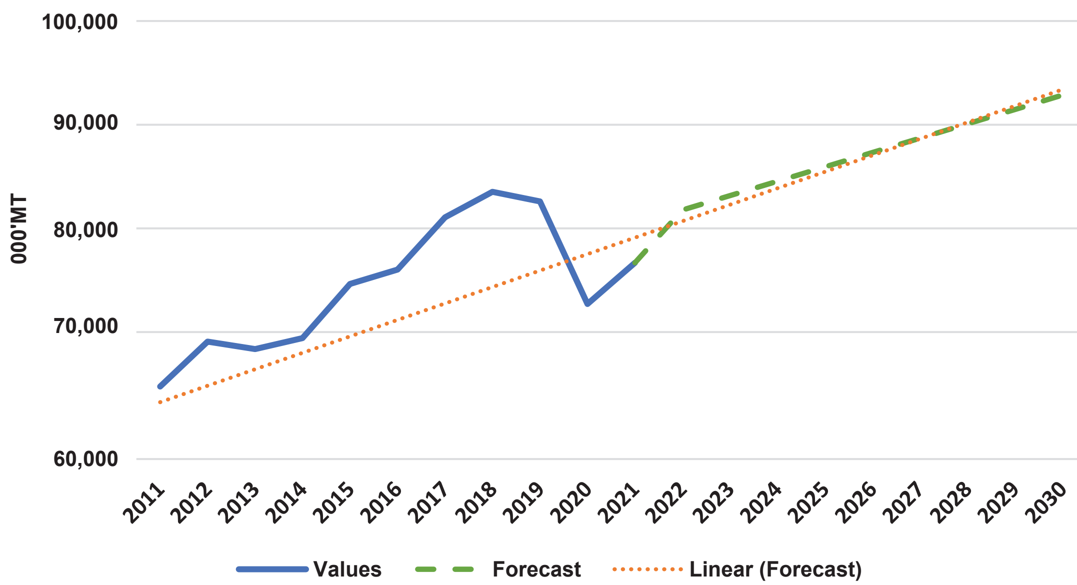


Figure 11: Diesel consumption predictions

Source: TERI's estimate based upon previous trends (BAU Scenario)

Total Wasteland Available	Recommended criteria for oilseed cultivation	Categories of wasteland suitable as per recommendation	Expected available land for cultivation
56 million hectares	1) Annual rainfall should exceed 600 millimetres 2) The pH of the soil should be less than 9 3) The temperature should not fall below 0°C and frost conditions should not prevail 4) The slope of land should not exceed 30° 5) The land should not be waterlogged 6) The land should not be barren or rocky	1) Land with dense scrub 2) Land with open scrub 3) Shifting cultivation - abandoned Jhum 4) Under-utilized/degraded forest (Scrub domin.) 5) Land affected by salinity/alkalinity	**Total**: 26.46 million hectares 1) Land with dense scrub- **9.96 Mha** 2) Land with open scrub- **7.40 Mha** 3) Shifting cultivation - abandoned Jhum- **0.46 Mha** 4) Under-utilized/degraded forest (Scrub domin.) - **8.64 Mha** 5) Land affected by salinity/alkalinity- **0.99 Mha**
Source: Wasteland Atlas of India, 2019	*Source: Government of India (GOI), 2007b. Integrated Analysis of Oil Seed Substitutes for Diesel in India. Ministry of Rural Development, and (Gunatilake, 2011)*	*Source: (Gunatilake, 2011), and TERI's calculations*	*Source: TERI's calculations*

Figure 12: Methodology followed for land availability calculations

9.3 Land requirement

There is no minimum land requirement for a plantation. The total land requirement is dependent on the productivity of the plantation, which is dependent on climate, planting material, irrigation water, fertilizer application practices, etc. (Gunatilake, 2011). On less fertile wasteland, with little rainfall, it is estimated that oilseeds can even yield about 1 tonne per hectare (Brittaine & Lutaladio, 2010). The oil content of the seeds is another factor that affects biodiesel yield. A conservative estimate of 1 tonne per hectare and 30% oil content can yield—thirty-two kilolitres per hectare of biodiesel (Gunatilake, 2011). According to the current understanding of the yield potential of the following mentioned (Table 21) oilseeds that the Indian government is widely promoting, it is reasonable to assume that about 7 million hectares would be required to meet the 5% blending target in the case of Jatropha, 4.7 million hectares in case of Karanja and Mahua plantation is required as well. This analysis concluded that improving agronomic practices and high-yielding varieties will be essential to reach the biodiesel target on the wasteland.

Biodiesel can also be produced on other types of unused land in the country besides wasteland. The National Policy on Biofuels, 2018 has identified other resources suitable for biodiesel production, such as UCO, animal tallow, acid oil, algal feedstock, etc. If all of this land and resources are used, and productivity increases through selection and breeding, the land requirement and feedstock commitment for 5% biodiesel blending can be met.

Table 21: Yields of non-edible oilseeds and land required

Name	Crop Yield (T/Ha)	Oil Content (%) (Avg.)	Land required to achieve B5 till 2030 (Million Hectares)
Jatropha	2	35	7
Karanja	3	35	4.7
Mahua	2.7	38	4.7

**Note: Calculations are based upon the closest self-estimates based upon previous estimates and stakeholder conversations.*

Source: TERI's calculation based upon: (Patel & Sankhavara, 2016), (Aransiola, Ehinmitola, Adebimpe, Shittu, & Solomon, 2019)

10. Conclusion

A challenge that is now being faced by almost all developing nations is how to meet relatively increasing energy demand and sustain economic growth while keeping GHG emissions low. The World energy market continues to count heavily on fossil fuels, and India is not far behind. India is highly dependent upon imports to fulfil its oil needs. However, there is a very good potential for building its biofuel resources, especially biodiesel, which could be a good source for blending with conventional diesel that contributes about 87% of total transport fuel demand. India imports more than 80% of crude oil to meet the annual demand, draining its forex reserves. The crude oil production in India only meets 25% of the national demand, and blending biofuel into transportation fuel enables India to reduce its dependence on foreign oil imports (Ganguli, Abhishek, Motkuri, & Bloyd, 2018).

Biodiesel is not a new concept in India; it has been in discussions for over two decades. Using edible oil to produce biodiesel is not feasible for India, unlike others; India is highly dependent upon edible oilseed imports to meet its domestic demand. Using that imported raw material to produce biodiesel and compromising its food needs is not feasible. The journey of biodiesel mandates and policies in India started in the early 2000s when the Government had set the Biodiesel Mission and had a challenging target of blending 20% biodiesel in conventional diesel by 2017. Still, unfortunately, because of the limited feedstock supply, lack of infrastructure and other challenges, the blending did not even start before 2015.

According to estimates, on-road diesel market penetration for biodiesel remains low at 0.07%. Several factors contribute to the current high feedstock prices, including supply constraints and high energy costs. The Russian-Ukraine conflict has further aggravated the situation. The country's biodiesel industry is still struggling to overcome plant closures due to the COVID-19 pandemic and high operational costs.

10.1 Feedstock options

Manufacturers use non-edible industrial oil, palm stearin, UCO, animal fat, tallow, and other oils as feedstock to produce biodiesel, utilizing about 32% of the total installed capacity. Many functional producers utilized palm acid oil in 2021 due to the bull run in palm oil and a limited supply of animal tallow (USDA, 2022). Due to the operational impacts posed by high palm growth cycles, only a few biodiesel plants operate during the winter months. The sector does not have proper regulations apart from UCO for supplying available feedstock for biodiesel production. Figure 13 illustrates the difference in the nameplate

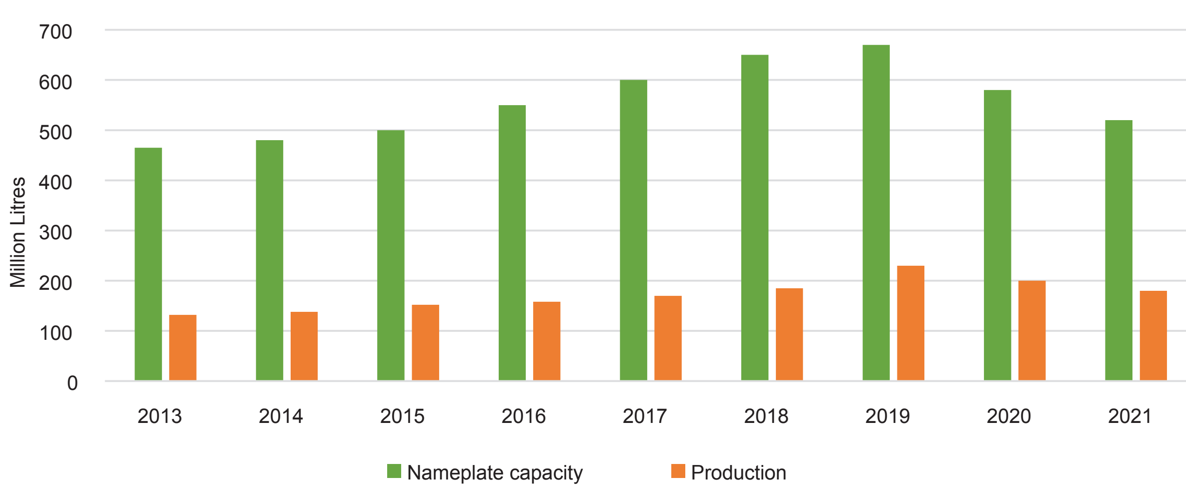


Figure 13: Nameplate capacity vs actual production of biodiesel

**Note: The nameplate capacity is the volume of biodiesel that can be produced during a period of 12 months under normal operating conditions.*

Source: (USDA, 2022) and Statista

capacity with the actual biodiesel production in India for the past few years, which indicates the underperformance of the sector due to different reasons.

The low yield of Jatropha and other inedible oilseeds makes its cultivation economically feasible on non-arable lands, India's biodiesel industry is in its infancy, and there is a lack of virgin (first-use) animal fat or vegetable oils available for biodiesel production. This translates into volatility in vegetable oil prices for the biodiesel manufacturers. Supply chain and shipment issues continue to affect the industry this year (USDA, 2022).

10.1.1 Edible sources

Using vegetable oil sources for biodiesel production will hurdle the country's food security. It will result in food vs fuel debates because palm stearin is one of the most common feedstocks used for biodiesel production, which is imported from Indonesia and other countries. Limiting non-edible domestic sources for production will result in removing dependency on foreign exchange and increasing domestic production, eventually leading to a better blend rate.

10.1.2 Non-edible sources

The non-edible source is one of the country's most promising sources of biodiesel production. In response to rapid population growth, urbanization, and industrialization, food production has been impacted by decreased land availability. Proper land distribution is required for agriculture, urbanization, commercial application, and forest reserve distribution. It will burden the land area for food production if edible oil crops are used as feedstock for biodiesel production. However, non-edible crops can be grown in non-fertile land like saline, sandy soil, and even on wastelands that are unsuitable for crop production. India has a major chunk of land that will require crop cultivation to meet B5 till 2030. The major challenge rests with the gestation period of the selected crops.

National Policy on Biofuels, 2018 also promotes using non-edible sources like Jatropha, Karanja, Mahua, etc., because of their growth potential, wasteland availability, yield, etc. The following crops could be explored as feedstock for biodiesel production (Table 22).

Table 22*: Annual production and oil yield of potential non-edible oil crops*

Non-edible oil crops	Scientific name	Major crop	Yield (kg per ha per year)	Oil content (wt. %)
Jatropha	*Jatropha curcas*	Seed	2500	40–60
Mahua	*Madhuca longifolia*	Seed	20–200 (per tree)	35–50
Candlenut	*Aleurites moluccanus*	Seed	16,000	60–65
Rubber	*Hevea brasiliensis*	Seed	100–150	40–50
Soapnut	*Sapindus mukorossi*	Seed	—	23–30
Jojoba	*Simmondsia chinensis*	Seed	500–5000	40–50
Tobacco	*Nicotiana tabacum*	Seed	1170	35–49
Neem	*Azadirachta indica*	Seed	2670	25–45
Karanja	*Millettia pinnata*	Seed	900–9000	30–50
Castor	*Ricinus communis*	Seed	450	45–50
Polanga	*Calophyllum inophyllum* L.	Seed	3700	65–75
Cotton	*Gossypium*	Seed	649	17–23
Kusum	*Carthamus tinctorius*	Seed	—	51–62
Yellow oleander	*Cascabela thevetia*	Seed	52000	60–65
Sea mango	*Cerbera odollam*	Seed	1900–2500	40–50
Tung	*Vernicia fordii*	Seed	450–600	30–40
Bottle tree	*Brachychiton rupestris*	Seed	250–300	50–60

***Source**: Shaah, et al., 2021*

Major challenges and barriers with the non-edible source are its current unavailability, proper cultivation, regularization, high polyunsaturated fatty acids, low unsaturated fatty acids content in oil, etc. However, this could be taken care of with technological advancements.

10.1.3 Used cooking oil, acid oil, and animal tallow

High-potential second-generation feedstock for biodiesel production uses cooking oil, acid oil, and animal tallow. A high conversion and yield percentage from raw material to biodiesel, cheap rates, and availability are some positives for these two feedstocks. The major barriers include the poor collection mechanism, disrupted supply-chain network, proper regulation mechanism, etc.

Used cooking oil has been a potential feedstock in India because of its availability and high procurement. According to the MoP&NG, India uses approximately 27 billion litres of cooking oil annually, of which about 1.4 billion litres of used oil could be collected from bulk users like restaurants, railways, etc., to generate about 1.1 billion litres of biodiesel.[37] Though the potential is very high, logistic issues in the collection and supply of feedstock, lack of adequate regulations and implementation, and other issues make achieving the target difficult. The COVID-19 pandemic has hit this industry very hard; the availability of used cooking oils was almost negligible during the pandemic from bulk users. However, post-pandemic period, it is expected to show some healthy growth.

FSSAI estimated that the country generates around 2.7 million tonnes of UCO annually, about 60% of which re-enters the food chain, posing a serious threat to people's health.[38] To make this used oil industry regularized and prevent UCO from re-entering the food chain, FSSAI took the initiative to form RUCO (Repurposed UCO) Initiative, which also has several biodiesel manufacturers registered with them to facilitate the flow of UCO from the industry to the manufacturers. However, the industry is still struggling with seamless collection and supply chain management because of a lack of aggregators in tier 2 and tier 3 cities, smaller private collectors, diversion to the soap industries, etc.[39]

Some oil is rejected as part of the refinement process, known as "Acid Oil". The amount of acid oil produced is approximately 5-7% of refined cooking oil, containing approximately 5-10% free fatty acids. Acid oil is one of the potential sources identified by the MoP&NG in the National Policy on Biofuels, 2018. However, this sector is still in the initial stage and requires a deep dive compared to other potential sources.

Animal tallow is yet another potential feedstock available in India for biodiesel production. India generated about 80,000 tonnes of animal tallow last year, which could fulfil the maximum need for the country's biodiesel.[40] However, exporting animal tallow to European countries makes it difficult for manufacturers to produce biodiesel at a similar rate. The unorganized tallow industry makes it much more difficult. The scope of animal tallow is higher in north India, but with a limited supplier, it becomes much more difficult to regularize this sector.

10.2 Pricing of biodiesel

The pricing of biodiesel has become one of the most debatable topics. The pricing depends upon several factors, such as feedstock availability, feedstock type, feedstock prices, cost of operations, transportation cost, handling and storage costs, etc. The major components of the biodiesel price are the feedstock prices and the cost of collection and transportation in case of UCO. The high cost of biodiesel, when compared to conventional diesel, is the main barrier to its commercialization on a large scale.

Various factors contribute to variations in feedstock cost, such as geography, crop yields, and the season. Fertilizers, herbicides, and insecticides contribute to the difference in plantation costs. A good irrigation system and high soil nutrients are generally needed for edible oil crops, resulting in higher plantation costs. Despite its high plantation cost per hectare, palm oil is extremely economically competitive due to its high oil yield, but its availability in India is the major barrier. Non-edible oils, on the other hand, have a lower cost than edible oils. UCO and animal tallow is so far an ideal option, but the unorganized sector makes its collection a major challenge.

The recent tender by the OMCs in India has given biodiesel a flat rate of INR 106.86/litre, exclusive of transportation costs and taxes. The details are as mentioned below[41]:

a) **Basic Rate of Biodiesel:** INR 106,860 per kilolitre

b) **Transportation Slab would be:**

Distance Slab in km (One-way)	Transportation Rate (INR/ kilolitre)
0 to 75	168
>75 to 200	391
>200 to 400	833
>400 to 600	1394
>600 to 800	1956
>800 to 1000	2751
>1000 to 1200	3596
>1200	3596+2.72 for additional km beyond 1200 km

c) **Goods and Service Tax (GST) in %:** GST @5% applies to HSN code 3826 for biodiesel.

d) The delivered cost will be a total of the basic rate for biodiesel, transportation rates, and GST as applicable.

Keeping the current rate as the base year and considering the average WPI rate for the last five years to be 6%, under the BAU scenario, the biodiesel prices are expected to rise to **INR170/litre**[42] (Figure 14), which would have a negative economic and social implication. India must develop a reliable feedstock supply and infrastructure for storage and delivery to ensure financial sustainability in its domestic industry and biodiesel prices.

However, this price increase will also directly be correlated to inflation, higher fuel costs, foreign currency differences, rise in prices of raw materials and other derivative products. Hence, the price of INR 170 per litre will be at about par with future prices of other goods (as shown in Figure 14).

10.3 Land requirement

The National Policy on Biofuels, 2018, promotes the cultivation of non-edible oilseed crops, such as Mahua, Karanja, and *Jatropha curcas*, for biodiesel production only on unused degraded land. Plantation productivity and other plantation management practices, such as irrigation water and fertilizer application, determine the total land required for a plantation. As oilseeds can be grown on dry wastelands, oilseed plantations do not need much irrigation. Assuming that trees and the environment in which they usually grow are similar, it can be said that biodiesel crops do not contribute significantly

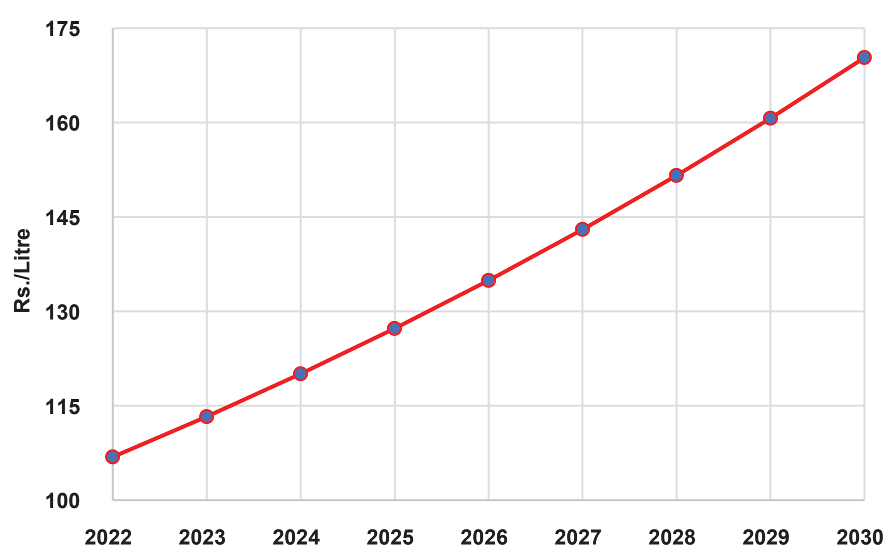


Figure 14: Biodiesel price estimates

Source: TERI's estimate based upon past and current trends in a BAU scenario at 6% WPI rates (last five years average) to irrigation water consumption in India (Mishra, Patnaik, Akbari, Kumar, & Patro, 2013).

The land requirement for biodiesel for blending purposes depends on fossil fuel consumption and their progressions. Following the linear BAU trend rate of diesel consumption growth in the past decade, India will consume about 92.85 million tonnes of the same by 2030. A 5% blending requirement implies the need for 4.64 million tonnes of biodiesel annually. Therefore, the question arises about whether enough land is available within the country to meet the B5 target. Out of the total 56 million hectares[43] of wasteland available in India, which could be explored for feedstock cultivation depending upon their suitability amongst which, the total potential area available was estimated to be 26.46 million ha[44] depending upon various factors mentioned in Potential and Land availability section (9.2).

With regard to the land requirement for cultivating major crops like jatropha, karanja, and mahua, the land requirement to achieve estimated B5 blending is estimated as (100% capacity each)[45]:

Jatropha- 7 million hectares

Karanja- 4 million hectares

Mahua- 4 million hectares

States like Chhattisgarh, Jharkhand, Bihar, Uttar Pradesh, and Rajasthan are among the favourites to host these cultivation programmes because of the availability of land, resources, and local support. The tribal population living in states like Chhattisgarh and Jharkhand could be a very optimum source for feedstock cultivation. Also, the local population will have better income from their lands and at the same time the industry production gets the domestically available feedstock at the lower prices for further processing.

"India should commence feedstock cultivation on wastelands"

-Biodiesel Manufacturers Association of India

10.4 Engine modifications for biodiesel use

A biodiesel engine does not require major modifications. It is not a technical challenge to run a vehicle's existing engine on biodiesel, rather, it is a matter of producing biodiesel that meets the engine specifications.[46]

"BS-VI norms aim to reduce fuel sulphur to negligible levels, which lead to issues related to fuel system lubricity. 2% biodiesel blending would address this issue. This will help India introduce biodiesel across the board, without engine hardware modification and help solve problems such as foreign exchange expenditure on petroleum imports, and boost the biodiesel industry. In future, higher biodiesel blending targets can be set, depending on availability"

-Prof. (Dr) Avinash K Agarwal, IIT Kanpur

11. Recommendations/Key Suggestions

Biodiesel is a potential fuel, especially for the transportation sector, as diesel dominates the road transport sector in the country. Using biodiesel will not only result in decreasing the emission levels from this sector but will also have a huge impact on foreign exchange and crude imports. Based upon our observations, finding, and most importantly, interactions and feedback from the concerned stakeholders from different domains like industry, academia, civil society organizations, etc., various recommendations have been proposed to facilitate an increase in biodiesel production in the country; they are:

11.1 Identification of domestically available potential feedstock

Despite having numerous feedstock options, identifying the best-suited potential source for biodiesel production is challenging. With so much diversity, India has a great potential to use different kinds of feedstock that are domestically produced. Countries like Indonesia, Malaysia, the US, etc., are currently the world leaders in biodiesel production, the major reason being utilizing locally available feedstock for production, enabling them to increase production as required. Likewise, India needs to invest in domestically grown feedstock varieties like UCO, animal tallow, and non-edible sources like jatropha, Karanja, etc.

11.2 Rising cost of feedstock needs to be controlled

The cost of feedstock used in the production of biodiesel is the major component of the final price. As discussed in the paper, feedstock costs depend on numerous factors, but, at the same time, domestic feedstock can reduce costs and eventually positively impact biodiesel prices. As India relies heavily on imported feedstock like palm oils, which come with high import duties and fluctuating prices, high production costs are associated with them.

Additionally, animal tallow is one of the potential domestically produced feedstocks. It is produced sufficiently to meet the country's basic needs. Nevertheless, since it is in high demand and offers a better price on the international market, it is being exported to major countries (like Afghanistan, Malaysia, Pakistan, UAE, etc.), thereby creating a shortage of raw materials for biodiesel production within the country and thereby creating a high demand, which ultimately translates into high prices.[47] This needs to be addressed and requires guidelines in place.

11.3 Involving locals' supports for optimum production: the role of manufacturers

As per TERI's estimates and wasteland Atlas of India's numbers, plenty of wastelands are available for feedstock cultivation in the country. However, a major portion of these lands is already occupied by local villagers and tribal populations unwilling to provide those lands and their support. Hence, for optimum land utilization and to increase feedstock production, the involvement of these locals becomes crucial.

Initially, one can sign a deal with the locals where the land ownership will remain with the locals only. Still, producers/manufacturers will use the land for crop cultivation and remunerate the locals/farmers for taking care of the crops and providing them employment opportunities.

Making them a part of the process by providing employment will not only enhance productivity but will facilitate many benefits like the security of land and crops, better yield capacities, etc.

Apart from this, a robust study of the supply-chain is imperative – from the collection of raw materials to the final product.

11.4 Role of government and other concerned organizations

When setting regulations and implementing them, the government and its arm play a crucial role. Biodiesel production needs a special point of interest for each case. In some states like Rajasthan, Uttar Pradesh, Karnataka, etc., a biofuel department looks after the sector at the state level. Despite this, there are few areas that needs a closer attention that will enable the optimum use of the resources. The lessons learned from these states could be applied to all states and UTs in the country to facilitate increased biodiesel production.

It might be possible to enhance biodiesel production by introducing a **National Feedstock Programme (NFP)** or a **Production Linked Incentives (PLI)** scheme to facilitate optimal production, regularization, and feedstock utilization.

For UCO and animal tallow, it is imperative to implement proper supply-chain management guidelines to prevent and minimize loopholes and improve collection mechanisms. The FSSAI's RUCO guidelines must be mandated with minor updates per current criteria, keeping soap manufacturers' uses in mind. Aggregators in tier 2 and tier 3 cities need to be explored to collect used oil from different sources to ensure optimal use and collection of UCO and introduce technological enhancements like tracking to enable traceability across the supply chain.

11.5 Utilizing by-products generated from biodiesel production to off-setting biodiesel price

Another important aspect of generating money out of by-products like methanol, glycerol, and seed waste, which are left as waste after the conversion of raw material to biodiesel converting them into useful products and generating money out of them. Glycerin is the major by-product generated, which is of the largest interest because it acts as revenue for manufacturers by selling it to major industries like food, pharmaceuticals, etc. Still, seed waste could also be used for agricultural purposes, such as manure.

11.6 Biodiesel- setting attainable goals

Despite having numerous advantages over conventional diesel, the biodiesel industry is still struggling in the country because of various reasons and challenges like availability and high feedstock pricing, operational hurdles, supply-chain management challenges, etc., as discussed in this paper.

Therefore, adopting a baby-step approach and setting attainable short-term goals will be a building block for the goal of B5 by 2030. For instance, keeping in mind the current 0.02% blending rate and based upon the inputs from various stakeholders, it is recommended that India should target 2% blending by the next couple of years (2024), and in the future, higher biodiesel blending targets can be set, depending on availability of feedstock.

11.7 Short-term and long-term solutions

During the study, several stakeholders provided their input regarding biodiesel blending. One of the major and common inputs was that biodiesel from FAME (Fatty Acid Methyl Ester) should be seen as a short-term solution, understanding its challenges and barriers.

In addition to this, a few major recommendations are as follows:

- Revising the excise duty from INR 2/litre for unblended fuel to a higher suitable value to enable a faster blending process in the country.
- Revisiting the export decision of UCO and animal tallow and finding a middle path for the sake of country's "Make in India" and "Vocal for Local" initiatives and B5 targets.

As potential long-term solution, synthetics such as methanol to dimethyl ethers blended with diesel or a green diesel are recommended. Green diesel is made from the same feedstock as biodiesel (primarily animal fats and vegetable oils), but the production process differs considerably. Moreover, green diesel has the same chemical properties as regular diesel, so no engine modifications are necessary (nor is it necessary to change the existing infrastructure to distribute petroleum-based diesel (Morone & Cottoni, 2016).

12. Ending Note

India has a fairly good advantage because of the diversity of feedstock options available, but the same advantage may sometimes act against. The problem with choosing the best suited feedstock is the lack of clarity as to what is the most suitable available option depending upon the method and location of production. Moreover, with such diverse geographic and climatic conditions, the country can rely on few specific feedstocks. As different technologies are used to produce biodiesel from different feedstock, their composition and physicochemical properties may vary significantly.

Therefore, there is a need for comprehensive research on how to account for such modification, for optimum blending and usage. Technological advancements are also required for usage of biodiesel (blended or neat) in different climatic conditions within the country; especially in areas with extreme winters and snow.

Annexure 1

Table 23: List of biodiesel manufacturers

S.N.	Name & Address	Plant Capacity		In Operation/ Under Construction
		TPD	KLPD	
1	RN Fuels India Pvt. Ltd., 40th KM Milestone, Mathura Road, Jharsaintly Village, Ballabgarh, Faridabad, Haryana – 121004	20.00	23.16	In Operation
2	Rajputana Biodiesel Pvt. Ltd., G-24, RIICO Industrial Area, Phulera, Jaipur, Rajasthan – 303338	25.00	28.95	In Operation
3	Plentifuel Industries Pvt. Ltd., 1002-B, Coral Place, Nr. Nakshtra Embassy, Palanpur Gam Road, Palanpur, Surat, Gujarat – 395005	86.37	100.00	In Operation
4	Bengal Biodiesel, Andharmanik, Bishnupur, South 24 Parganas, West Bengal – 743503	20.00	23.16	In Operation
5	Make India Biofuel Energy, Plot No. 58, Banke Bihari Industrial Area, Village-Dehra, Tehsil-Chomu, Jaipur, Rajasthan – 303806	43.19	50.00	In Operation
6	M11 Industries Pvt. Ltd., 389, M.B. Road, Kaveri Layout, Srirangapatra , Mandya, Karnataka – 571438	500.00	578.90	In Operation
7	Muenzer Bharat Pvt. Ltd., Plot No. D-177 A, MIDC, TTC Industrial Area, Nerul, Navi Mumbai, Maharashtra – 400706	10.00	11.58	In Operation
8	Adnoc Chem Pvt. Ltd., Kadwali Bujurg, Faraspur, Sanwer, Indore, Madhya Pradesh – 453771	25.91	30.00	Under Construction
9	Puredrop Biofuels Pvt. Ltd., Plot No.-04, 05, (Survey No. 252), Kamla Amrut Industrial Estate, Mehsana, Gujarat – 382715	86.37	100.00	In Operation
10	Vajrakaya Green Power Pvt. Ltd., B-38/3-A-3-G Shop No.5, Mehmoorganj, Varanasi, Uttar Pradesh – 221010	40.00	46.31	Under Construction
11	NSR Industries, 50-42-8/1, P&T Colony, Road No.8, Near Gurudwara, Seethammadhara, Visakhapatnam, Andhra Pradesh – 530013	17.27	20.00	In Operation
12	E Shakti Binary Currents Pvt. Ltd., W-79, Chikalthana, MIDC, Aurangabad, Maharashtra – 4312190	15.00	17.37	In Operation
13	Viaan Agritech Pvt. Ltd., Old No. 42, New No. 34, Bashyakarlu Street, Kondithopu, Chennai, Tamil Nadu – 600079	50.00	57.89	Under Construction
14	BioD Energy (India) Pvt. Ltd., Plot No. 2-5, Sector-9, IMT Bawal, Rewari, Haryana – 123501	100.00	115.78	In Operation
15	Eco Green Fuels Pvt. Ltd., E-4, 9B, KIADB Road, 2nd Phase, Peenya Industrial Area, Bengaluru, Karnataka – 560058	20.00	23.16	In Operation
16	Monopoly Innovations Pvt. Ltd., 42-45 Emerald Industrial Estate Dheku, Taluka Khalapur , Raigad, Maharashtra – 410203	100.00	115.78	In Operation
17	Kaleesuwari Refinery and Industry Pvt. Ltd., Phase-III, Industrial Park, Vakalapudi, Kakinada Rural, Kakinada, Andhra Pradesh – 533 005	300.00	347.34	In Operation
18	BR Bio Diesel Private Limited., 564, Perecherla (V), Medikonduru(m), Guntur District, Andhra Pradesh –522006			In Operation

S.N.	Name & Address	Plant Capacity		In Operation/ Under Construction
19	Pyrene Industries., No. 16, Doddakalasandra, Karnakapura Road, Bangalore, Karnataka – 560062			In Operation
20	Agarwal Green Energy Pvt. Ltd., F-309,310,311 Industrial Area Growth Center Ext., Dholpur, Rajasthan			In Operation
21	Yantra Fintech (India) Limited, Survey No 2/3B, 3/1 & 3/2 Naduvakkaral Village, Pattaralkalani Post, Thirukazhukundram Taluk, Kancheepuram Distt, Tamil Nadu – 603109	50.00	57.89	In Operation
22	Dhanalakshmi Chemical Industries Limited/ Pan Oleo Energy Ltd., 1/261, Ponnai Road, Mukundarayapuram, Walajah Taluk, Ranipet District, Tamil Nadu – 632405			In Operation
23	Geekay Bio Products, 610/1, Therpathai, Gethelrev Village, Dharapuram Taluk, Tiruppur Distt., Tamil Nadu – 638107			In Operation
24	K. Nandini Refineries, 6/1, Vill. - Hetamdandi, Amaria, Teh. & Distt. – Pilibhit, Uttar Pradesh – 262121	12.00	10.00	In Operation
25	R.R.S.P Marketing Pvt. Ltd., A-15, Industrial Estate, Hathras, Uttar Pradesh – 204101			In Operation
26	Krishna General Engineering Works, 1/1 Industrial Estate, C B Ganj, Bareilly, Uttar Pradesh – 243502	10.00	11.00	In Operation
27	Sunshine Industries, Ground Floor, Brahmanand Chambers, Opp. Arts College, Surendranagar, Gujarat – 363001	50.00	54.00	In Operation
28	Surya Enviro, Plot No. 22-C, Industrial Area, Lodhimajra, Baddi, District - Solan, Himachal Pradesh – 174102			In Operation
29	Universal Biofuels, Diamond House, Flat No. 202, Door No. 6-3-663/E, Punjagutta, Hyderabad – 500082, Telangana	300.00	347.34	In Operation
30	Vishwa Khanij, R-5, Hare Ram Complex, Nizampura Vadodara, Gujarat – 390024			In Operation
31	Devilal Kutir Soap, Pragati Path, Near Hotel Samrat Chottor Road, Washwell Bhilwara, Rajasthan – 311001	30.00	34.73	In Operation
32	Edizel Biofuels, Karmvir Towers, Kapadwand Road, Nadiad Kheda, Gujarat – 387001			In Operation
33	Khanda Biofuels, Survey No. 101/39/A1&A2, Hothi B, Village Zaheerabad, Medak, Telangana – 502220	30.00	34.73	In Operation
34	Bhooma Energy Ventures Pvt. Ltd., 11 Dheeraj, New Juhu Versova Link Road, D.N. Nagar, Andheri (West), Mumbai, Maharashtra – 400058	30.00	30.00	In Operation
35	DD Shah Petrochem, 10-D, Rajhansh Society, Near St. Xavier's Corner Commerce College Road, Ellisbridge, Ahmedabad, Gujarat – 380006			In Operation
36	Emami Agrotech Ltd., 687, Anandapur E.M. Bypass Kolkata, West Bengal – 700107	300.00	347.34	In Operation
37	Jai Industries, 44, Mahaveer Nagar, Ranjke Vale Baba Ki Gali Tonk, Rajasthan – 304001	17.00	20.00	In Operation
38	Jay Petrochem Industries, Plot No. 67/68, Phase No. 1, GIDC, Wadavan Surendranagar, Gujarat – 363001			In Operation
39	JBG Biofuels Pvt. Ltd., 205-206, Vinayak Residency, Sanganer Road Bhilwara, Rajasthan – 311001			In Operation
40	Kissan Envirocare India Pvt. Ltd. E-44/D1, Khushkhera Rajasthan – 301707			In Operation

S.N.	Name & Address	Plant Capacity		In Operation/ Under Construction
41	Kotyark Industries Pvt. Ltd., F-86 to F-90, RIICO Industrial Area, Swaroopganj Sirohi, Rajasthan – 307026	500.00	578.90	In Operation
42	Mileage Biodiesels, Gudhagourji, Udaipurwati, Jhunjhunu, Sikar, Rajasthan – 332713		20.00	In Operation
43	Shri Parth Petrochem, Survery No. 146/147, Anjesar, Tundav, Savli Vadodara, Gujarat – 391775	20.00	40.00	In Operation
44	Vinayak Biofuels, E-002, Pearl Green Acre, Shri Gopal Nagar, Gopal Pura Bypass, Kishangarh Jaipur, Rajasthan – 302019			In Operation
45	Yamuna Bioenergy Pvt. Ltd., G. F. 11, Divyajyot Complex, Ramakaka Temple Road, Chhani , Vadodara, Gujarat – 391740	100.00	115.78	In Operation
46	Chemenergy Biofuel Pvt. Ltd., Plot No. 35, Khurja-Pahasu-Chhatari Road, Tehsil Shikarpur, Distt. Bulandshahr, Uttar Pradesh – 203395			In Operation
47	DV Chemicals, B-81 A , Growth Centre , RIICO Industrial Area , Ondela Road, Dholpur, Dhaulpur, Rajasthan –328001		30.00	In Operation
48	Nirvaanraj Energy Private Ltd., Khasra no 129, Village Uldeypur , Tehsil Meerut, Distt Meerut, Meerut –250001, Uttar Pradesh	30.00	30.00	In Operation
49	Erigo Bio Fuels Private Limited, Pearl Kannur, Ananthapuram Industrial Area, VIA, Kasaragod, Kerala –671321			In Operation
50	K. Nandi Refinery Pvt. Ltd., Village - Nagariya Bhagati Paiga Nagri, Tehsil - Meerganj, Distt. Bareilly, Uttar Pradesh			In Operation
51	SS Biodiesel Pvt. Ltd., Door 17B, S/F No. 165/2A.1B, Murusamy Street, Athipet, Chennai – 600058, Tamil Nadu			In Operation
52	Life Biodiesel LLP, 5/1498G, Pent House, Opposite Malayala Manorama, Kozhikode, Kerala – 673001			In Operation
53	Nextgen Biofuels, D.N. 4-383/14, Opp Kalpatharuvu Spinning Mill, Thimmapuram Village, Guntur, Andhra Pradesh			In Operation
54	Vzen Industries Pvt. Ltd., 502, PS Aviator, Chinar Park Crossing, , Arghora, New Town, Kolkata – 700136, West Bengal	20.00	23.50	In Operation
55	Fame Biofuels Private Limited, Plot No. 327-328, Manjusar GIDC, Manjusar, Savli, Vadodara – 391775, Gujarat			In Operation
56	Kshumat Energy Private Limited, A Wing Ground Floor, Shop No. 2, Keddy Acrade, Nagpada, Mumbai Central, Mumbai – 400008, Maharashtra			In Operation
57	Satgaru Biofuel Ltd., lot No. 113, Preet Nagar, NH-44 Police Line, Ambala City, Haryana			In Operation

Source: BMAI

Annexure 2

List of Council Members

1. Mr Sudhendu J Sinha, NITI Aayog
2. Mr Abhay Bakre, Bureau of Energy Efficiency (BEE)
3. Prof. Ashish Verma, Indian Institute of Science (IISc), Bangalore
4. Mr Amit Bhatt, International Council on Clean Transportation (ICCT)
5. Ms Akshima Ghate, Rocky Mountain Institute (RMI) India
6. Mr Pawan Mulukutla, Clean Mobility & Energy Tech, WRI India
7. Ms Anumita Roy Chowdhury, Centre for Science and Environment (CSE)
8. Dr Himani Jain, Council on Energy, Environment and Water (CEEW)
9. Dr A R Sihag, The Energy and Resources Institute (TERI)
10. Mr Ambuj Sharma, (Rtd. IAS), Ex-DHI
11. Mr K K Gandhi, Auto and Fuel Expert

Annexure 3

List of Expert Members for "Biodiesel as Fuel" Workshop

Date: August 24, 2022 | Time: 14.00 – 16.00 IST

1. Mr Neil Karani, Vice President and Treasurer, Biodiesel Manufacturer Association of India
2. Mr Ajit Srivastava, Director General, Biodiesel Manufacturer Association of India
3. Prof. Avinash K Agarwal, IIT Kanpur
4. Prof. Ashish Verma, IISc Bangalore
5. Dr Neeraj Atray, Senior Principal Scientist and Head, Biofuels Esterification Area, Biofuel division, CSIR-Indian Institute of Petroleum, Dehradun
6. Dr Heena Yadav, Technical Officer & Project Coordinator for RUCO initiative, Food Safety and Standards Authority of India
7. Dr Pankaj Sharma, Add. Director I/c (D&ES), Petroleum Planning and Analysis Cell
8. Mr Vijay Kansal, Add. Director (D&ES), Petroleum Planning and Analysis Cell
9. Ms Avantika Garg Tayal, Asst. Director (D&ES), Petroleum Planning and Analysis Cell
10. Mr Sameer Pandita, Bureau of Energy Efficiency (BEE)
11. Dr Chris Malins, Cerulogy
12. Mr Aayush Pant, BIOD Energy Pvt. Ltd.
13. Dr Piyali Das, Senior Fellow, The Energy and Resources Institute (TERI)
14. Dr Sanjukta Subudhi, Senior Fellow, The Energy and Resources Institute (TERI)

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Endnotes

1 Stated Policies Scenario (STEPS) provides a balanced assessment of the direction in which India's energy system is heading based upon today's policy settings and contains and an assumption that the spread of Covid-19 is largely brought under control in 2021.

2 COP26 Chartered of Actions by TERI, 2021

3 mb/d = million barrels per day

4 Details available at https://beeindia.gov.in/content/fuel-efficiency

5 Details available at https://beeindia.gov.in/content/fuel-efficiency

6 Details available at https://www.bharatpetroleum.in/images/files/Biodiesel(2).pdf

7 Details available at Microsoft PowerPoint - NTDPC Presentation vFF.pptx (niti.gov.in)

8 5% biodiesel and 95% diesel by volume

9 20% biodiesel and 80% diesel by volume

10 Details available at http://www.biodieseltechnocrats.in/jatropha.html

11 Details available at http://www.biodieseltechnocrats.in/palm.html

12 Details available at http://www.biodieseltechnocrats.in/rapeseed.html

13 Refers to the temperature below which biowax in biodiesel forms cloudy appearance. The presence of solidified waxes thickens the oil and clog fuel filters and injectors in engines.

14 Details available at http://www.biodieseltechnocrats.in/animal.html

15 Details available at https://MoP&NG.gov.in/files/uploads/Bio-Diesel_Purchase_Policy.pdf

16 Details available at http://petroleum.nic.in/sites/default/files/Order-Distr_GSR728_29_06_2017.pdf

17 Details available at https://MoP&NG.gov.in/files/uploads/NATIONAL_POLICY_ON_BIOFUELS-2018.pdf

18 Details available at https://ppac.gov.in/WriteReadData/userfiles/file/Sale%20of%20Bio%20Diesel%20policyr%20Apr%202019.pdf

19 Details available at http://petroleum.nic.in/sites/default/files/biofuels.pdf

20 BMAI

21 Blended with 5% pure biodiesel with 95% conventional diesel fuel.

22 https://www.oecd-ilibrary.org/sites/89d2ac54-en/index.html?itemId=/content/component/89d2ac54-en#figure-d1e22758

23 Details available at https://task39.sites.olt.ubc.ca/files/2020/12/IEA-Bioenergy-Task-39-Newsletter-Issue-56-Final-Draft.pdf

24 Details provided by PPAC

25 Goods and Services Tax

26 https://oilseeds.dac.gov.in/doddocuments/APYTotalOilseeds.pdf

27 https://www.indiabudget.gov.in/economicsurvey/ebook_es2022/index.html#p=265

28 https://www.indiabudget.gov.in/economicsurvey/ebook_es2022/index.html#p=265

29 https://pib.gov.in/PressReleseDetailm.aspx?PRID=1753462

30 As per stakeholder workshop held on August 24, 2022.

31 https://www.indiabudget.gov.in/economicsurvey/ebook_es2022/index.html#p=265

32 Annual Export-Import databank, Ministry of Commerce and Industry

33 https://dolr.gov.in/documents/wasteland-atlas-of-india

34 https://dolr.gov.in/sites/default/files/Wastelands%20Map%20of%20India%202015-16%2C%20State-wise%20and%20Category-wise%20distribution%20of%20Wastelands%20during%202015-16%20vis-a%20vis%202008-09.pdf

35 https://www.ppac.gov.in/content/147_1_ConsumptionPetroleum.aspx

36 BAU Scenario: TERI's linear estimates, based upon past 10 years data on consumption of HSD (Data source: PPAC).

37 https://pib.gov.in/PressReleasePage.aspx?PRID=1581544

38 https://eatrightindia.gov.in/ruco/file/ruco_booklet.pdf

39 Through workshop discussions held on Aug. 24, 2022 under NTDC

40 Through stakeholder consultation with biodiesel manufacturers

41 EOI no. – OMC/EOI/NUCO/BD/JUL22 dated 23 July 2022

42 As per TERI's estimates

43 https://dolr.gov.in/documents/wasteland-atlas-of-india

44 As per TERI's estimates

45 Calculations are based upon the closest self-estimates based upon previous estimates and stakeholder conversations. Refer section: 9.3 Land requirement

46 Through workshop discussions held on Aug. 24, 2022 under NTDC

47 Information received from one of the biodiesel manufacturers during stakeholder interactions.