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# A Comparative Evaluation of Usage of Methyl Esters of Jatropha and Fish Oil for Environmental Protection

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## Abstract

Economic and societal development of any nation depends very much on the availability of energy sources. Energy sources as an essential input in the areas of any production, but unfortunately the energy sources available are not only limited in volume and quality but also whatever is available are fast getting depleted, storing is necessary for mankind to develop non-conventional sources of energy that not only fulfils the demand but also at the same time keeps the environmental clean or green. Biodiesel takes its place as the most promising alternate fuel because of its renewability and sustainability. Biodiesel is made from rechargeable natural resources that does not produce harmful by-products. Biodiesel can be obtained from various sources like vegetable oils, recycled cooking oil, animal fats and algae, which are cost efficient is easy to make and use. In this work, biodiesel obtained from Jatropha seeds and Fish wastes are used as alternative fuel to diesel in stationary diesel engines. An attempt has also been made to assess the current energy scenario, potential of non-edible oil over edible oils, selected non-edible oil seeds as biodiesel feed-stocks, impact of bio-fuel on environment and future direction. Experimental analysis by different researchers on these non-edible oils has showed their great potential as feed-stocks for biodiesel production. Carbon monoxide (CO), UBHC and smoke emissions are observed to be less at all loads for both the blends compared to diesel fuel while NOx emissions are slightly higher. This paper also reviews the possibility, availability,economic and cost analysis in dept.

## 1. Introduction

For any growth in industrialization the need for the energy also increases day by day, the prosperity of a nation is very much limited to the availability and consumption of energy. At present energy is supplied from conventional sources (Coal, Petroleum based fuels, natural gas, etc) and other renewable source (solar, wind, geothermal, biogas, etc.) The major portion of energy at present is petroleum based fuel and countries like India there are a necessity to import oil making them dependable on the oil producing countries. Table 1 shows India's crude oil production and import details, where it could be seen that the import is nearly 75% per annum of the requirement and this percentage has been increasing over the year.

Commercial fuel imports by India are mainly in the form of crude oil and natural gas therefore development of renewable energy is one of the most important requirements for a long-term sustainable energy production. With increased awareness of environmental concerns caused by air pollution, it is imperative that fuel generation and usage is environment friendly as well. Key driving factors are depleting fossil-fuel reserves all over the globe as well as the environmental impact of burning fossil fuels that cause pollution and global warning. India's energy security would remain vulnerable until alternative fuels to substitute/supplement petro-based fuels are developed based on indigenously produced renewable feedstocks [1,2].

The invention of internal combustion engine and development in engine technology has resulted in exploitation of the petroleum based reserves which is depleting at a rapid rate. Internal Combustion (IC) engines are mainly classified as Spark Ignition (SI) and Compression Ignition (CI) engines which use petrol and diesel respectively. Combustion of these fuels in engines release substantial amount of pollutants such as Carbon Dioxide ($CO_2$), Carbon Monoxide (CO), Unburned Hydrocarbon (UBHC), Nitrogen Oxides (NOx), and Particulate Matter (PM). Reducing these emissions and increasing the fuel economy of IC engines are the primary concern for all developing nations [3].

**Table 1**:Crude Oil Production and Import Details*

| Year | Production (MT) | Import (MT) | Total (MT) | Import (%) | Average Crude oil Prices US$/per barrel | Increase in oil Price(%) |
|---|---|---|---|---|---|---|
| 2004-05 | 33.981 | 95.861 | 129.842 | 73.82 | 39.21 | 40.14 |
| 2005-06 | 32.190 | 99.409 | 131.599 | 75.54 | 55.72 | 42.11 |
| 2006-07 | 33.988 | 111.502 | 145.49 | 76.63 | 62.46 | 12.10 |
| 2007-08 | 34.118 | 121.672 | 155.79 | 78.10 | 79.25 | 26.88 |
| 2008-09 | 33.508 | 132.775 | 166.283 | 79.84 | 83.57 | 05.45 |
| 2009-10 | 33.690 | 159.259 | 192.949 | 82.53 | 69.76 | 16.53 |
| 2010-11 | 37.684 | 163.595 | 201.279 | 81.27 | 85.09 | 21.98 |
| 2011-12 | 38.090 | 171.729 | 209.819 | 81.84 | 111.89 | 31.50 |

***Source: Ministry of Petroleum and Natural Gas. 2012**

**Table 2:**$CO_2$ Emissions from Power Sector in India (Working Group on Power for 12th Plan,2012)

| $CO_2$ Emissions | Thermal Gross Generation (Coal+ Lignite +Gas) in MU | Total $CO_2$ Emission in million tone of $CO_2$ equivalent | Average Emission in million tone of $CO_2$ equivalent | Gross Generation (including generation from renewable) in MU | Average Emission Factor from Gross Generation in kg/kWh |
|---|---|---|---|---|---|
| Anticipated at the end of 12$^{th}$ Five Year Plan | 1,211,848 | 1,078 | 0.889 | 1,493,001 | 0.722 |
| Anticipated at the end of 13$^{th}$ Five Year Plan | 1,625,343 | 1,421 | 0.874 | 2,119,897 | 0.670 |

The continuously increasing use of petroleum based fuels in IC engines has given rise to serious consequences. Global warming is major among these effects, which resulted in environmental impacts due to emission of increased greenhouse gases. One of the major by products or combustion is carbon dioxide, a greenhouse gas [4]. Greenhouse gases which includes $CO_2$, chlorofluorocarbon, methane, nitrous oxides decrease the rate of infrared radiation and increases the earth's surface temperature making it warmer. One way to reduce the amount of $CO_2$ produced by the combustion of fossil fuels from IC engines is to reduce the amount of fuel consumed through improved efficiency or using renewable bio fuels. A decrease in the use of fossil fuels also carries important implications. As future economic growth not only crucially depends on the long-term availability of energy from sources that are affordable and accessible, it is also necessary that the energy sources thus developed should be environmental friendly. From Table 2, it can be inferred that the average $CO_2$ eq. emission factor reduces by ~0.167 kg/kWh by including renewable energy in the total energy mix of the country. With an anticipated increase in RE at the end of the 13$^{th}$ Five Year plan the emission factor is projected to go down further as compared to the 12$^{th}$ Five Year plan numbers.

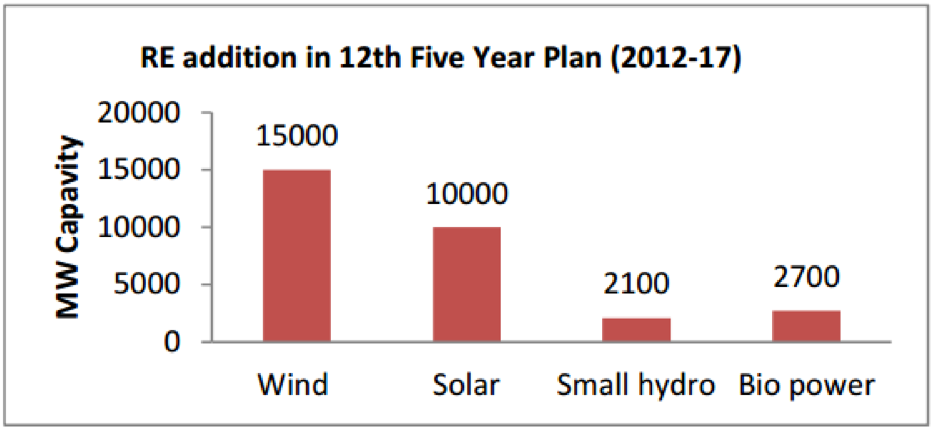


**Figure 1:**Renewable Energy Distribution in 12th Five Year Plan

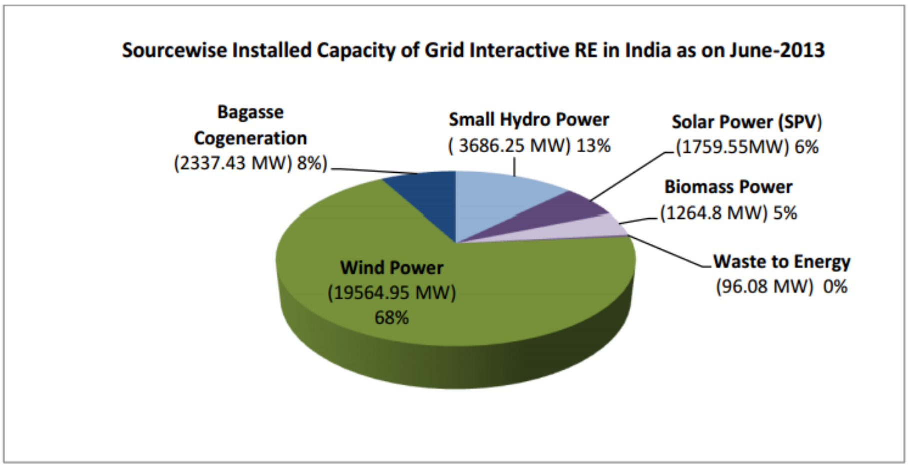


**Figure 2:**Renewable Energy Generation in India- End of March 2012 (Source MNRE Website)

Past trends and future scenario for the RE sector in the country are depicted in Figure 1. Going by the projections, the RE space in the country is going to witness many high capacities RE projects in the coming years. The renewable energy installed capacity in India is growing steadily. In March 2012, RE installed capacity stood at 24, 914.24 MW which was 10.5% of the power mix in the country (Central Statistics Office, 2003). Within 15 months the RE capacity in the country has expanded by 15%, as on June 2013 this was 28708.9 MW (Source: MNRE Website) as shown in Figure 2. Biodiesel provides a strategic advantage to promote sustainable development and to supplement conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth, as well as in meeting the energy needs of India's vast rural population.

Rudolph Diesel was the first to demonstrate the possibility of using vegetable oil as diesel fuel by operating a diesel engine with peanut oil in the year 1895. However, using raw vegetable oils in diesel engine can give rise to many engine-related problem like server engine deposits, injection coking, and piston ring sticking due to their high viscosity and low volatility [5,6]. It is necessary to remove glycerin from base vegetable oils to produce biodiesel which has low viscosity so that they can be used in diesel engine. Bio-diesel derived from edible, non-edible oils and animal fats can be used in diesel engines with little or no modifications. The advantages of using bio-diesels are as follows:

- Bio-diesels are cleaner sources of energy than conventional petroleum based diesel.
- Emission of greenhouse gases is reduced significantly.
- Reduced imports of petroleum based fuel providing energy security for the country.
- Employment opportunities in the rural sector which will help rural development.
- Reduction in fossil fuel use.
- Bio-diesel is biodegradable, non-toxic and renewable.
- High flash point of bio-diesel makes it safer as chances of burning after accidents are less.
- Reduced smoke, UBHC and CO emissions, as bio-diesels are oxygenated fuels.

Some of the plant-based oils suitable for generation of biodiesel are rapeseed/mustard, peanut, coconut, soybean, sunflower, palm, corn, rice bran, need, mahua, jatropha, cotton seed, linseed and karanja/pungam oil. For developing countries like India with a large population, there is an increasing demand for edible oil for human consumption. The development of a biodiesel industry is thus likely to create competition for these agricultural products and lead to a spike in food costs. Moreover, the enormous amount of land required to grow energy corps for production of biodiesel is likely to reduce the agricultural land available for food supply. Therefore, production of biodiesel from edible oil is not an affordable solution for countries like India, where it might lead to conflict with food security. Instead, non-edible oil and animal fat could be considered as better options.

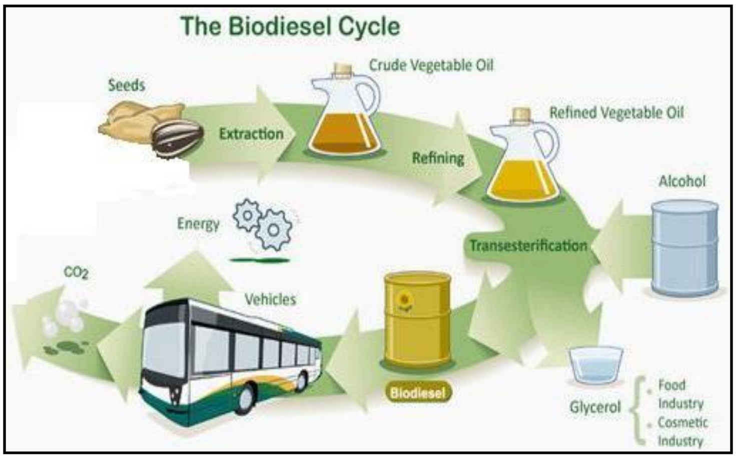


**Figure 3:**Typical Biodiesel Cycle

Though vegetable oils have various advantages as mentioned above, they do also have certain drawbacks like high viscosity, fuel line clogging, poor oxidation stability, thermal cracking in engines. To avoid these drawbacks, it is required to modify the vegetable oils by transesterification with methyl or ethyl esters as shown in the biodiesel cycle shown in Figure 3. Biodiesel is sulphur-free, non-toxic, oxygenated, renewable, eco-friendly, safe to handle and biodegradable, and is the most promising alternative fuel for diesel engine. Geller & Goodrum observed that biodiesel has better lubricity than diesel fuel which will reduce the need for lubricity additives being added to diesel fuel [7][8]. Combustion of biodiesel in engine is less polluting than petroleum diesel and emits less CO, HC, Particulate matter and aromatic compounds emissions. Biodiesel can be used in existing engine without any major modifications. Jatropha oil methyl esters (JOMEs) and fish oil methyl esters (FOMEs) are one of the best options in non-edible category and animal fat category respectively.

## 2. Materials and Methods

*2.1. Jatropha Oil Methyl Ester (JOME)*
Jatropha oil methyl esters are well proven alternatives to petroleum diesel. Jatropha oil methyl esters are renewable environmental friendly nature, less expensive to cultivate with little amount of water, grow on all climatic conditions and soils, high yield, approximately 50 years of plant life, rural employment and livelihood opportunities, etc. Jatropha cultivation is not easy and can grow in wetlands with good quality Jatropha plant seed to generate sufficiency oil with yield that starts from 9-12 months’ time and one hectares of the tree can normally give 400 to 600 liters of oil and the residue can be caked and used as biomass to produce electricity plants also can be used as animal feed. Indian government is promoting Jatropha oil as a source of biofuel by planting Jatropha trees in waste lands available in the country, like railway track sides and other non-food cultivation/dry lands. Use of Jatropha oil as fossil fuel will be a partial substitute to petroleum diesel to reduce the cost of petroleum products imported.

*2.2 Fish Oil Methyl Ester (FOME)*
Biodiesel produced from fish oil is a very good and low cost alternative to petroleum diesel. Fish processing industry generates large quantities of tissue waste (the viscera, fins, eyes, tails, etc.) and by-products which are either discarded or retailed at low price for fertilizer and animal feed [9,10]. These discarded tissue wastes and by-products may be converted to bio-diesel at a low cost [11]. Biodiesel produced from fish oil is a very good and low cost alternative to petroleum diesel. India is one of the countries in Asia having a long coastline with excellent potential for marine fishing. Biodiesel based on fish oil is easy to produce and provides cleaner-

burning fuel. Biodiesel and blended diesel, (Petroleum-based diesel mixed with biodiesel), could potentially replace or reduce petroleum-based diesel fuel requirement of the country. Even though biodiesel offers reduction in Smoke, UBHC and CO emissions due to the molecular oxygen present in it, emissions are higher which can be reduced by using exhaust gas recirculation (EGR).

The use of animal fat to produce biodiesel has attracted public interest recently. Searching aquatic sources for energy production makes economic sense in addition to ecological sense also. And also the fish oil obtained has long carbon chain fatty acids which makes combustion to be efficient and reduces carbonaceous emissions greatly. In addition to the purified fish oil obtained from those wastes in fishing industry, caustic soda is added. Eventually methanol is produced. 1 kg of fish oil waste can produce up to 1.13lts of bio-diesel. Glycerine is a valuable by-product obtained which is used for pharmaceutical and cosmetic purposes. Biodiesel derived from the trans-esterification of fats and oils [12] is a possible fuel for diesel engines.

*2.3 Procedure for lead determination method*

Fish processing industry generates large quantities of tissue waste and by products which are either discarded or retailed at low value for fertilizer or animal feeds [13]. A better way to utilize these by-products is to convert it to biodiesel for use in diesel engines [14]. Locally produced fish oil biodiesel blend fuels have the potential to create a sustainable energy supply for use in remote regions together with dramatic cost savings and reducing dependence on imported petroleum products. Easy to manufacture, cleaner-burning fish oil biodiesel and its blends could potentially replace or reduce traditional diesel fuel requirements in India.

In Alaska, roughly 8 million gallons of fish oil is produced each year. Most of the oil is used as boiler fuel for drying the fish meal while smaller quantities are blended with diesel and used for power production. In 2005, Food and Agricultural Organization (FAO) estimated the world fish production is 142 million tons of which 25% is destined for producing fish meal and oil. In 2008, the amount of wastes was around 50% of total fish production and oil produced ranges from 40-65% [15][16].

## 3. Experimental details

The tests are conducted on a single cylinder, four stroke, naturally aspirated, air-cooled diesel engine coupled with an electrical swinging field dynamometer. AVL 415 Variable Sampling Smoke meter is used to measure the particulate matter in the exhaust. MRU delta 1600L Exhaust Gas Analyzer is used to measure HC, CO and NOx emissions. AVL 615 Indimeter system is used to get pressure crank angle diagram at various loads using piezoelectric pressure transducer and angle encoder and to process the same for getting various parameters such as heat release rate curve, peak pressure, angle of occurrence of peak pressure, imep, etc. Fuel consumption is calculated at any load from the measurement of time for 10cc of consumption. Exhaust gas temperature was measured using K-type thermocouple. All the equipments were calibrated as per the supplier's specifications before the beginning of the experiments.

*3.1.Preparation of JOME and FOME*

Transesterification is a chemical process of transforming large, branched, triglyceride molecules of vegetable oils and fats into smaller, straight chain molecules, almost similar in size to the molecules of the species present in diesel fuel [17]. The process takes place by reacting the vegetable oil with an alcohol in the presence of catalyst. A catalyst is usually used to improve the reaction rate and yield. Basic catalyst has faster reaction and also keeps the whole process slightly alkaline for neutralizing free fatty acids. It can be either Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH). Since the transesterification reaction is reversible, excess alcohol is required to shift the reaction equilibrium to the products side [18].

Transesterification is an equilibrium reaction in which excess alcohol is required to drive the reaction close to completion [19]. During methanolysis, two distinct phases are present as the solubility of oil in methanol is low and the reaction mixture needs vigorous stirring. Glycerol phase separation does not occur when less than 67% of the theoretical amount of methanol is used. The excess methanol, however, is removed by distillation. Traces of methanol, catalyst, free fatty acids (FFAs), chlorophil, etc., go into the glycerin phase, which can be processed in two stages [20]. Since methanol is used in the reaction, it is also termed methanolysis. Triglycerides are readily transesterified in the presence of alkaline catalyst at atmospheric pressure and at a temperature of approximately 50 to 70°C with an excess of methanol. The mixture at the end of reaction was allowed to settle. The lower glycerol layer is drawn off while the upper methyl ester layer was washed to remove entrained glycerol and is then processed further [21]. The excess methanol is recovered by distillation and sent to a rectifying column for purification and recycled [22].

## 4. Results and Discussion

### *4.1. Comparison and Optimization of JOME and FOME*

The brake thermal efficiency of 20% JOME and 20% FOME is marginally lower than that of diesel. It can be observed that CO, HC and soot emissions are lower while NOx emissions are higher for 20% methyl ester blends compared to diesel. JOME and FOME are procured in the open market at Rs.90/-($1.5) per liter and Rs. 60/-($1.0) per liter respectively when compared to Diesel at Rs.54/- ($0.9) per liter. Cost of operation per hour is highest for 20 % JOME as the basic cost of JOME per liter is high.

**Table 3:** Comparison of 20% JOME, 20% FOME and Diesel Fuel at Rated Power

| Parameters | Unit | Diesel | 20% JOME | 20% FOME |
|---|---|---|---|---|
| Carbon monoxide (CO) | g/kW h | 16.75 | 10.33 | 12.60 |
| Unburnt Hydrocarbon (UBHC) | g/kW h | 0.74 | 0.67 | 0.72 |
| Oxides of Nitrogen (NOx) | g/kW h | 7.25 | 7.46 | 7.60 |
| Soot | $mg/m^3$ | 166 | 120 | 125 |
| Brake Thermal Efficiency | % | 28.4 | 28.1 | 27.7 |
| Cost Per Liter | INR ($) | 54 (0.87) | 61(0.98) | 55 (0.88) |
| Cost Per Hour at Rated Power Output | INR ($) | 83 (1.33) | 96 (1.54) | 88 (1.41) |

(1 US dollar ($) = INR 62 as of Nov, 2015)

Lower calorific value of FOME blends (38,650 kJ/kg) compared to diesel (43,500 kJ/kg) result in higher fuel consumption of blends compared to diesel at all the power outputs resulting in lower brake thermal efficiency [23]. A significant reduction in UBHC emissions is noticed for both the methyl esters and their blends at all the power outputs compared to diesel [24]. The addition of methyl ester to diesel increases the oxygen content enhancing the combustion reactions resulting in high combustion temperature which lowers UBHC emissions. In general, the CO emissions are low for diesel engines as they are operated with lean mixtures. With methyl esters where oxygen content is higher, it leads to efficient and effective combustion. Therefore, a CO emission reduces for all the blends comparatively. As the percentage of methyl ester in the blend increases it is observed that the CO emission decreases. Oxides of Nitrogen (NOx) consist of Nitric oxide (NO) and Nitrogen dioxide ($NO_2$). Nitric oxide is predominant in the oxides of nitrogen produced inside the engine cylinder. $NO_2$/NO in a diesel engine is approximately in the ratio of 0.1 to 0.3. Oxides of Nitrogen emissions (NOx) emissions are higher for the methyl ester and its blend compared to diesel. The fossil fuels do not contain nitrogen or very negligible amount of nitrogen. Hence, the amount of NO formed from the fuel is very low and it is observed that NO increases slowly with increasing temperature and increased NO levels can occur at increased flame temperatures. Soot emissions for FOME are significantly reduced compared to diesel due to the higher oxygen content and No aromatic compounds that induces soot which is available in petroleum diesel fuel.

An optimum percentage of methyl esters in the blend is necessary as simultaneous reduction of soot and NOx is desirable. The variation of soot and NOx values normalized with respect to baseline diesel operation at rated power output for various percentages of JOME and FOME in the blends is shown in Figures 4 and 5 respectively.

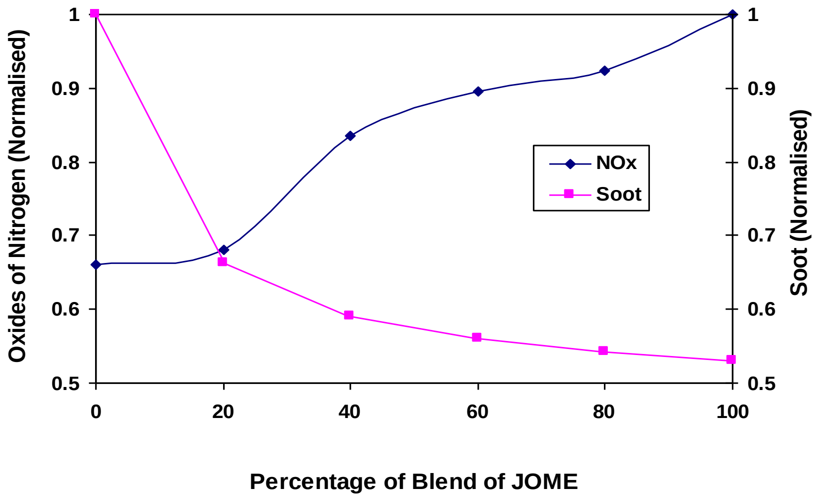


**Figure 4:** Trade-off between Oxides of Nitrogen and Soot Emissions for Various Percentage of JOME in Blend

19% JOME and 22 % FOME are observed to be optimum considering both NOx and soot emissions and this is approximated to be 20% for both JOME and FOME. The cost of operation per hour at rated power output, various emissions and brake thermal efficiency at rated power output are given in Table 3. The prescribed blending levels will be reviewed and moderated periodically as per the availability of bio-diesel. To take care of fluctuations in the availability of biofuels, Oil Marketing Companies (OMCs) will be permitted to bank the surplus quantities left after blending of bio-diesel in a year, and to carry it forward to the subsequent year when there may be a shortfall in their availability to meet the prescribed levels.The blending would have to follow a protocol and certification process, and conform to BIS specification and standards, for which the processing industry and OMCs would need to jointly set up an appropriate mechanism and the required facilities. Motor Vehicles Act already allows conversion of an existing engine of a vehicle to use bio-fuels. Engine manufacturers would need to suitably modify the engines to ensure compatibility with biofuels, wherever necessary. Development of test methods, procedures and protocols would be taken up on priority along with introduction of standards and certification for different bio-fuels and end use applications. The Bureau of Indian Standards (BIS) has already evolved a standard (IS-15607) for Bio-diesel (B100), which is the Indian adaptation of the American Standard ASTM D-6751 and European Standard EN-14214.

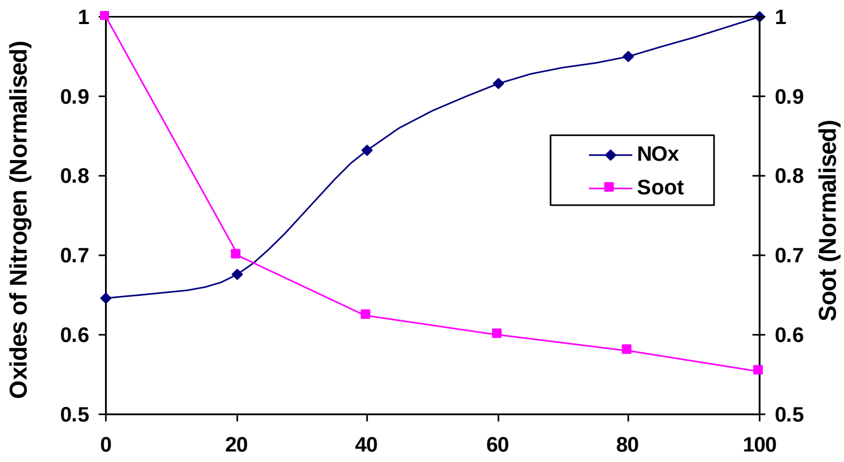


**Figure 5:** Tradeoff between Oxides of Nitrogen and Soot Emissions for Various Percentage of FOME in Blend

*4.2 Distribution and Marketing of Bio-fuels*

The responsibility of storage, distribution and marketing of bio-fuels would rest with Oil Marketing Companies (OMCs). This shall be carried out through their existing storage and distribution infrastructure and marketing networks, which may be suitably modified or upgraded to meet the requirements for bio-fuels. In the determination of bio-diesel purchase price, the entire value chain comprising production of oil seeds, extraction of biodiesel, its processing, blending, distribution and marketing must be considered. The Minimum Purchase Price (MPP) for bio-diesel by the OMCs will be linked to the prevailing retail diesel price. The MPP for biodiesel, will be based on the actual cost of production and will be determined by the Bio-fuel Steering Committee and decided by the National Bio-fuel Coordination Committee. In the event of diesel or petrol price falling below the MPP for bio-diesel OMCs will be duly compensated by the Government.

*4.3 Financing*

Plantation of non-edible oil bearing plants, the setting up of oil expelling/extraction and processing units for production of bio-diesel and creation of any new infrastructure for storage and distribution would be declared as a priority sector for the purposes of lending by financial institutions and banks. National Bank of Agriculture and Rural Development (NABARD) would provide re-financing towards loans to farmers for plantations. Carbon financing opportunities would also be explored on account of avoidance of $CO_2$ emissions through plantations and use of bio-fuels for various applications. Investments and joint ventures in the bio-fuel sector are proposed to be encouraged. Bio-fuel technologies and projects would be allowed 100% foreign equity through automatic approval route to attract Foreign Direct Investment (FDI), provided bio-fuel is for domestic use only, and not for export. Plantations would not be open for FDI participation. Financial and Fiscal Incentives Financial incentives, including subsidies and grants, may be considered upon merit for new and second generation feedstocks; advanced technologies and conversion processes; and, production units based on new and second generation feedstocks. In the context of the International perspectives and National imperatives, it is the endeavor of this Policy to facilitate and bring about optimal development and utilization of indigenous biomass feedstocks for production of bio-fuels. The Policy also envisages development of the next generation of more efficient bio-fuel conversion technologies based on new feedstocks. The policy sets out the vision, medium term Goals, strategy and approach to bio-fuel development, and proposes a framework of technological, financial and institutional interventions and enabling mechanisms.

## Conclusions

The cost of methyl esters is likely to come down soon with mass production whereas the cost of diesel fuel will increase continuously. From the present experimental results, it can be concluded that 20% JOME and 20% FOME can be successfully used in existing diesel engines without any modifications. Experimental analysis by different researchers on these non-edible oils has showed their great potential as feed-stocks for biodiesel production. Carbon monoxide (CO), UBHC and smoke emissions are observed to be less at all loads for both the blends compared to diesel fuel while NOx emissions are slightly higher. Further it is concluded that the renewable energy programme in India should move towards investing, supporting and strengthen the call for clean and renewable energy policies through advocacy and awareness building and creating a supportive renewable energy implementation environment. Its activities are also aimed at helping compliance with evolving renewable energy deployment targets; and building supportive policy evidence through research around grid as well as off-grid business models.

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