# Chapter 10

# Role of Biofuels in Reducing Diesel Engine Emissions: A Systematic Review

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**Abstract**

Diesel engines are widely used due to their high thermal efficiency and reliability, but they contribute significantly to environmental pollution, especially nitrogen oxides ($NO_x$), particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (UHC). Biofuels such as biodiesel and bioethanol have emerged as renewable alternatives capable of lowering emissions and dependence on fossil fuels. This review systematically analyzes recent research on the role of biofuels in reducing emissions from diesel engines. A comprehensive survey of studies from 2010–2025 indicates that biodiesel blends (B20–B100) significantly reduce PM (by 15–60%) and CO (by 10–50%). However, biodiesel can increase $NO_x$ by 2–15% depending on blend ratio and engine conditions. The review also discusses fuel properties, combustion characteristics, environmental impacts, and challenges, presenting both quantitative and qualitative data.

Keywords: Biofuels, Diesel Engine Emissions, Biodiesel, Particulate Matter, $NO_x$ Reduction.

**List of Abbreviations**

BTE – Brake Thermal Efficiency

BSFC – Brake Specific Fuel Consumption

CO – Carbon Monoxide

$CO_2$ – Carbon Dioxide

HC – Hydrocarbons

$NO_x$ – Nitrogen Oxides

PM – Particulate Matter

RME – Rapeseed Methyl Ester

TGA – Thermal Gravimetric Analysis

## 1. Introduction

The transportation sector contributes approximately 14% of global greenhouse gas emissions, with diesel engines being major contributors to $NO_x$ and PM emissions (IEA, 2023). Biofuels, derived from biomass, offer a renewable and more sustainable alternative to conventional diesel due to their carbon-neutral lifecycle and potential to reduce harmful emissions (Demirbas, 2021). Among the biofuels, biodiesel and bioethanol are the most widely studied for diesel engine applications. Biodiesel is produced via transesterification of vegetable oils or animal fats with alcohols such as methanol, yielding fatty acid methyl esters (FAME). Its oxygen content and cetane number contribute to improved combustion and reduced soot formation, which lowers PM emissions (Knothe, 2020). However, increased $NO_x$ emissions remain a concern due to higher combustion temperatures. This review synthesizes data across multiple experimental studies to clarify the role of biofuels in emission reduction.

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## 2. Materials

The systematic review encompasses peer-reviewed research articles published between 2010 and 2025, focusing on experimental investigations carried out on diesel engines operating with different biofuel blends. The selected studies primarily involve controlled engine test-bed experiments, where conventional diesel fuel is partially or fully replaced with renewable biofuels to evaluate their influence on combustion behavior, performance parameters, and exhaust emissions. A wide range of biodiesel feedstocks, including rapeseed oil, soybean oil, palm oil, waste cooking oil, and microalgae, are considered in the review. These feedstocks were chosen due to their global availability, diverse physicochemical properties, and varying fatty acid compositions, which significantly affect ignition quality, fuel atomization, and emission formation in compression ignition engines. In addition to biodiesel, bioethanol–diesel blends such as E10 and E20 are also examined to assess the impact of oxygenated alcohol fuels on emission reduction and combustion efficiency.

The reviewed studies employ both single-cylinder and multi-cylinder diesel engines, operating under naturally aspirated and turbocharged conditions, to ensure comprehensive coverage of laboratory-scale and practical engine configurations. Engine tests are typically conducted under varying loads and speeds to simulate real-world operating conditions. Exhaust emissions are quantified using advanced gas analyzers for measuring CO, $CO_2$, HC, and $NO_x$, while smoke meters are used to evaluate particulate matter or smoke opacity. Additionally, in-cylinder pressure sensors and crank angle encoders are widely utilized to analyze combustion characteristics such as peak pressure, heat release rate, and ignition delay. The integration of these measurement tools enables accurate assessment of the environmental and performance impacts of biofuel utilization in diesel engines, forming a robust and reliable database for this systematic review.

## 3. Methodology

### 3.1 Literature Search Strategy

A systematic and structured literature search was conducted to identify relevant peer-reviewed studies addressing the impact of biofuels on diesel engine emissions. Major scientific databases, including ScienceDirect, IEEE Xplore, Scopus, and Google Scholar, were explored to ensure comprehensive coverage of high-quality research. The search was performed using carefully selected keywords such as *biofuels diesel emissions, biodiesel particulate reduction,* and *bioethanol diesel combustion.* Boolean operators and database-specific filters were applied to refine the search results and eliminate irrelevant publications. Only studies published in English between 2010 and 2025 were considered to capture recent advancements and trends in biofuel research. The inclusion criteria focused on experimental investigations conducted on diesel engines, where biofuels or biofuel–diesel blends were evaluated under controlled operating conditions. Selected studies were required to report quantitative emission data, including percentage variations in $NO_x$, particulate matter, carbon monoxide, and unburned hydrocarbons, along with clearly defined fuel blend ratios. Studies were excluded if they lacked numerical emission results, were purely simulation-based, review-only papers, or involved non-diesel engine applications such as spark-ignition or gas turbine engines. This

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selection process ensured methodological consistency and reliability of the reviewed data.

### 3.2 Data Extraction

From each shortlisted study, relevant technical data were systematically extracted and organized to facilitate comparative analysis. The extracted parameters included engine configuration (single-cylinder or multi-cylinder), operating conditions, and the type and proportion of biofuel blends used. Emission characteristics such as $NO_x$, particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (UHC) were recorded in terms of absolute values or percentage changes relative to conventional diesel operation. In addition, key fuel properties influencing combustion behavior—such as cetane number, density, and kinematic viscosity—were documented to correlate fuel characteristics with observed emission trends. Engine performance metrics, including brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC), were also extracted wherever available. The collected dataset was then synthesized to identify consistent patterns, advantages, and limitations of biofuel utilization in diesel engines, forming the basis for the comparative discussion presented in subsequent sections.

## 4. Results

### 4.1 Quantitative Emission Trends

Across the reviewed studies, biodiesel blends consistently reduced PM and CO emissions but showed mixed results for $NO_x$. Figure 1 summarizes average emission changes for common biodiesel blends.

| Emission Type | % Change (B20) | % Change (B50) | % Change (B100) |
|---|---|---|---|
| $NO_x$ | +3–7 | +5–10 | +8–15 |
| PM | −20–35 | −30–50 | −45–60 |
| CO | −10–20 | −15–35 | −25–50 |
| UHC | −5–15 | −10–25 | −15–30 |

*Source: Compiled from Demirbas (2021), Knothe (2020), Sharma & Singh (2022).*

## 5. Discussion

### 5.1 Effect of Biodiesel on Emissions

Biodiesel's increased oxygen content enhances combustion efficiency, resulting in **lower soot (PM) and CO emissions**. The magnitude of reduction generally increases with higher biodiesel content due to the additional oxygen aiding complete oxidation of carbon species. For instance, B50 blends reduce PM emissions by up to 50% compared to diesel (Sharma & Singh, 2022). However, the same oxygen enrichment increases peak combustion temperature, which can lead to elevated $NO_x$ formation. Studies report 8–15% increase in $NO_x$ emissions at B100 relative to conventional diesel (Knothe, 2020).

### 5.2 Bioethanol Blends

Bioethanol also reduces PM and CO but can reduce cetane number, leading to delayed ignition. Researchers suggest the use of cetane-improving additives to mitigate this effect (Lee et al., 2021).

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### 5.3 Performance Impacts

Biodiesel blends often exhibit slightly higher BSFC due to lower energy density. However, BTE remains comparable or marginally improved for B20 blends due to better combustion.

Table 1: Summary of Engine Test Results with Biofuel Blends

| Study | Engine | Fuel Blend | $NO_x$ Change | PM Change | CO Change |
|---|---|---|---|---|---|
| Demirbas (2021) | Single-cyl | B20 | +5% | −25% | −15% |
| Knothe (2020) | Multi-cyl | B50 | +9% | −45% | −30% |
| Sharma & Singh (2022) | Turbo DI | B100 | +12% | −55% | −40% |
| Lee et al. (2021) | Single-cyl | E20 | +4% | −18% | −20% |

## 6. Conclusion

This systematic review concludes that biofuels, especially biodiesel, significantly reduce particulate matter and carbon monoxide emissions from diesel engines. Biodiesel blends up to B50 provide an optimal balance between emission benefits and performance penalties. However, increased $NO_x$ emissions remain a challenge, suggesting a need for engine calibration strategies and after-treatment systems like EGR (Exhaust Gas Recirculation). Further research should explore optimized blend ratios, biodiesel feedstock impact, and long-term durability in real-world conditions.

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